Comparative Greenhouse Gas Emissions Analysis of Alternative Scenarios for Waste Treatment and/or Disposal

BASELINE SCENARIO - LANDFILL

1,000 tpd

ALTERNATIVE SCENARIO - INTEGRATED MRF WITH CONVERSION TECHNOLOGIES

1,000 tpd

County of Los Angeles
Department of Public Works

February 2016

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LIST OF ABBREVIATIONS

AD	Anaerobic Digestion
ARB	Air Resources Board
CalEEMod	California Emissions Estimator Model
CFR	Code of Federal Regulations
CT	Conversion Technology
DV	Digestible Component
EMFAC2011	ARB-developed model to calculate GHG emission for transport
EPA	United States Environmental Protection Agency
EpE	Entreprises pour l'Environmental Model
GHG	Greenhouse Gas
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
LandGEM	EPA model to calculate GHG emissions for buried refuse
LFG	Landfill Gas
LFG-to-energy	Landfill gas-to-energy
MBT	Mechanical and Biological Treatment
MRF	Materials Recovery Facility
MSW	Municipal Solid Waste
MTCO2E	Metric Tons of Carbon Dioxide Equivalent
NMOC	Non-Methane Organic Compounds
NSCR	Non-Selective Catalytic Reduction
RDF	Refuse-Derived Fuel
SCAQMD	South Coast Air Quality Management District
SCR	Selective Catalytic Reduction
tpd	Tons per Day
WARM	Waste Reduction Model

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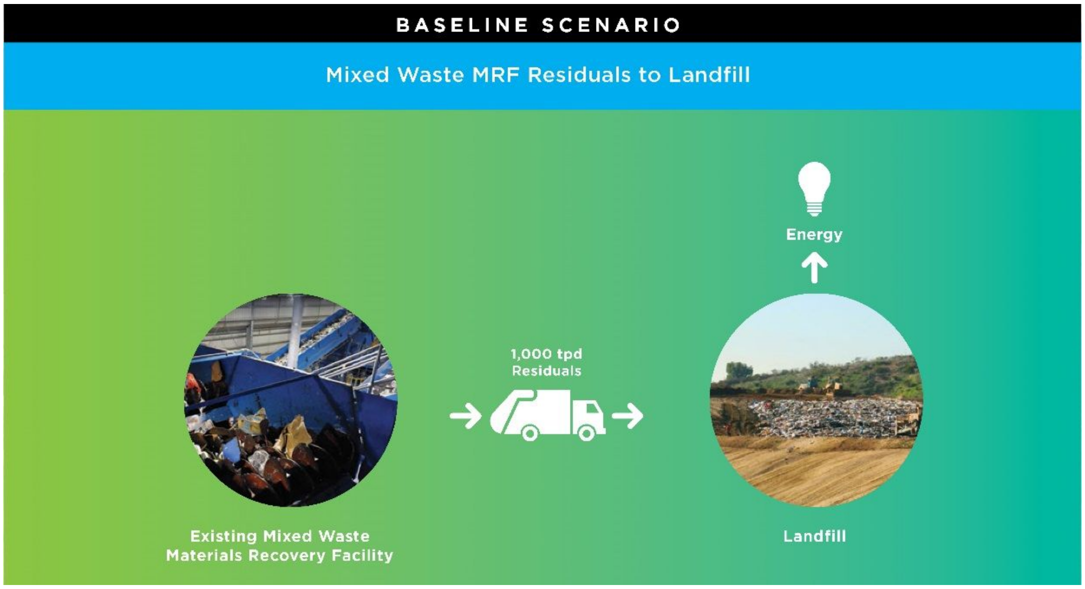
EXECUTIVE SUMMARY

This analysis compares the net greenhouse gas (GHG) emissions of two scenarios. The first scenario is the transport and disposal of 1,000 tons per day (tpd) of residuals from a mixed waste Materials Recovery Facility (MRF) to a modern sanitary landfill (Baseline Scenario). The second scenario proposes to process the same residuals at an Integrated MRF with Conversion Technologies (Alternative Scenario). The Baseline Scenario results in a net increase of approximately 1.64 million metric tons of carbon dioxide equivalent ($MTCO_2E$), while the Alternative Scenario results in net avoided GHG emissions of (0.67) million $MTCO_2E$. Therefore, shifting from the Baseline Scenario to the Alternative Scenario would result in a total GHG reduction of approximately 2.31 million $MTCO_2E$. The study parameters were strictly focused on analysis of GHG emissions and other air pollutants and do not consider other environmental, social or economic parameters.

In both scenarios, cumulative GHG emissions were analyzed for handling 1,000 tpd of post-recycled residuals (i.e., after recycling efforts) from a mixed waste MRF over a period of 25 years. For the Baseline Scenario, GHG emissions were modeled for a 100-year period after the landfill ceased to accept waste to account for GHG emissions generated by the decomposition of the waste disposed in the landfill.

The models used in the analysis to estimate GHG emissions from transportation and landfill operations are developed by air districts throughout California and consider future truck fleets with better emissions controls such as alternative fuels. The Baseline Scenario also assumes a soil cover (or cap) for the refuse and landfill gas to energy (LFG-to-energy) which is common of landfills in Southern California.



