ASSESSMENT OF SUSTAINABLE MATERIALS MANAGEMENT APPLICATION IN CALIFORNIA

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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 California.

Five SMM application approaches were developed and applied to California 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. California only reported the individual mass of beverage materials recycled. To estimate the remaining individual materials recycled, and their generated, combusted and landfilled masses other California Department of Resource Recovery and Recycling (CalRecycle) published reports related to MSW and the US EPA's 2015 Advancing Sustainable Materials: Facts and Figures report were retrieved, and assumptions were applied to those data. Using CalRecycle 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 California 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 CA 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 California.

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 ($tCO_2eq.$) 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 $tCO_2eq.$ 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 $tCO_2eq.$) 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.

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

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.

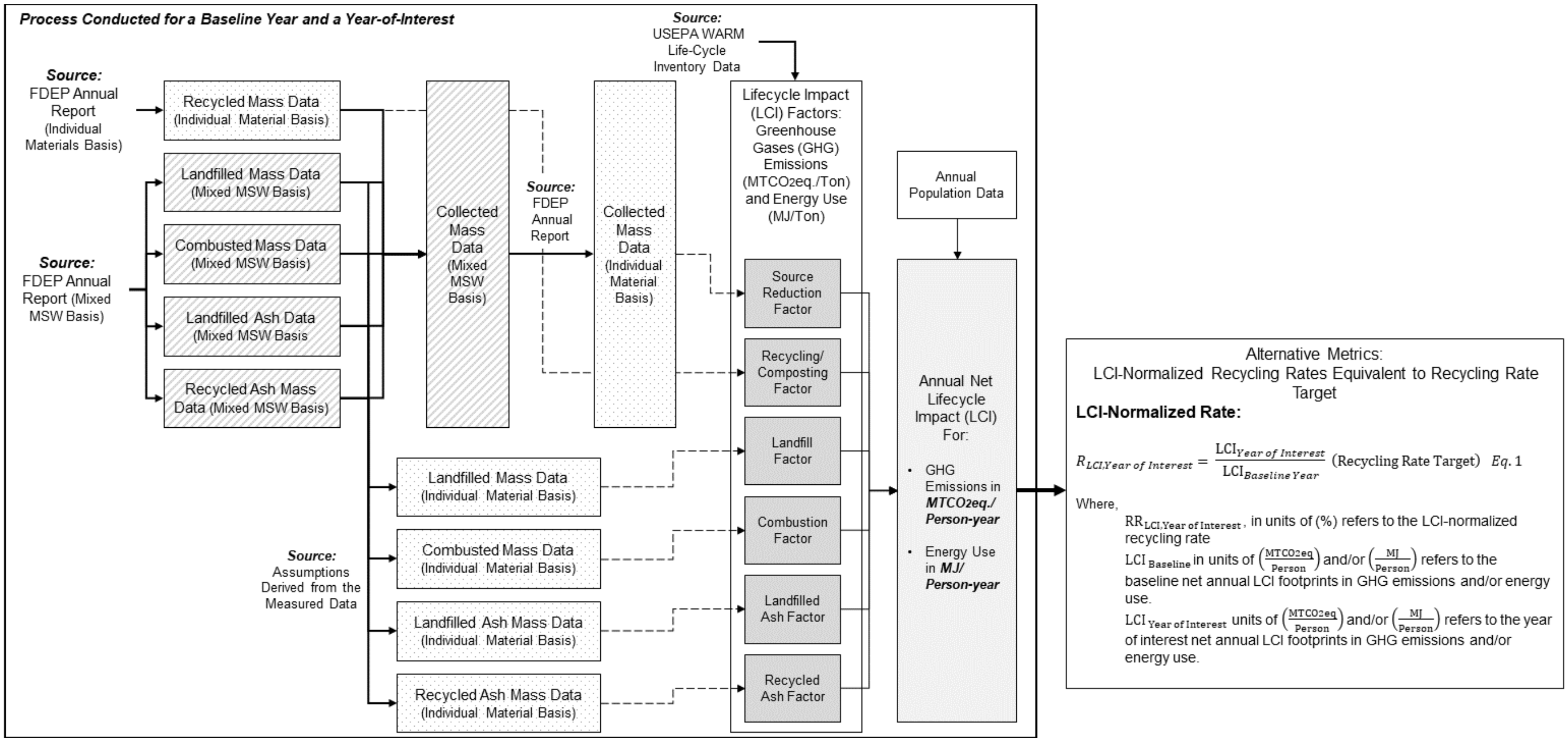

Figure 2-1. Florida-specific methodology to estimate mass data (recycled, landfilled, combusted, landfilled & recycled ash) used as inputs to calculate a baseline year and year-of-interest's net lifecycle impact (LCI) (in GHG emissions and energy use) which was converted to an LCI-normalized recycling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

3 DATA AVAILABLE FOR CALIFORNIA

As previously discussed, the main objective of this study was to evaluate the application of the SMM methodology in other states, specifically CA. To execute the application of the SMM methodology in CA, data was compiled for 2005 and 2015 from the California Department of Resources Recycling and Recovery (CalRecycle) published annual reports that detailed waste management data managed by CA 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).

CalRecycle began publishing only recently (since 2015) annual reports titled either "State of Disposal in California", "State of Recycling in California", or "State of Disposal and Recycling in California. From 2015 to 2017 CalRecycle released five reports that presented various MSW management data and mass estimates for mixed MSW generated, recycled, combusted, and landfilled data for either CY 2013, 2014, or 2016. CalRecycle did not release a report pertaining to 2005 or 2015 data. However, the reports included a standardized methodology to estimate the mass data presented in the reports that can be used for other years. The methodology used data reported on the CalRecycle website, so data was collected for 2005 and 2015 from the following webpages or reports: 2000-2018 Population from State of California Department of Finances, Disposal Reporting System California Annual Solid Waste Disposal, California Waste Tire Market Report, Disposal Reporting System Other Beneficial Reuse by Material Type.

We used the webpages and reports above and applied the methodology found in the "State of Recycling in California 2015" to estimate 2005 and 2015 mass data, as shown in Table 3-3. CalRecycle estimated the total mass generated by assuming a generation rate of 10.7 pounds/day-person (based off a baseline waste generation rate for 1990-2010) and multiplied it by the Department of Finances reported annual California population. The traditional disposal, alternative daily cover, alternative intermediate cover, and waste-to-energy masses were reported in the Disposal Reporting System California Annual Solid Waste Disposal webpage. The other beneficial reuse and composting only masses were reported in in the Disposal Reporting System Other Beneficial Reuse by Material Type report. The waste tire-derived fuels were reported in the California Waste Tire Market Report 2015. The recycled, composted or source reduced mass was calculated per the methodology as the sum of the composted only and recycled and source reduction only masses. The recycled and source reduction only mass was calculated per the methodology as the total generation minus the sum of traditional disposal, alternative daily cover, alternative intermediate cover, waste-to-energy, waste tire-derived fuels, and composting only masses.