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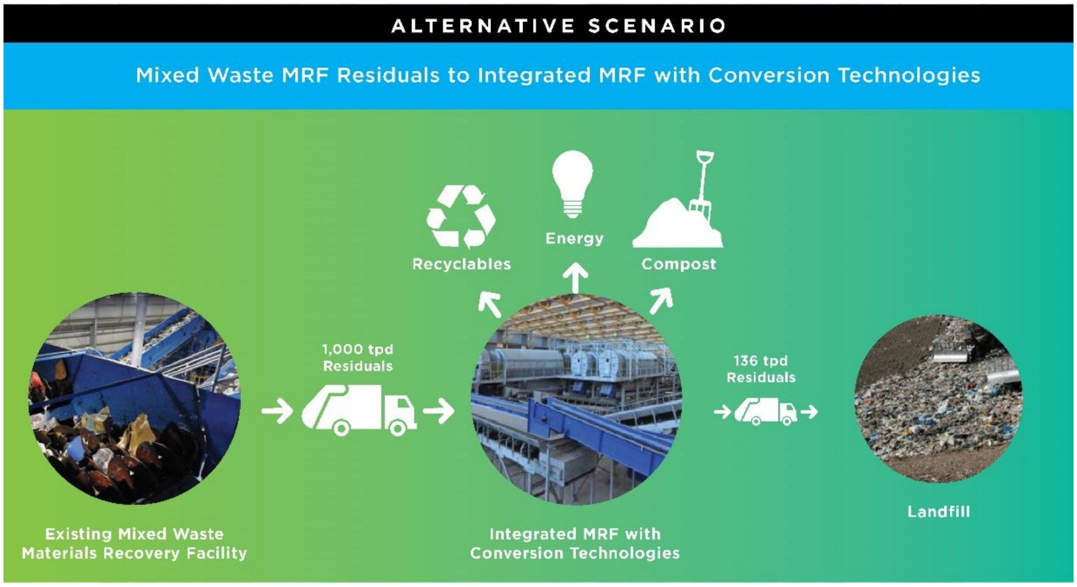


Under the Alternative Scenario, the post-recycled residuals from a mixed waste MRF are assumed to be further processed in an Integrated MRF with Conversion Technologies over a 25 year period, after which the facility is assumed to cease operating. The Integrated MRF with Conversion Technologies assumed in this study is modeled after a combination of technologies employed elsewhere in the world, including mechanical pre-processing to recover additional recyclable material and to separate residuals into a wet fraction for anaerobic digestion and composting, and a dry fraction for thermal gasification. These facility components and practices reflect actual modern, commercial scale operating mechanical pre-processing and anaerobic digestion facilities in the European Union, and thermal gasification and ash melting facilities in Asia.

In order to model emissions from a facility in California, the latest available statewide post-recycled MRF residual waste composition data (at the time of the analysis) from CalRecycle was assumed as the feedstock for the analysis. The Alternative Scenario also accounts for transport and disposal of the Integrated MRF with Conversion Technologies residuals to landfill, assuming a landfill with a cap and flare (due to residuals having very low organic content and thus low landfill gas generation from those residuals not sufficient for LFG-to-energy).

The net GHG emissions results calculated in this study are based on non-biogenic emissions (i.e., fugitive methane emissions from landfills and emissions from combustion of fossil fuels) pursuant to the Intergovernmental Panel on Climate Change (IPCC) guidelines, and industry accepted GHG models such as EPA Waste Reduction Model (WARM), European Union's EpE model and California Air Resources Board models. Biogenic emissions are not included in these conclusions, as these emissions naturally cycle through the atmosphere by processes such as photosynthesis, and are therefore carbon neutral and do not impact net GHG emissions.

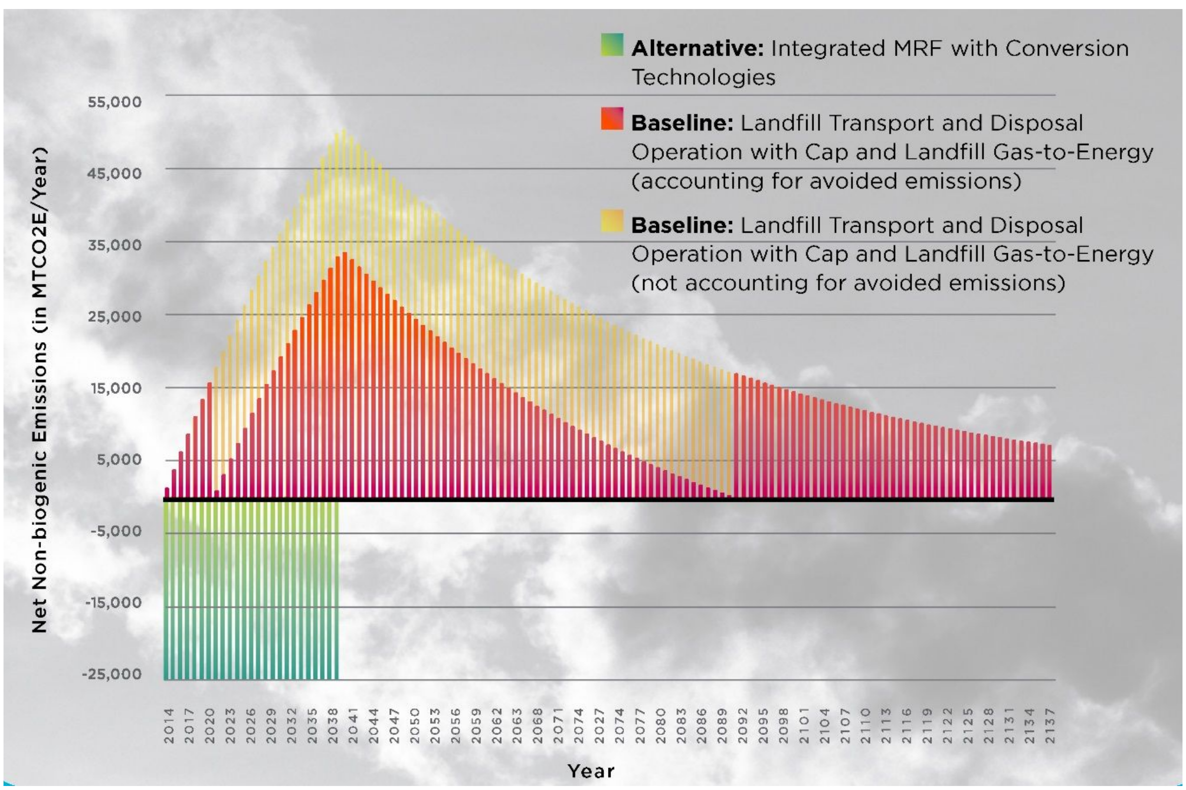
The analysis compares the overall net GHG emissions for the two scenarios measured in terms of $MTCO_2E$ for 1,000 tpd of post-recycled MRF residuals. The Baseline Scenario results in net

GHG emissions of approximately 1.64 million $MTCO_2E$, over a 125 year period taking into account continued GHG emissions from waste decomposition in the landfill, which is comparable to 340,000 passenger vehicles driven for one year. The Alternative Scenario results in net avoided GHG emissions of (0.67) million $MTCO_2E$ over a 25 year period, which is comparable to 140,000 fewer passenger vehicles driven for one year.

The two scenarios evaluated emissions from transportation, operation, and avoided emissions. The most significant difference between the two scenarios is that the avoided emissions are much greater for the Alternative Scenario. This is due to the energy generated from anaerobic digestion and gasification, which would replace fossil fuels, as well as the additional integrated MRF recycling in the Alternative Scenario. Avoided emissions in the Baseline Scenario are due to LFG-to-energy replacing the use of fossil fuels.

The avoided emissions in the Baseline Scenario are due to LFG-to-energy replacing the use of fossil fuels during the time period that enough landfill gas is generated to support a LFG-to-energy facility. The net annual GHG emissions results (after accounting for avoided emissions) associated with the management of waste materials for the Baseline and Alternative Scenarios is graphically shown below.

Figure ES: Net Non-Biogenic GHG Emissions Over Time: Baseline vs. Alternative Scenario



The analysis results found that the Baseline Scenario (landfill disposal with LFG-to-energy of 1000 tpd of MRF residuals) generates 2.31 million more $MTCO_2E$ of net GHG emissions than the Alternative Scenario (Integrated MRF with Conversion Technologies).

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The County of Los Angeles Department of Public Works commissioned this study which was conducted by an independent consultant Project Team of Tetra Tech, Inc., E. Tseng & Associates and HDR Inc. as well as student researchers from UCLA Extension Engineering Certificate program. Acknowledgement and thanks is also given to Peer Reviewers who reviewed the draft study and whose comments and responses are included in Appendix 8.

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PART I: INTRODUCTION

SECTION 1: INTRODUCTION

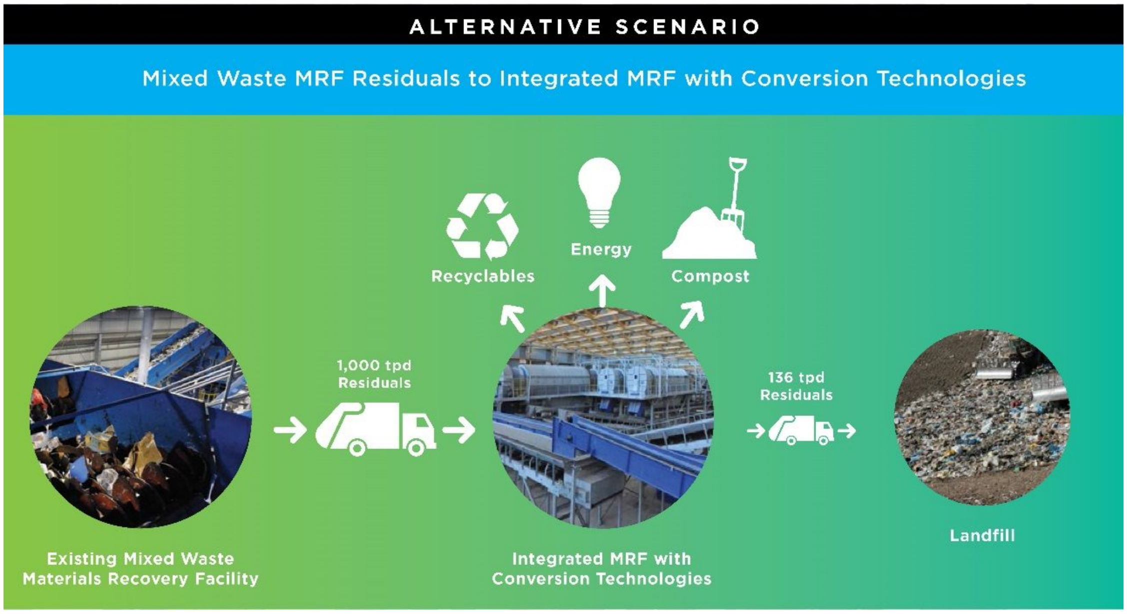
This analysis was commissioned by the County of Los Angeles Department of Public Works (DPW) to compare the net greenhouse gas (GHG) emissions for two waste management scenarios. The analysis compares GHG emissions resulting from traditional transport and landfill disposal of residuals from a mixed waste Material Recovery Facility (MRF) with the GHG emissions of processing those same MRF residuals through an Integrated MRF with Conversion Technologies. The material assumed to be processed under both scenarios is 1,000 tons per day (tpd) of post-recycled (after initial recycling efforts) residuals from a mixed waste MRF.