It should be noted that CalRecycle does currently not require the tracking of individual materials recycled masses. However, a 2015 statute called Assembly Bill 901 was recently codified and expectant to be instituted which awards CalRecycle enforcement authority to collect the following information, "disposal, recycling, and compost facilities, exporters, brokers, and transporters of recyclables or compost will be required to submit information directly to CalRecycle on the types, quantities, and destinations of materials that are disposed of, sold, or transferred inside or outside of the state". Until the statute is enforced the only individual recycled materials (except for composted organics) were beverage containers found in the CalRecycle "Biannual Report of Beverage Container Sales, Returns, Redemption, and Recycling Rates". This report contained the number of aluminum, glass, #1 PET, #2 HDPE, #3 PVC, #4 LDPE, #5 PP, #6 PS, #7 Other, and bimetal containers recycled, refilled, and post-filled for each year beginning in 1988 until 2017.

We estimated the individual recycled mass by first using the materials listed in the CalRecycle beverage report that provided the number of containers recycled and post-filled and their individual associated conversion factors that convert from the number of containers to a mass. To find the remaining materials recycled, we subtracted the mass of the containers recycled from the mass of mixed MSW recycled only and applied the US EPA recycling composition found in the "2015 Advancing Sustainable Materials Management: Facts and Figures Data Tables" report. The EPA reports provided a total recycled mass and its material composition for 2005 and 2015. We identified the beverage containers in the EPA data that corresponded to the beverages in the CalRecycle report and removed those materials from the EPA data to calculate a modified recycled materials composition. Then we applied the modified composition to the remaining total recycled mass to estimate the remaining materials' masses of California's recyclables stream. This approach was done for each year, 2005 and 2015, independently.

CalRecycle contracted Cascadia Consulting Group, Inc. to conduct a statewide disposal-based composition study in 2004 and 2014 (Cascadia Consulting Group, Inc., 2015, 2004). Results of each composition studies were applied to the mixed MSW combusted and landfilled masses for 2005 and 2015 to estimate the individual materials landfilled and combusted. Then, the individual material generated mass was estimated by summing the materials recycled, combusted, and landfilled masses. The per-person material masses were calculated using population statistics from State of CA Department of Finance for 2005 and 2015. Table 3-1 provides detailed information related to the mass-based recycling rate target for CA in 2005 and 2015, Table 3-2 provides the type of data available for CA in 2005 and 2015, and Table 3-3 shows the methodology we used to estimate some of the values in Table 3-2. The results of the mass estimates are shown for 16 individual materials in Table 3-4 for 2005 and 2015.

Table 3-1. Recycling information related to recycling rate or waste diversion targets for CA.

	Baseline Year (2005)	Year-of-Interest (2015)
Recycling Rate or Waste Diversion Target	50% diversion jurisdictional mandate goal; and a 6.3 pounds per person-day statewide disposal target	75% recycling rate statewide goal by 2020.; a 50% diversion jurisdictional mandate goal; and a 2.7 pounds per person-day statewide disposal target

Table 3-2. Input parameters needed to implement a CA-specific SMM approach. The check mark symbols imply that CalRecycle provides published reports 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*	✓	35,869,173		✓	38,912,464	CA Dept. of Finance
MSW Composition Study	n/a	✓, published in 2004	From Table ES-3, Statewide Waste Characterization Study 2004 Cascadia Consulting Group, Inc. Integrated Waste Management Board	✓, published in 2014	-	From Table ES-3, 2014 Disposal-Facility-Based Characterization of Solid Waste in California, Cascadia Consulting Group, CalRecycle California Department of Resources Recycling and Recovery
Total Mixed MSW Data						
Generated	✓[a]	70,043,528	Calculated see Table 3-3.	✓[a]	75,986,314	Calculated see Table 3-3.
Managed	✓[a]	70,043,528		✓[a]	75,986,314	
Recycled	✓[a]	16,519,843		✓[a]	30,854,200	
Combusted	✓[a]	811,271		✓[a]	812,403	
Landfilled	✓[a]	52,712,414		✓[a]	44,319,711	
Recycled Ash	n/a	-		n/a	-	
Ash and By-pass	n/a	-		n/a	-	
Back-End Scrap Metal	n/a	-		n/a	-	
Landfilled Ash	n/a	-		n/a	-	
MSW-ash, back-end scrap metal, & by-pass	n/a	-		n/a	-	
Non-MSW ash & By-pass	n/a	-		n/a	-	
Individual Material Data						
Generated	n/a	n/a		n/a	n/a	
Managed	n/a	n/a		n/a	n/a	
Recycled	n/a[b]	n/a[b]		n/a[b]	n/a[b]	
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: Data for California in 2005 and 2015 is not directly reported in CalRecycle reports but the data for generated, recycled, combusted, and landfilled were calculated using CalRecycle published tables and figures and an advised CalRecycle methodology.

b: No direct individual materials data for recycled in California (2005 and 2015) exist, however data on beverage materials recycled and redeemed are provided in Biannual Report. This report provides the number of beverage containers recycled, reused, and post-filled and corresponding conversion factors to convert the number of beverages to pounds. This report was used to estimate the mass of beverage materials recycled, and the remaining individual materials recycled data were estimated by applying the USA recycling composition (that does not include any beverage

Table 3-3. 2005 and 2015 mixed MSW mass estimates for the California. The data was extracted from many sources and followed the methodology described by the California Department of Resources Recycling and Recovery (CalRecycle) in the “State of Disposal in California Updated 2016” report.

Item	Item Title	Data	Units	Sources	Data	Units	Sources
A	Year	2005			2015		
B	Generation Rate	10.7	pounds/ day	Table 2, State of Recycling in CA 2015 Report	10.7	pounds/ day	Table 2, State of Recycling in CA 2015 Report
C	Population	35,869,173	persons	Table 1-E4 for 2000-2010, State of CA Dept. of Finance	38,912,464	persons	Table 1-E4 for 2011-2018, State of CA Dept. of Finance
D	Total Generation	70,043,528	tons	Calculated by: (B/2000 lbs)*365 day/yr*C	75,986,314	tons	Calculated by: (B/2000 lbs)*365 day/yr*C
E	Traditional Disposal	47,942,740	tons	From Disposal Reporting System California Annual Solid Waste Disposal	37,651,367	tons	From Disposal Reporting System California Annual Solid Waste Disposal
F	Alternative Daily Cover	4,669,674	tons	From Disposal Reporting System California Annual Solid Waste Disposal	3,516,961	tons	From Disposal Reporting System California Annual Solid Waste Disposal
G	Alternative Intermediate Cover	-	tons	*Not reported in Disposal Reporting System California Annual Solid Waste Disposal*	80,175	tons	From Disposal Reporting System California Annual Solid Waste Disposal
H	Waste-To-Energy	811,271	tons	From Disposal Reporting System California Annual Solid Waste Disposal	812,403	tons	From Disposal Reporting System California Annual Solid Waste Disposal
I	Other Beneficial Reuse	-	tons	*Not reported in Disposal Reporting System Other Beneficial Reuse by Material Type*	2,986,208	tons	From Disposal Reporting System Other Beneficial Reuse by Material Type
J	Waste Tire-Derived Fuels	100,000	tons	From Figure 2, California Waste Tire Market Report 2015	85,000	tons	From Figure 2, California Waste Tire Market Report 2015
K	Composting Only	9,868,112	tons	From Disposal Reporting System Other Beneficial Reuse by Material Type	9,316,416	tons	From Disposal Reporting System Other Beneficial Reuse by Material Type
L	Recycled and Source Reduction Only	6,651,731	tons	Calculated by: D-(E+F+G+H+I+J+K)	21,537,784	tons	Calculated by: D-(E+F+G+H+I+J+K)
M	Recycled, Composted or source reduced	16,519,843	tons	Calculated by: K + L	30,854,200	tons	Calculated by: K + L

Table 3-4. 2005 and 2015 individual material mass estimates and associated recycling rates for CA.