Conversion technologies refers to a wide array of technologies capable of converting post-recycled or residual solid waste into useful products, green fuels, and renewable energy through non-combustion thermal, chemical, or biological processes. Conversion technologies may include mechanical pre-processing when combined with a non-combustion thermal, chemical, or biological conversion process.[1] The conversion technologies selected includes a thermal process to treat the dry waste fraction and a biological process to treat the wet waste fraction. The study parameters were focused on analysis of GHG emissions and other air pollutants and do not consider other environmental, social or economic parameters.

The Baseline Scenario depicted below assumes that 1,000 tpd of post-recycled residuals from a mixed waste MRF are transported directly to a landfill for disposal over a 25-year period. The cumulative GHG emissions from the landfill were evaluated over a 125-year period to account for continued GHG emissions from the decomposition of waste disposed in the landfill.

[1] http://dpw.lacounty.gov/epd/SoCalConversion/Technologies/Definitions

In the Alternative Scenario depicted below, it is assumed that 1,000 tpd of post-recycled mixed-waste MRF residuals are additionally treated at an Integrated MRF with Conversion Technologies to achieve maximum diversion from landfills for a 25-year period. The typical useful life of an Integrated MRF with Conversion Technologies equipment is at least 25 years (therefore, dismantling the equipment is not included in GHG emissions calculations).



The purpose of the Integrated MRF with Conversion Technologies is to recover additional recyclables and materials not recovered by source separation programs or by a mixed waste MRF (i.e., facility which recovers recyclables from commingled municipal solid waste, utilizing manual and mechanical separation processes). In the Integrated MRF, a mechanical material separation process removes additional recyclables and prepares feedstock for conversion technologies. Additional diversion from landfill disposal is achieved by combining technologies that include anaerobic digestion, composting, and thermal processing with ash recovery/recycling.

<u>Baseline Scenario – Landfill Transport and Disposal</u>

The Baseline Scenario assumes transport of 1,000 tpd of post-recycled residuals from a mixed waste MRF to a modern sanitary landfill. Emissions were analyzed for the following: (1) transporting refuse from a location in Los Angeles County to a hypothetical out-of-County landfill location; (2) routine landfill operations including the use of equipment used in grading, compaction, and applying cover; and (3) landfill gas emissions from buried waste. The models used in the analysis to estimate GHG emissions from transportation and landfill operations are developed by air districts throughout California and consider future truck fleets and landfill equipment with better emissions controls such as alternative fuels.

Furthermore, the Baseline Scenario landfill operation was analyzed for two options: (1) landfill with cap and flare; and (2) landfill with cap and a LFG-to-energy system. For the summary comparison, the option including LFG-to-energy was assumed, because this is a common practice for sanitary landfills in Southern California.

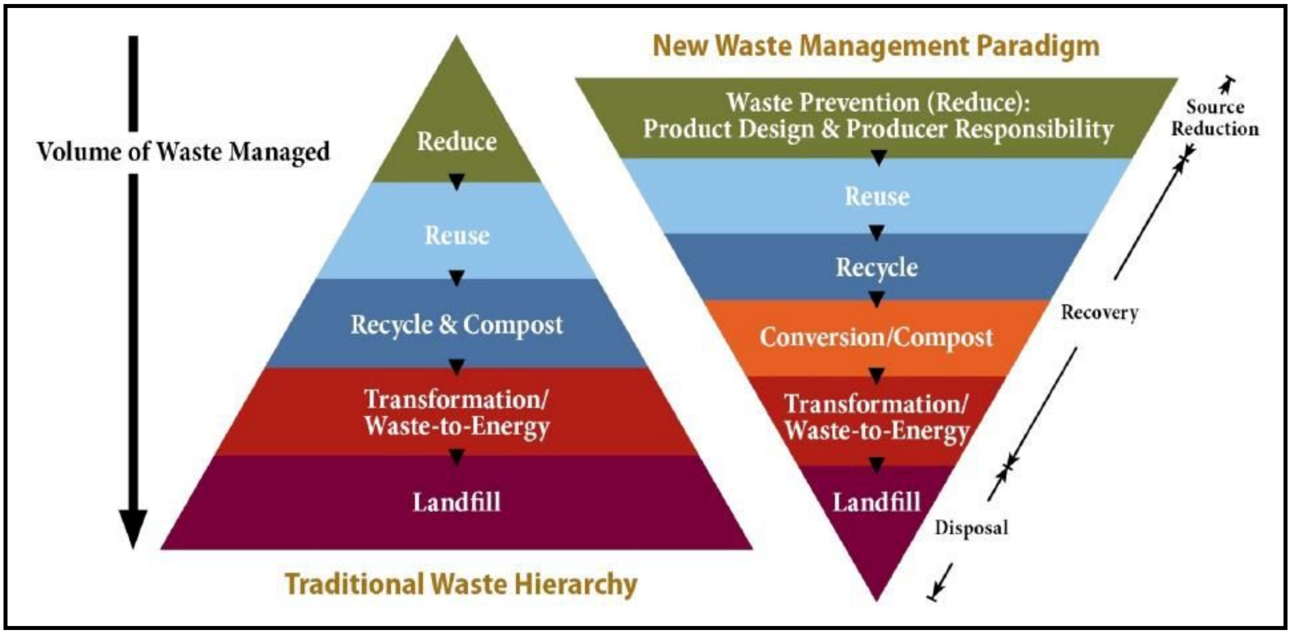
Assumptions and emissions models used in these analyses are provided in more detail in Section 2, Data Source and Calculation Methodology and in the Appendices.

Alternative Scenario – Integrated MRF with Conversion Technology

The Integrated MRF with Conversion Technologies assumed for this study is a modeled facility that combines traditional MRF recycling operations with a combination of full-scale, commercially operating technologies from other countries. Optimizing material reduction, reuse and recycling upstream is a higher priority for solid waste management but residuals still need to be handled. In order to better model emissions from a facility in California, the latest available statewide post-recycled MRF residual waste composition from CalRecycle (at the time of the analysis) was assumed as the feedstock for the analysis. The modeled facility was intended to maximize the beneficial uses of solid waste to achieve minimum landfill disposal, consistent with the current U.S. Environmental Protection Agency (EPA) waste management hierarchy and "MRF-First" policy of recovering marketable recyclables to the maximum extent reasonably possible.

The waste management hierarchy adopted by the Los Angeles County Solid Waste Management Committee/Integrated Waste Management Task Force is represented in two images below (Figure 1). A Traditional Waste Management Hierarchy integrates waste reduction measures, reuse practices, recycling and composting techniques, and waste-to-energy processing to manage a large portion of the typical solid waste stream. This has resulted in increased diversion of solid waste from landfills, however, a large volume of waste is still disposed of at landfill facilities (Californian's disposed approximately 30.2 million tons in 2013). By inverting the Traditional Waste Management Hierarchy and establishing a New Waste Management Paradigm, a greater emphasis is placed on maximizing the benefits and use of materials over disposal. This creates a new vision to significantly reduce, and someday, eliminate waste. The Integrated MRF with Conversion Technologies addresses the new integrated waste management hierarchy by prioritizing recycling, conversion technologies, and composting, with landfill disposal as a final option.

Figure 1: Waste Management Hierarchy



Note: Conversion refers to energy, fuels and/or products.

There are several regulations driving the implementation of conversion technologies in California. Assembly Bill (AB) 32, the California Global Warming Solutions Act and CalRecycle's AB 341, the Mandatory Commercial Recycling Law, are designed to reduce the greenhouse gas emissions through increased diversion from landfills. In May 2014, the California Air Resources Board (ARB) issued the "First Update to the Climate Change Scoping Plan", and the "Key Recommended Actions for the Waste Sector" include the following:

> ARB and CalRecycle will lead the development of program(s) to eliminate disposal of organic materials at landfills. Options to be evaluated will include: legislation, direct regulation, and inclusion of landfills in the Cap-and-Trade Program. If legislation requiring businesses that generate organic waste to arrange for recycling services is not enacted in 2014, then ARB, in concert with CalRecycle, will initiate regulatory action(s) to prohibit/phase out landfilling of organic materials with the goal of requiring initial compliance actions in 2016.

In 2014, California enacted mandatory organics diversion (AB 1826) and elimination of the use of green material as alternative daily cover at landfills to be counted as diversion (AB 1594). CalRecycle's focus for these laws is to reduce GHG emissions and reduce disposal of organics at landfills which is the source for methane generation resulting in GHG emissions (see Appendices 3 and 4 for additional discussion of regulatory drivers). The European Union (Directive 1999/31/EC) and many countries in Asia have taken similar approaches to solid waste management.

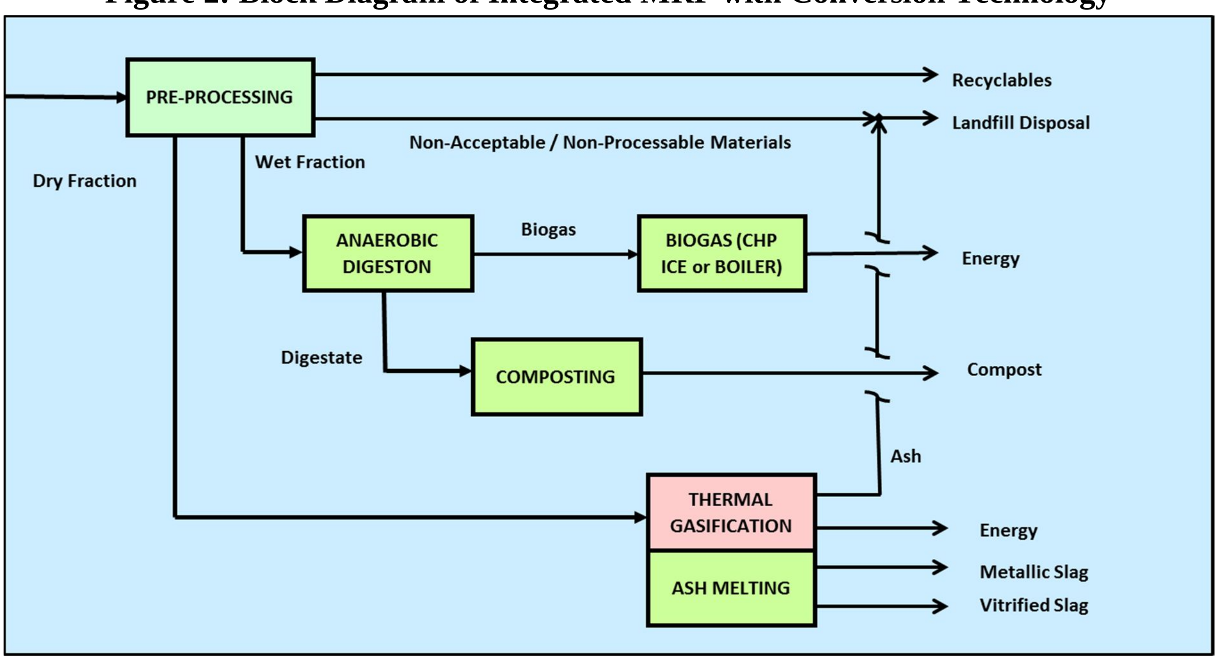
Diversion of organics and other materials have been modeled herein for an idealized Integrated MRF with Conversion Technologies. For this case study, Project Team members selected internationally recognized technologies for the purpose of obtaining reference data to be analyzed for use in conducting the comparative assessment in this study.