		2005				2015				2005	2015
Item No.	Material	Generated (Tons/ Person)	Recycled & Composted (Tons/ Person)	Combusted (Tons/ Person)	Landfilled (Tons/ Person)	Generated (Tons/ Person)	Recycled & Composted (Tons/ Person)	Combusted (Tons/ Person)	Landfilled (Tons/ Person)	Recycling Rate[a]	Recycling Rate[a]
1	Newspaper	0.052	0.020	0.000	0.032	0.046	0.032	0.000	0.014	37.4%	69.7%
2	Glass	0.054	0.020	0.001	0.034	0.052	0.023	0.001	0.028	36.4%	44.1%
3	Aluminum Cans	0.007	0.004	0.000	0.003	0.006	0.003	0.000	0.002	54.2%	60.0%
4	Steel Cans	0.015	0.003	0.000	0.012	0.018	0.010	0.000	0.008	20.9%	54.5%
5	Corrugated Paper	0.131	0.046	0.001	0.084	0.204	0.168	0.001	0.035	35.3%	82.4%
6	Plastic Bottles	0.019	0.004	0.000	0.015	0.020	0.007	0.000	0.013	19.4%	35.7%
7	Yard Trash	0.418	0.317	0.002	0.100	0.469	0.369	0.002	0.098	75.7%	78.7%
8	Mixed Plastics	0.128	0.001	0.002	0.125	0.113	0.005	0.002	0.106	0.6%	4.7%
9	Food Waste	0.219	0.001	0.003	0.215	0.222	0.012	0.004	0.206	0.7%	5.4%
10	Mixed Paper	0.219	0.022	0.003	0.194	0.225	0.073	0.003	0.149	10.1%	32.6%
11	Mixed Metals	-	-	-	-	-	-	-	-	-	-
12	Textiles	0.071	0.004	0.001	0.066	0.082	0.014	0.001	0.066	5.0%	17.6%
13	Tires	0.008	0.003	0.000	0.004	0.015	0.014	0.000	0.001	43.4%	92.3%
14	Electronics	0.027	0.008	0.000	0.019	0.039	0.028	0.000	0.010	28.3%	72.9%
15	C&D Debris	0.322	-	0.005	0.317	0.230	-	0.004	0.226	-	-
16	Miscellaneous	0.263	0.009	0.004	0.250	0.213	0.034	0.003	0.177	3.4%	15.7%
	Total	**1.953**	**0.461[b]**	**0.023**	**1.470**	**1.953**	**0.793[b]**	**0.021**	**1.139**	**23.6%[a]**	**40.6%[a]**
	Total (w/o C&D or Misc.)	**1.368**	**0.452[b]**	**0.014**	**0.902**	**1.510**	**0.759[b]**	**0.014**	**0.737**	**33.0%[a]**	**50.3%[a]**

Note: The estimates were calculated using data tables found in the Appendix. The combusted and landfilled masses were estimated by applying a CalRecycle statewide disposal waste composition study. Generated mass was calculated as the sum of recycled, combusted, and landfilled. The material categories in the report were re-organized to the 16 material categories. Calrecycle does not report estimates of C&D but using the composition studies we estimated the mass combusted and landfilled. Mixed metals follow the US EPA recycling composition which does not include not metallic materials because they were assigned to either aluminum or steel cans.

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 CA's solid waste management, we identified that there were still knowledge gaps. Directly the mass of individual materials generated, recycled, 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. Furthermore, both the 2005 and 2015 reports did not directly report the mass or composition of recycled and landfilled combustor ash.

Additional data needs concerns were associated with the tracking and reporting of material types. In this analysis we estimated disposition masses for the materials reported using the US EPA recycled composition and the CalRecycle reported waste composition studies. Also, the 2004 and 2014 waste composition studies differed, however, we re-organized the suite of materials evaluated for simplification. A final re-organization occurred for the 2005 and 2015 recycled materials and the 2004 and 2014 waste composition materials. 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 recyclables were not required to be tracked- and vice versa. All materials re-organization are shown in the Appendix.

5 SUSTAINABLE MATERIALS MANAGEMENT IN CALIFORNIA

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 CA.

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 3-4, we estimated a net environmental footprint of -0.997 $tCO_2eq.$/person and -7,211 MJ/person associated with CA's 2015 waste management system and -0.286 $tCO_2eq.$/person and -2,617 MJ/person associated with CA's 2005 waste management system. The total footprint was calculated by summing the footprints associated with recycling, landfilling, and combusting MSW. Each of these footprints were provided on a per person and a total basis in Tables 5-3 and 5-4 for 2005 and 2015. Tables 5-5 and 5-6 showed the material components that were used in Tables 5-3 and 5-

4. 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 CA in 2005.

Disposition	GHG Emissions (tCO_2eq.)	Energy Use (10,000 MJ)	GHG Emissions (tCO_2eq./Person)	Energy Use (MJ/Person)
Recycling	-14,330,940	-9,162,253	-0.400	-2,554
Combustion	23,226	-308,604	0.001	-86
Landfill	4,054,029	84,337	0.113	24
Total Footprint	-10,253,684	-9,386,519	-0.286	-2,617

Note: Tables 5-5 and 5-6 details each materials GHG emissions and energy use per person for 2005.

Table 5-4. Environmental footprint for recycling, combustion, and landfill for California in 2015.

Disposition	GHG Emissions ($tCO_2eq.$)	Energy Use (10,000 MJ)	GHG Emissions ($tCO_2eq./Person$)	Energy Use (MJ/Person)
Recycling	-43,003,009	-27,877,115	-1.105	-7,164
Combustion	50,953	-310,639	0.001	-80
Landfill	4,140,997	126,751	0.106	33
Total Footprint	-38,811,060	-28,061,003	-0.997	-7,211

Note: Tables 5-5 and 5-6 details each materials GHG emissions and energy use per person for 2015.