The Project Team intended for this study analysis to reflect real-world facility designs, operations, and emissions data. The Project Team devoted significant effort to using variables in several GHG and other emissions models that reflected real-world data. Project Team members worked with the executive management and engineering staff of selected facility operators who provided process engineering design data, mass and energy balance, and GHG emissions data based on existing projects/operating facilities for reviewing, vetting, comparing, and contrasting the data.

The California reference waste composition for this project (CalRecycle Residuals Composition for California Mixed Waste MRFs, 2006) was used to prepare independently developed calculations of the emissions and energy output data for each of the operational modules of the Integrated MRF with Conversion Technologies. The Project Team conducted a separate analysis of GHG emissions for the gasification component of the Integrated MRF with Conversion Technologies using U.S. EPA's Waste Reduction Model (WARM) and the same waste composition data assumed for the operating facilities. This separate analysis was performed to cross-check the emissions and energy results based on actual operating facilities data.

A block diagram showing the major operational components of the Integrated MRF with Conversion Technologies modeled in this study is presented below in Figure 2.

Figure 2: Block Diagram of Integrated MRF with Conversion Technology



Note: The boundary of the analysis did not include transport of heat sources (coke) for thermal gasification or compost and slag to off-site receiving facilities

Pre-processing: The pre-processing operation shown above reflects the most modern Integrated MRF with Conversion Technology approach in the European Union, which is designed to recover additional marketable recyclables remaining in the post-recycled MRF residuals feedstock as well as optimize the wet fraction feedstock in preparation for anaerobic digestion and composting, and process the dry fraction for thermal gasification and energy recovery. The front-end process design chosen for the study also considers the California regulatory requirement (in AB 1126) to remove PVC plastic in the process of creating refuse-derived fuel (RDF), minimum fuel values, and maximum moisture content requirements. The "Engineered Municipal Solid Waste" feedstock processing requirements of AB 1126 creates a RDF which has a lower ash content, higher heating value and lower moisture content (for reduction of chlorine thus minimizing the potential for formation of dioxin/furans)

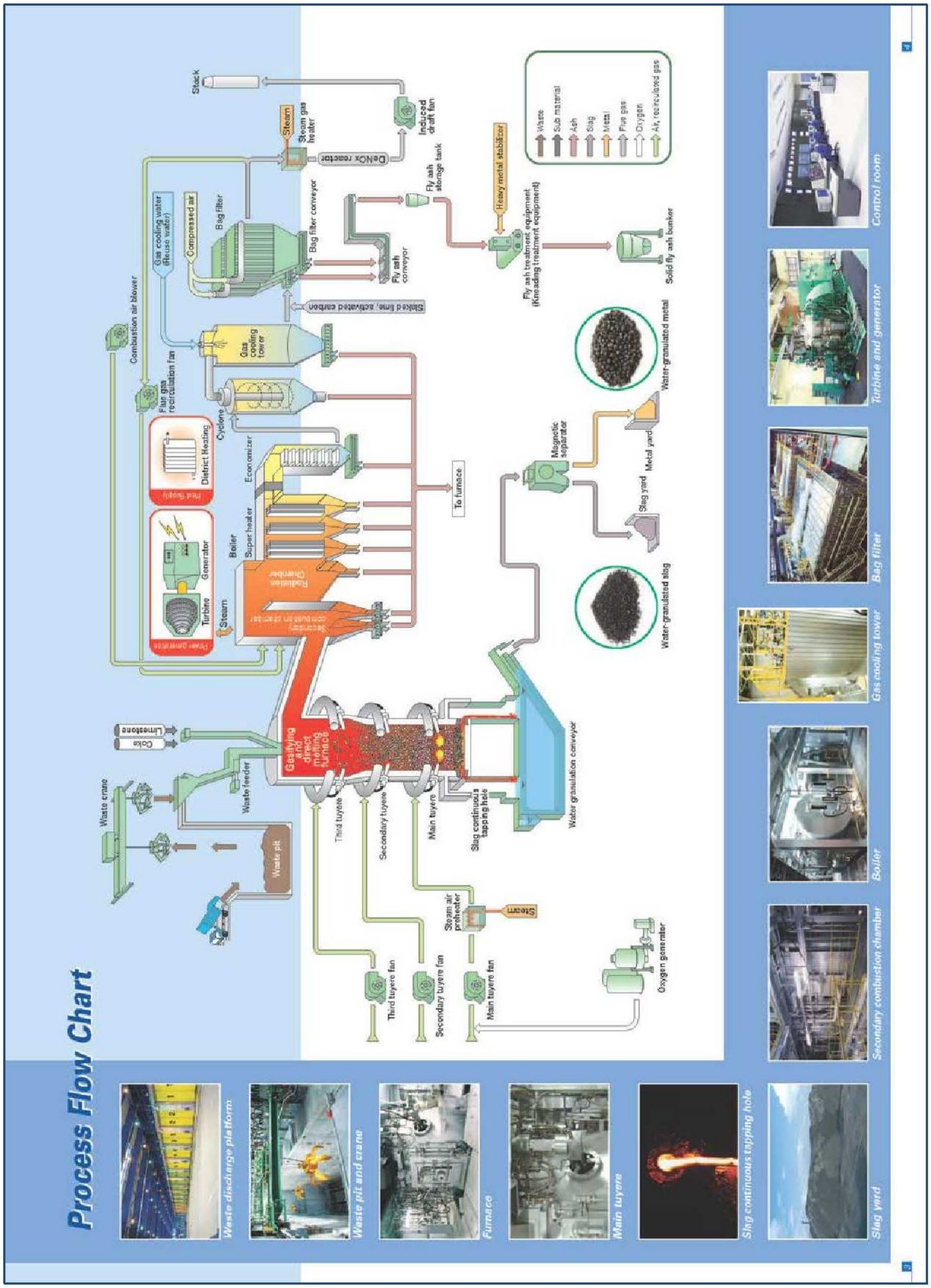
Anaerobic Digestion and Composting: The anaerobic digestion and composting module component is based on a wet anaerobic digestion technology employed at numerous operating facilities in Europe and Asia. The resulting biogas is utilized onsite for the generation of energy via an internal combustion combined heat and power system. In selecting the model anaerobic digestion process for the study, the Project Team reviewed proposed CalRecycle regulations for digestate/compost land application standards.[2] This review helped to select a process that would produce digestate and compost that would meet proposed physical contamination limits, which specifies that compost shall not contain more than 0.1 percent by weight of physical contaminants greater than four millimeters.