Table 5-5. GHG emissions footprint for each material's disposition (i.e., recycling & compositing, combustion, and landfill) for CA 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	-0.0539	-0.0003	-0.0266	-0.0808	-0.0880	-0.0001	-0.0112	-0.0311	-0.1305	-0.0994
2	Glass	-0.0054	<0.0001	0.0007	-0.0047	-0.0063	<0.0001	0.0006	-0.0011	-0.0068	-0.0057
3	Aluminum Cans	-0.0321	<0.0001	0.0001	-0.0320	-0.0317	<0.0001	<0.0001	-0.0035	-0.0351	-0.0316
4	Steel Cans	-0.0057	<0.0001	0.0002	-0.0055	-0.0176	<0.0001	0.0002	0.0084	-0.0090	-0.0175
5	Corrugated Paper	-0.1446	-0.0007	0.0197	-0.1256	-0.5241	-0.0003	0.0083	0.4059	-0.1102	-0.5162
6	Plastic Bottles	-0.0036	0.0003	0.0003	-0.0030	-0.0070	0.0003	0.0003	0.0024	-0.0041	-0.0065
7	Yard Trash	-0.0463	-0.0003	-0.0268	-0.0734	-0.0540	-0.0003	-0.0262	n/a	-0.0806	-0.0806
8	Mixed Plastics	-0.0008	0.0023	0.0025	0.0040	-0.0055	0.0024	0.0021	-0.0277	-0.0287	-0.0010
9	Food Waste	-0.0003	-0.0005	0.1166	0.1158	-0.0021	-0.0005	0.1120	0.0094	0.1187	0.1094
10	Mixed Paper	-0.0780	-0.0015	0.0245	-0.0550	-0.2591	-0.0014	0.0189	0.0423	-0.1994	-0.2416
11	Mixed Metals[a]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
12	Textiles	-0.0083	0.0011	0.0013	-0.0058	-0.0340	0.0013	0.0013	0.0421	0.0108	-0.0313
13	Tires	<0.0001	<0.0001	0.0001	-0.0012	<0.0001	<0.0001	<0.0001	<0.0001	0.0252	-0.0052
14	Electronics	-0.0192	0.0001	0.0004	-0.0188	-0.0705	0.0001	0.0002	0.5807	0.5105	-0.0702
15	C&D Debris[b]	-	-	-	-	-	-	-	-	-	-
16	Miscellaneous[b]	-	-	-	-	-	-	-	-	-	-
	Total	**-0.3982**	**0.0006**	**0.1130**	**-0.2859**	**-1.099**	**0.0013**	**0.1064**	**1.028**	**0.0608**	**-0.9974**

Note: Each disposition's GHG emissions were calculated by first multiplying each materials' recycling & composted masses found in Table 3-4 (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 and 5-4.

a. *Mixed metals mass dispositions (in tons/person) were not estimated and thus the GHG emissions and energy use footprints were not assessed in the study, refer to Table 3-4 for more details.*

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

Table 5-6. Energy use footprint for each material's disposition (i.e., recycling & compositing, combustion, landfill, and source reduction) for CA in 2005 and 2015.

Item No.	Material	2005 Recycling & Composting Energy Use (MJ/Person)	2005 Combustion Energy Use (MJ/Person)	2005 Landfill Emissions Energy Use (MJ/Person)	2005 Total Energy Use (MJ/ Person)	2015 Recycling & Composting Energy Use (MJ/ Person)	2015 Combustion Energy Use (MJ/Person)	2015 Landfill Energy Use (MJ/ Person)	2015 Source Reduction (SR) Energy Use (MJ/ Person)	2015 Total Energy Use with SR (MJ/Person)	2015 Total Energy Use without SR (MJ/Person)
1	Newspaper	-341.4	-3.955	1.773	-343.5	-556.8	-1.991	0.7495	-250.9	-808.97	-558.09
2	Glass	-44.07	0.2738	9.567	-34.22	-51.21	0.2747	8.059	-15.58	-58.45	-42.88
3	Aluminum Cans	-568.12	0.0285	0.8319	-567.26	-560.7	0.0263	0.6447	-67.27	-627.3	-560.0
4	Steel Cans	-66.41	0.0897	3.328	-62.99	-205.0	0.0725	2.257	86.98	-115.7	-202.6
5	Corrugated Paper	-736.97	-9.036	-21.70	-767.7	-2,671	-4.536	-9.145	1,708	-977.2	-2,685
6	Plastic Bottles	-155.6	-3.517	4.160	-154.9	-306.4	-3.571	3.546	77.63	-228.8	-306.5
7	Yard Trash	195.2	-4.023	12.50	203.6	227.5	-4.697	12.25	0	235.0	235.0
8	Mixed Plastics	-32.99	-27.65	35.36	-25.28	-220.3	-27.93	29.98	-826.8	-1,045	-218.2
9	Food Waste	0.8914	-7.168	-5.316	-11.59	7.359	-8.203	-5.107	39.44	33.49	-5.951
10	Mixed Paper	-476.6	-21.01	-42.36	-540.0	-1,583	-19.24	-32.58	194.7	-1,441	-1,635
11	Mixed Metals[a]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
12	Textiles	-79.33	-7.720	18.72	-68.33	-326.4	-9.185	18.70	1,059	742.6	-316.9
13	Tires	-12.92	-1.969	1.248	-13.64	-52.03	-0.6060	0.3224	536.9	484.6	-52.32
14	Electronics	-236.0	-0.3816	5.407	-231.0	-865.4	-0.2438	2.901	11,610	10,747	-862.8
15	C&D Debris[b]	-	-	-	-	-	-	-	-	-	-
16	Miscellaneous[b]	-	-	-	-	-	-	-	-	-	-
	Total	**-2,554**	**-86.04**	**23.51**	**-2,617**	**-7,164**	**-79.83**	**32.57**	**14,152**	**6,941**	**-7,211**

Note: Each disposition's GHG emissions were calculated by first multiplying each materials' recycling & composted masses found in Table 3-4 (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 and 5-4.

a. Mixed metals mass dispositions (in tons/person) were not estimated and thus the GHG emissions and energy use footprints were not assessed in the study, refer to Table 3-4 for more details.

b. 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 3-4):

→ **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 California

Table 5-7 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 corrugated paper, mixed paper, and electronics. 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). CA solid waste policy makers can prioritize their efforts to focus on which materials to recycle based off the environmental impacts.

Table 5-7. Results of the Best Target Materials Recycling approach applied to CA's waste management in 2015.

	Material		Material
Material Organized by Their Impact to Reduce the 2015 GHG Emissions Footprint (Larger to Smaller)	Corrugated Paper	Material Organized by Their Impact to Reduce the 2015 Energy Use Footprint (Larger to Smaller)	Corrugated Paper
	Mixed Paper		Mixed Paper
	Electronics		Electronics
	Newspaper		Aluminum Cans
	Textiles		Newspaper
	Aluminum Cans		Textiles
	Steel Cans		Plastic Bottles
	Food Waste		Mixed Plastics
	Plastic Bottles		Steel Cans
	Glass		Glass
	Mixed Plastics		Tires
	Tires		**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 3-4):

→ **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 California

Table 5-8 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 5-8. Illustration of the Best Disposal Management approach for CA'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 CA 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 CA passes a mandatory statute to collect, construct, and operate an organics composting facility; 2) commercial recycling, which assumes CA institutes a statute for mandatory commercial recycling of glass, aluminum cans, steel cans, corrugated paper, plastic bottles, and mixed paper ;and 3) source reducing (or waste prevention of) food waste, where CA implements a policy to encourage restaurants and other consumers to minimize the purchase and then disposal of unconsumed food. The following steps were used to identify which scenario resulted in the most GHG emissions and energy use avoidance using 2015 mass data (Table 3-4):

→ **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 source reducing food waste scenario the mass of food waste landfilled was multiplied by 0.15.

Note: the 0.15 value represented a 15% reduction of food waste landfilled mass. 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 source reduced and we estimated its environmental footprint by multiplying the mass by its respective WARM GHG emission and energy use factors for source reducing food waste. The source reducing food waste 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 California

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.

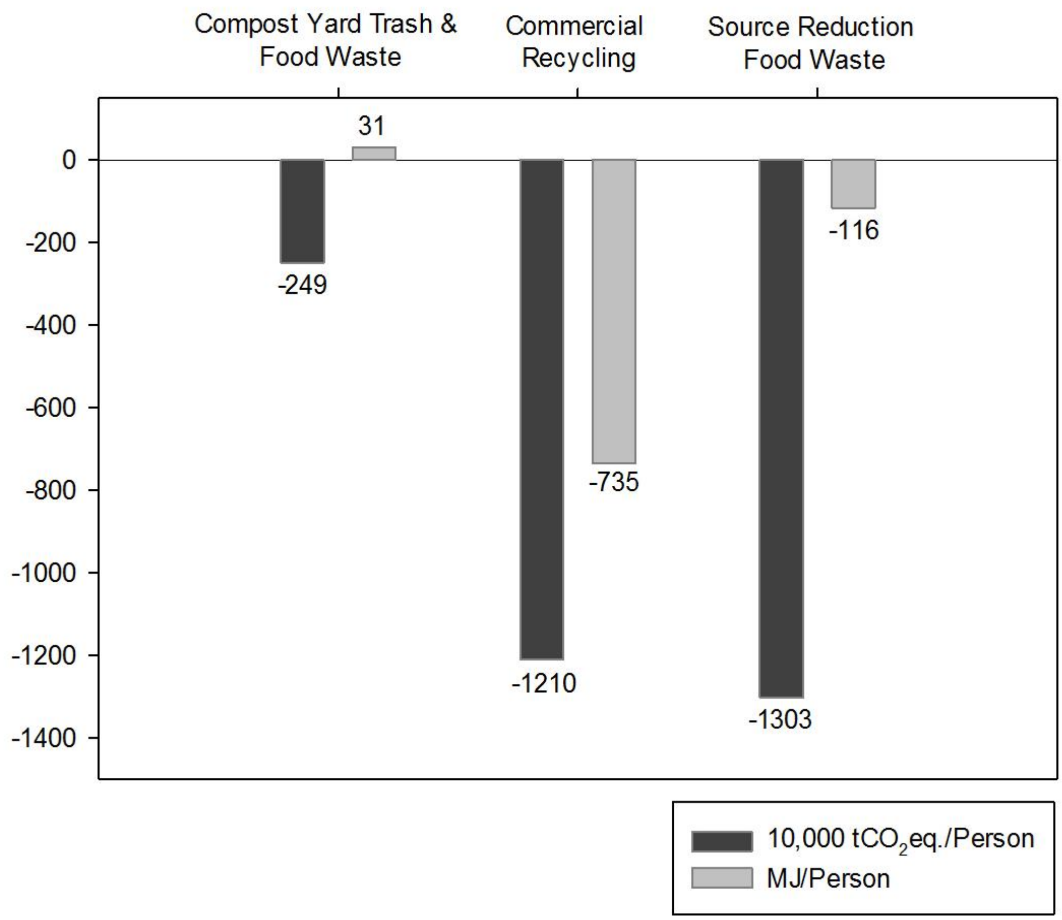

Figure 5-1. Example results of applying the Prioritizing Policy and Technology approach illustrated using three scenarios: 1) composting yard trash and food waste; 2) commercial recycling; and 3) source reduction food waste. Each scenario's environmental footprint was compared to the original 2015 footprint 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 3-4):

→ **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 California

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 CA'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). CA 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.

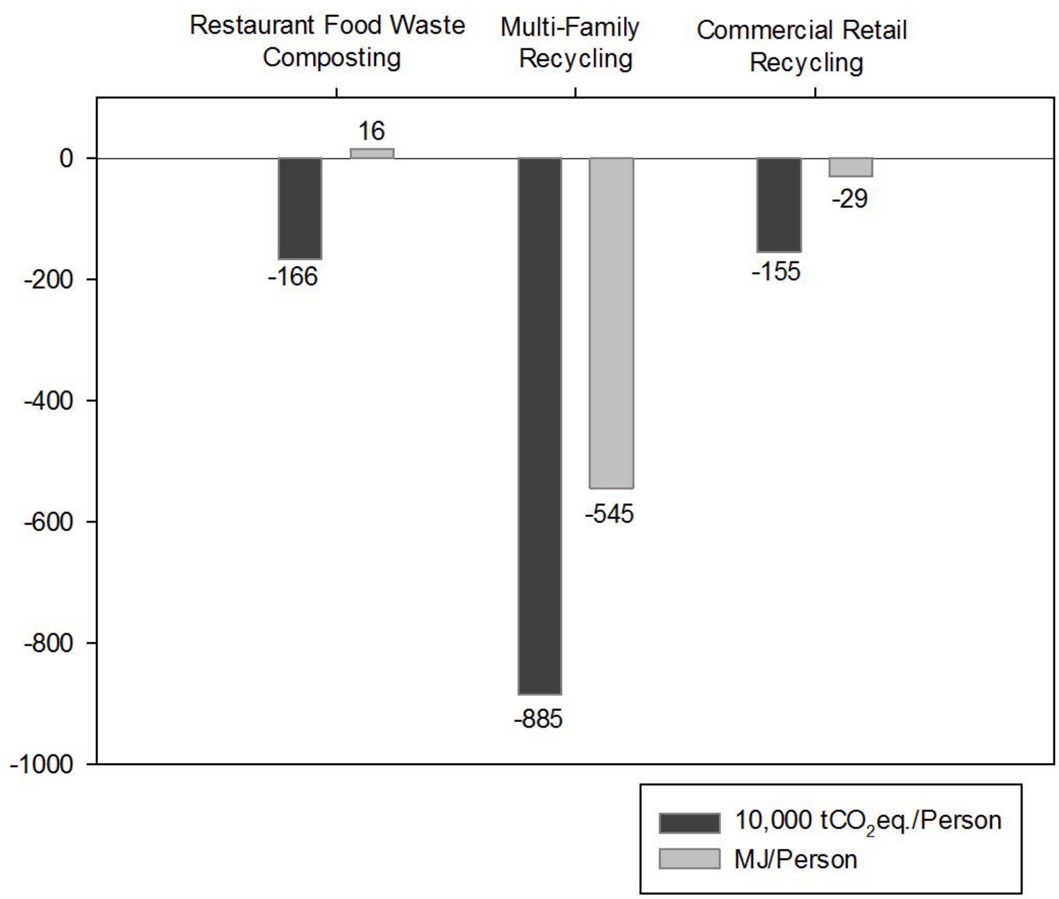

Figure 5-2. Example results of applying the Prioritizing Stakeholders approach illustrated using three scenarios: 1) restaurant food waste composting; 2) multi-family recycling; and 3) commercial retailers recycling. Each scenario's environmental footprint was compared to the original 2015 footprint 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 3-4, application of this approach using a historic target (i.e., 2005) will not be evaluated for CA 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 CA 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 Maryland Department of the Environment'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. 2-5 show the general methodology.