Thermal Gasification and Ash Melting: The high temperature thermal gasification and ash melting module component is based on existing market leader thermal gasification technologies in commercial use in Japan (see process flow diagram in Figure 3).

In Japan, the ash from these gasification units is usually melted (vitrified) to produce recyclable byproducts. For this study analysis of GHG emissions, gasification with ash melting technology was chosen because it maximizes diversion from landfill. Although ash melting requires additional energy for the melting, quenching and slag separation process, the resultant vitrified ash can potentially be recycled for use as paving blocks, road base, and other construction materials, with the metal slag also potentially recycled as raw material (e.g., aggregate for concrete blocks, tiles, road base) which are uses approved in Japan. The material specifications would need to be tested in the U.S. for meeting U.S. standards.

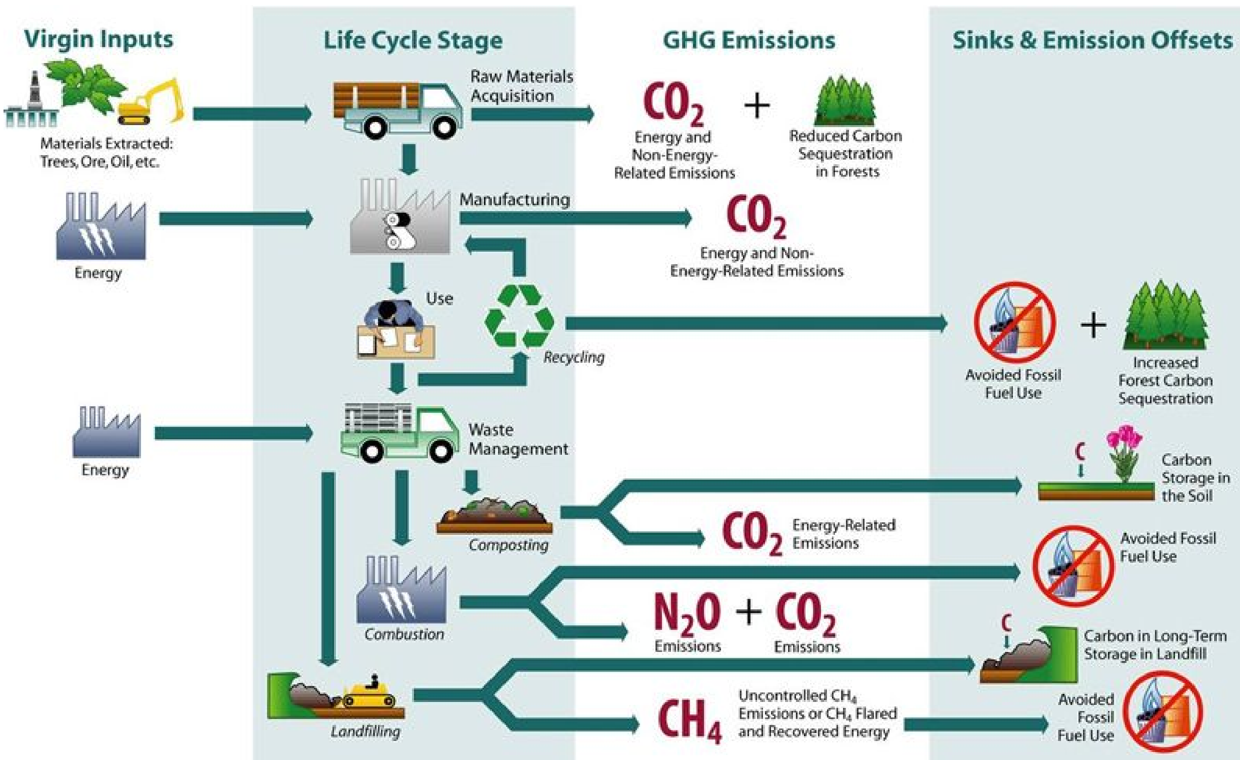
[2] http://www.calrecycle.ca.gov/Laws/Rulemaking/Compost/DraftText3.pdf

Figure 3: Process Flow Chart for High Temperature Gasification and Ash Melting



As discussed above, the primary focus for an Integrated MRF with Conversion Technologies approach is driven by the State of California's focus on GHG emissions reduction from solid waste management systems. The following Figure 4 presents the life cycle stages of material and solid waste management starting with extraction from the earth of virgin materials through material acquisition, manufacturing, human use and management of waste products. For each life cycle stage, Figure 4 shows GHG emissions generation, sinks, and emissions offsets associated with material acquisition, manufacturing, recycling, composting, combustion and landfilling.