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

$$\mathrm{RR_{Mass,Baseline}} = \mathrm{LCI_{Baseline\ Year}} \quad \text{Eq. 2}$$

Where,

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

$\mathrm{LCI}_{\mathrm{Baseline}}$ 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 $\mathrm{LCI}_{\mathrm{n}}$:

$$\frac{\mathrm{RR_{Mass,Baseline}}}{\mathrm{LCI_{Baseline}}} = \frac{1\%}{\mathrm{LCI_n}} \quad \text{Eq. 3}$$

$$1\% = \mathrm{LCI_n} \quad \text{Eq. 4}$$

Where,

$\mathrm{LCI}_{\mathrm{n}}$ 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 $\mathrm{R_{LCI,Year\ of\ Interest}}$):

$$\mathrm{R_{LCI,Year\ of\ Interest}} = \mathrm{LCI_{\ Year\ of\ Interest}}\ (\frac{1\%}{\mathrm{LCI_{\ n}}}) \quad \text{Eq. 5}$$

Where,

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

$\mathrm{LCI_{\ Year\ of\ Interest}}$ units of $\left(\frac{\mathrm{tCO_2eq.}}{\mathrm{Person}}\right)$ and/or $\left(\frac{\mathrm{MJ}}{\mathrm{Person}}\right)$ 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 California

For the hypothetical 2015 target baseline its associated recycling rate and environmental footprints are presented in Table 5-9. We used this information and the Equations 2-5 to estimate conversion factors shown in Table 5-10. 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 CA the LCI-normalized recycling rate were greater than the mass-based recycling rate, suggesting that CA 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, CA lacks the individual materials' recycled masses which is needed to properly apply the Effective Recycling Rates Approach. In the future CA should focus on tracking the annual mass of individual material's recycled, but also their generated, landfilled, and combusted masses.

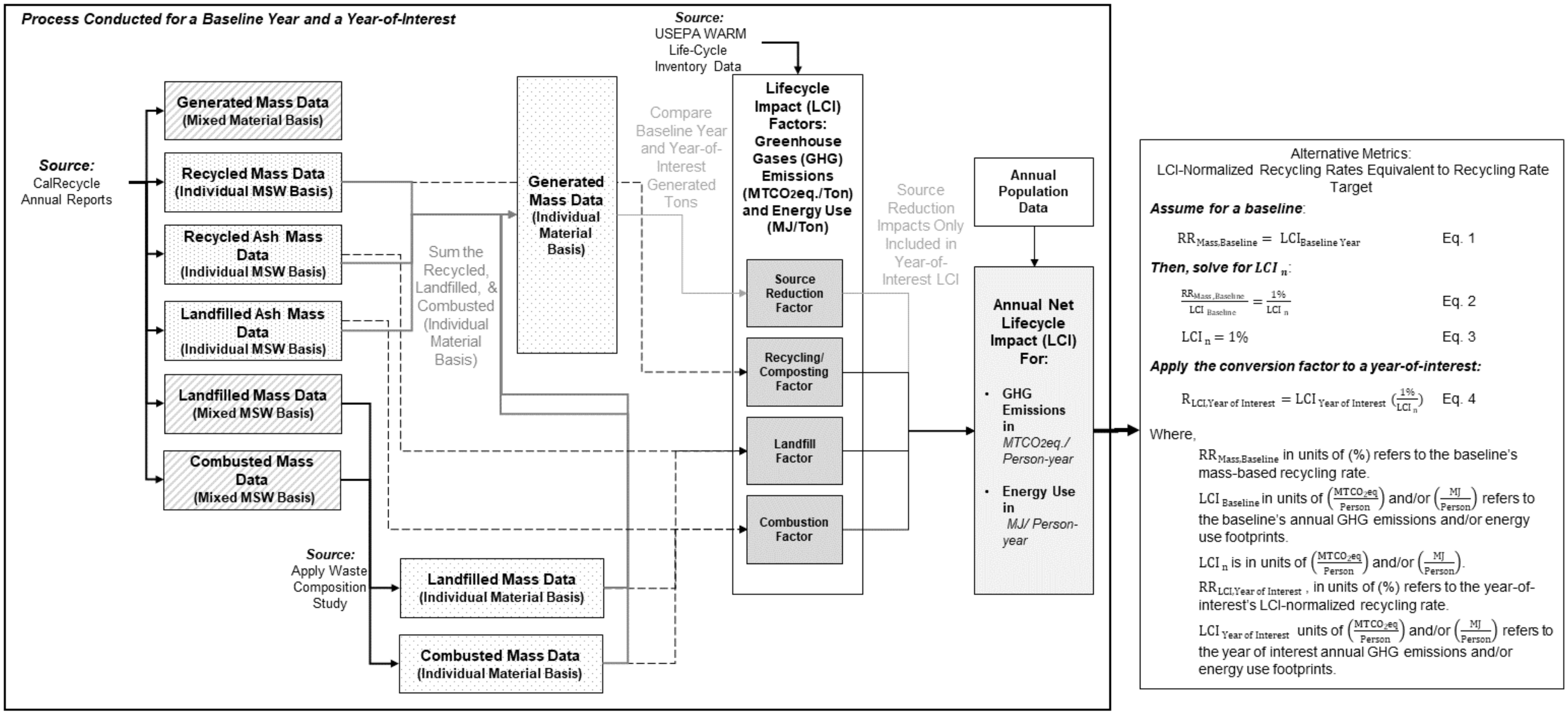

Figure 5-3. CA-specific methodology to estimate mass data (recycled, landfilled, combusted, landfilled & recycled ash) used as inputs to calculate a baseline year and year of interest's net lifecycle (LCI) impact (in GHG emissions and energy use) which is then converted to an LCI-normalized recycling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

Table 5-9. Recycling rate and environmental footprint for the 2015 hypothetical baseline.

State	Recycling Rate	GHG Emissions (tCO_2eq./Person)	Energy Use (MJ/Person)
CA	57.4%	-0.9909	-6,577

Table 5-10. Conversion factors for CA used in the Effective Recycling Rates approach. The 1% recycling rate refers to the recycling rate and the environmental footprints are associated with the 2015 target, shown in Table 5-9 and calculated using Equations 2-5.

Region	Recycling Rate		GHG Emissions (tCO_2eq./ Person/ 1% Recycling Rate)	Energy Use (MJ/ Person/ 1% Recycling Rate)
CA	1%	=	-0.0173	-114.6

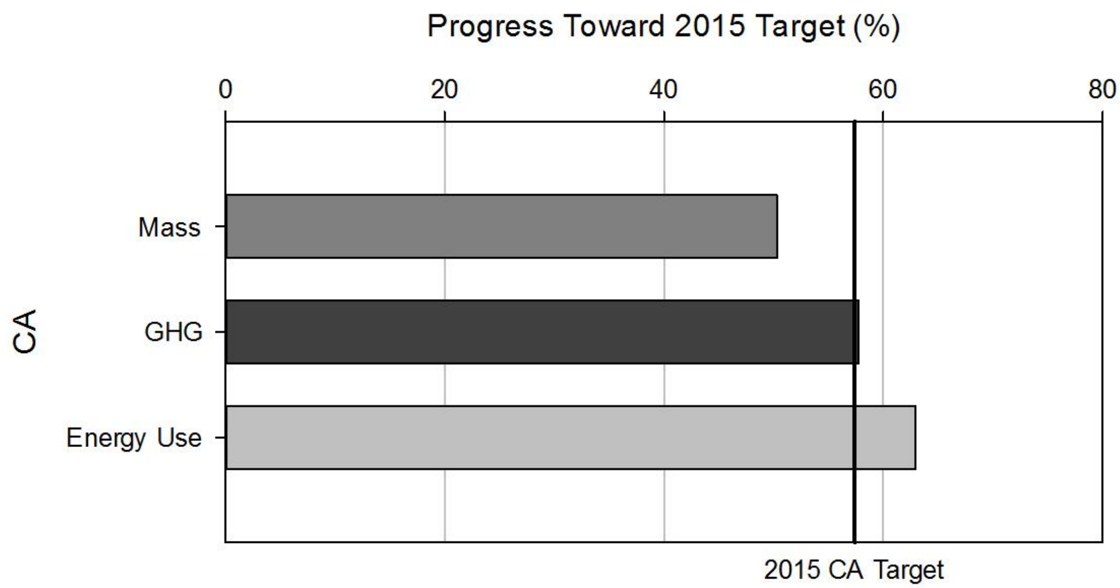

Figure 5-4. The Effective Recycling Rates approach applied to CA. A 2015 hypothetical baseline was created and the 2015 recycling rate, and environmental footprints were compared to see the progress of the 2015 performance to the 2015 target. The bar labeled mass refers to the 2015 mass-based recycling 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 CA 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 CA.

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, CA 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. In fact, CA aims to do so through the passing of Assembly Bill 901. We calculated CA's recycling rate as 23.6% and 40.6% in 2005 and 2015, respectively. These values do not include recycled miscellaneous or C&D debris. From the mass-based recycling rate, we see that CA has made progress in recycling more of their waste stream since 2005, but we cannot identify from the recycling rate whether CA 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 CA 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 CA 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 CA's environmental footprint. CA 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 CA 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.

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APPENDIX

Table A1. Waste composition data extracted from the 2004 California Waste Composition Study (Cascadia Consulting Group, Inc., 2004).

Item No.	Material	Total Percentage of Waste Stream	Item No.	Material	Total Percentage of Waste Stream
1	**Paper**	**21.0%**	33	**Organic**	**30.2%**
2	Uncoated Corrugated Cardboard	5.7%	34	Food	14.6%
3	Paper Bags	1.0%	35	Leaves and Grass	4.2%
4	Newspaper	2.2%	36	Prunings and Trimmings	2.3%
5	White Ledger	1.1%	37	Branches and Stumps	0.3%
6	Colored Ledger	0.1%	38	Agricultural Crop Residues	0.0%
7	Computer Paper	0.1%	39	Manures	0.1%
8	Other Office Paper	0.7%	40	Textiles	2.4%
9	Magazines and Catalongs	0.8%	41	Carpet	2.1%
10	Phone Books and Directories	0.2%	42	Remainder/Composite Organics	4.4%
11	Other Miscellaneous Paper	3.5%	43	**Construction & Demolition**	**21.7%**
12	Remainder/Composite Paper	5.7%	44	Concrete	2.4%
13	**Glass**	**2.3%**	45	Asphalt Paving	0.0%
14	Clear Glass Bottles and Containers	0.9%	46	Asphalt Roofing	1.9%
15	Green Glass Bottles and Containers	0.4%	47	Lumber	9.6%
16	Brown Glass Bottles and Containers	0.3%	48	Gypsum Board	1.7%
17	Other Colored Glass Bottles and Containers	0.0%	49	Rock, Soil, and Fines	2.4%
18	Flat Glass	0.4%	50	Remainder/Composite Construction and Demolition	3.6%
19	Remainder/Composite Glass	0.3%	51	**Household Hazardous Waste**	**0.2%**
20	**Metal**	**7.7%**	52	Paint	0.0%
21	Tin/Steel Cans	0.8%	53	Vehicle and Equipment Fluids	0.0%
22	Major Appliances	1.5%	54	Used Oil	0.1%
23	Used Oil Filters	0.0%	55	Batteries	0.0%
24	Other Ferrous	2.4%	56	Remainder/Composite Household Hazardouse	5.1%
25	Aluminum Cans	0.2%	57	**Special Waste**	**0.1%**
26	Other Non-Ferrous	0.3%	58	Ash	0.0%
27	Remainder/Composite Metal	2.5%	59	Sewage Soilds	0.0%
28	**Electronics**	**1.2%**	60	Industrial Sludge	0.0%
29	Brown Goods	0.1%	61	Treated Medical Waste	0.0%
30	Computer-related Electronics	0.3%	62	Bulky Items	3.4%
31	Other Small Consumer Electronics	0.2%	63	Tires	0.3%
32	Television and Other Items with CRTs	0.6%	64	Remainder/Composite Special Waste	1.2%

Table A1 (continued).

Item No.	Material	Total Percentage of Waste Stream	Item No.	Material	Total Percentage of Waste Stream
65	**Plastic**	**9.5%**	**76**	**Mixed Residue**	**1.1%**
66	PETE Containers	0.5%			
67	HDPE Containers	0.5%			
68	Miscellaneous Plastic Containers	0.5%			
69	Plastic Trash Bags	1.0%			
70	Plastic Grocery and Other Merchandise Bags	0.4%			
71	Non-Bag Commerical and Industrial Packaging Film	0.7%			
72	Film Products	0.2%			
73	Other Film	2.1%			
74	Durable Plastic Items	1.4%			
75	Remainder/Composite Plastic	2.2%			

Table A2. Waste composition data extracted from the 2014 California Waste Composition Study (Cascadia Consulting Group, Inc., 2015).

Item No.	Material	Total Percentage of Waste Stream	Item No.	Material	Total Percentage of Waste Stream
1	**Paper**	**17.4%**	18	**Organic**	**37.4%**
2	Uncoated Corrugated Cardboard	3.1%	19	Food	18.1%
3	Paper Bags	0.2%	20	Leaves and Grass	3.8%
4	Newspaper	1.2%	21	Prunings and Trimmings	3.1%
5	White Ledger	0.4%	22	Branches and Stumps	1.7%
6	Other Office Paper	0.3%	23	Manures	0.6%
7	Magazines and Catalongs	0.6%	24	Textiles	4.0%
8	Phone Books and Directories	0.0%	25	Carpet	1.8%
9	Other Miscellaneous Paper	3.9%	26	Remainder/Composite Organics	4.3%
10	Remainder/Composite Paper	7.5%	27	**Inerts and Other**	**19.9%**
11	**Glass**	**2.5%**	28	Concrete	1.2%
12	Clear Glass Bottles and Containers	0.9%	29	Asphalt Paving	0.2%
13	Green Glass Bottles and Containers	0.2%	30	Asphalt Roofing	0.7%
14	Brown Glass Bottles and Containers	0.4%	31	Lumber	11.9%
15	Other Colored Glass Bottles and Containers	0.0%	32	Gypsum Board	1.1%
16	Flat Glass	0.1%	33	Rock, Soil, and Fines	2.4%
17	Remainder/Composite Glass	0.9%	34	Remainder/Composite Inerts and Other	2.3%

Table A2 (continued).

Item No.	Material	Total Percentage of Waste Stream	Item No.	Material	Total Percentage of Waste Stream
35	**Metal**	**3.1%**	59	**Household Hazardous Waste**	**0.4%**
36	Tin/Steel Cans	0.7%	60	Paint	0.2%
37	Major Appliances	0.2%	61	Vehicle and Equipment Fluids	0.0%
38	Used Oil Filters	0.0%	62	Used Oil	0.0%
39	Other Ferrous	0.8%	63	Batteries	0.0%
40	Aluminum Cans	0.2%	64	Remainder/Composite Household Hazardous	0.2%
41	Other Non-Ferrous	0.5%	65	**Special Waste**	**5.0%**
42	Remainder/Composite Metal	0.8%	66	Ash	0.1%
43	**Electronics**	**0.9%**	67	Treated Medical Waste	0.1%
44	Brown Goods	0.3%	68	Bulky Items	4.4%
45	Computer-related Electronics	0.1%	69	Tires	0.1%
46	Other Small Consumer Electronics	0.2%	70	Remainder/Composite Special Waste	0.3%
47	Video Display Devices	0.2%	71	**Mixed Residue**	**3.0%**
48	**Plastic**	**10.4%**			
49	PETE Containers	0.6%			
50	HDPE Containers	0.5%			
51	Miscellaneous Plastic Containers	0.6%			
52	Plastic Trash Bags	1.2%			
53	Plastic Grocery and Other Merchandise Bags	0.5%			
54	Non-Bag Commercial and Industrial Packaging Film	0.3%			
55	Film Products	0.2%			
56	Other Film	1.8%			
57	Durable Plastic Items	2.2%			
58	Remainder/Composite Plastic	2.5%			

Table A3. Estimated recycled materials and their masses using Table A2 and the US EPA 2015 recycling composition found in the "2015 Advancing Sustainable Materials Management: Facts and Figures" report (US EPA, 2018).

Item No.	Material	Recycled & Composted (Tons)	Recycled & Composted (Tons)
1	Aluminum Packaging	126,433	135,363
2	Glass	704,857	888,629
3	Steel Packaging	113,082	378,629
4	PET	79,255	210,319
5	HDPE	49,646	65,087
6	Mixed Plastics	28,877	209,170
7	Major Appliances	182,003	649,230
8	Small Appliances	76,712	421,640
9	Bulky Items	376	2,396
10	Carpet	18,802	50,309
11	Tires	123,341	539,029
12	Batteries	198,548	673,187
13	Newspaper	703,945	1,245,755
14	Mixed Paper	792,314	2,855,654
15	Textiles	106,795	510,280
16	Corrugated Boxes	1,662,092	6,535,422
17	Food Waste	51,893	464,762
18	Yard Trimmings	1,493,626	5,050,099
19	Disposable Diapers	376	1,198
20	Other Miscellaneous Nondurables	376	33,540
21	Wood Packaging	137,630	615,690
22	Other Misc. Packaging	376	1,198
23	Miscellaneous Inorganic Wastes	376	1,198

Table A4. Recycling beverage containers mass estimated using from the CalRecycle "Biannual Report of Beverage Container Sales, Returns, Redemption, and Recycling Rates" (Scott Smithline, 2018).

Baseline Year (2005)		Year-of-Interest (2015)	
Material	**Recycled Mass (Tons)**	**Material**	**Recycled Mass (Tons)**
Beverage Containers	**957,375**	**Beverage Containers**	**1,300,255**
Aluminum Cans	123,049	Aluminum Cans	135,363
Glass	704,857	Glass	888,629
BiMetal	270	BiMetal	111
PET	79,255	PET	210,319
HDPE	49,646	HDPE	65,087
PVC	2	PVC	0
LDPE	0	LDPE	40
PP	1	PP	14
PS	1	PS	132
Other Plastics	293	Other Plastics	559
TOTAL	**957,375**	**TOTAL**	**1,300,255**

Table A5. Re-organized landfilled/combusted materials for 2005 and 2015. The materials column shows the re-organized materials category and the assumptions columns (which references materials from Table A1 for 2005 and Table A2 for 2015) shows which materials are included in the re-organized material categories.

Material	Assumptions for 2005 Disposed Materials	Assumptions for 2015 Disposed Materials
Newspaper	4	4
Glass	13	11
Aluminum Cans	25	40
Steel Cans	21	36
Corrugated Paper	2	2
Plastic Bottles	66 + 67	49 + 50
Yard Trash	35 thru 37	20 + 21+22
Mixed Plastics	68 thru 75	51 thru 58
Food Waste	34	19
Mixed Paper	3 + 5 thru 12	3 + 5 thru 10
Mixed Metals	22 thru 24 + 26 + 27	37 thru 39 + 41 + 42
Textiles	40 + 41	24 + 25
Tires	63	69
Electronics	28	43
C&D Debris	43	27
Miscellaneous	38 + 39 + 42+ 51+ 57 + 76	23 + 26 +59 + 65 +71

Table A6. 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 A3) shows which materials are included in the re-organized material categories.

Material	Assumptions for 2005 and 2015 Recycled Materials
Newspaper	13
Glass	2
Aluminum Cans	1
Steel Cans	3
Corrugated Paper	16
Plastic Bottles	4 + 5
Yard Trash	18
Mixed Plastics	6
Food Waste	17
Mixed Paper	14
Mixed Metals	Not Estimated
Textiles	15
Tires	11
Electronics	7 + 8 + 12
C&D Debris	Not Estimated
Miscellaneous	9 + 19 thru 23