Figure 4: Life Cycle of Materials



Source: USEPA, State and Local Climate and Energy Program, Solid Waste & Materials Management

In summary, the study's model Integrated MRF with Conversion Technologies combines proven technologies for individual wet fraction (anaerobic digestion/composting) and dry fraction (thermal gasification) process components, organized to reflect the most modern European Union system approach. The modeled facility technically embodies the new waste management hierarchy and the "MRF First" Policy approach to reduce GHG emissions, optimize highest and best use of materials and maximize landfill diversion.

PART II: DATA SOURCES AND METHODOLOGY

SECTION 2: DATA SOURCES AND CALCULATION METHODOLOGY

Various sources of data and modeling techniques were used to estimate the total GHG emissions (biogenic and non-biogenic sources) for the two scenarios examined in this study.

For the landfill transport and disposal (baseline) scenario, various industry-accepted models were used to calculate GHG emissions for transport (Air Resources Board -developed EMFAC2011 model), landfill operations (CalEEMod), and buried refuse (U.S. EPA LandGEM model), as further discussed in Section 4 and in Appendix 1. The global warming potential (GWP) factor in these models were updated to reflect the most current values (at the time of the analysis in 2013) stated in the IPCC, Fifth Assessment Report, Climate Change 2013, The Physical Science Basis.[3] Avoided emissions calculations (for recovered energy) that reflect California-specific factors for avoided emissions in the various models were also used.[4]

Two widely used GHG emissions modeling tools for comparing waste management options were used for the Alternative Scenario: the U.S. EPA's Waste Reduction Model (WARM) and the *Entreprises pour l'Environment* (EpE) tool. Limitations on these analytical tools are that WARM does not have emissions factors for anaerobic digestion, neither model has emissions factors for gasification and ash melting and neither model could apply the IPCC Fifth Assessment Report GWP factors or California grid-specific emissions factors. To estimate the GHG impacts associated with the avoided electricity-related emissions, the material specific emission factors for the Pacific region utility mix were extracted from the WARM model and calculations were performed via a spreadsheet outside of WARM.

The Project Team used the applicable component parts of the various analytical tools. For gasification, the technology facility operator provided emissions calculations based on the reference dry fraction waste composition (further discussed in Section 3) and on actual plant operation experience from a reference facility in Japan. Information provided by the operating reference facility in Japan was reviewed, assessed, vetted, and compared with the WARM results independently developed by Project Team members (included in Appendix 2). WARM had emissions factor estimators for "incineration" and was used to cross-check vetted emissions calculations for gasification provided by the facility operator.

The assumptions, various data sources, and the models used to calculate the GHG emissions are further discussed in Part III of this study. Detailed calculations for the GHG emissions are provided in the Appendices.

[3] http://www.climatechange2013.org/images/uploads/WGIAR5_WGI-12Doc2b_FinalDraft_All.pdf
[4] http://cfpub.epa.gov/egridweb/ghg.cfm - eGRID2007 Version 1.1 Year 2005 GHG Annual Output Emission Rates

SECTION 3: COMPOSITION OF POST-RECYCLED RESIDUALS FROM MIXED WASTE MRF

The mixed-waste MRF residuals composition is based on the CalRecycle Statewide Study completed in 2006 for that specific waste composition. This composition reflects a statewide average composition of post-recycled residuals from a mixed waste or “dirty” MRF (after being source separated curb-side) going to landfill disposal.[5]

This composition was selected because it was the latest published statewide data available from CalRecycle at the time the study was initiated in 2013 that represents the waste characterization of “post-recycled” residuals (marketable recyclables recovered in a mixed waste MRF after curb-side source separation), and reflects the State’s “MRF First” Policy. CalRecycle recently updated their statewide waste characterization titled 2014 Disposal-Facility-Based Characterization of Solid Waste in California, dated November 4, 2015. With additional pre-processing, recyclables previously missed in curb-side recycling or at the mixed waste MRF can be recovered from the waste stream currently bound for disposal. Table 1 shows the California statewide waste composition study results.

Using the CalRecycle statewide waste composition data, the 1,000 tpd of post-recycled mixed waste MRF residuals composition was further separated into its major fractions to be optimized for further processing. The major fractions include the following:

- Wet fraction (“DC” for digestible component)
- Dry fraction (“RDF” for refuse-derived fuel)
- Landfill (non-processable/non-acceptable materials)
- Rejects (problematic materials)

The wet fraction refers to the organic residuals from the mixed waste MRF, not all of which are digestible. It does not refer to previously source separated materials which are already being composted and/or digested. The dry fraction consists of non-recyclable, non-digestable and non-compostable materials (e.g. plastics, composite paper materials).

In calculating GHG emissions for thermal treatment, the Project Team took into account the statistical variation of the waste composition and calculated average, lower-bound, and upper-bound emissions for GHG (see Appendix 7). The composition by material type and quantity for the major fractions is shown in Table 2.

The detailed composition for each process fraction was developed in conjunction with the process flow shown previously in Figure 2. The composition took into consideration the CalRecycle mixed waste MRF residuals (by material type) composition resulting from the

[5] http://www.calrecycle.ca.gov/Publications/Detail.aspx?PublicationID=1182

additional processing of the mixed waste feedstock as the materials sequentially move from one unit process to the next. The waste stream splits, and the resulting composition, identified by individual material type and quantity in each of the major fractions, is based on the operating experience of actual facilities and equipment manufacturers. This data was used as input to the various models utilized for calculating GHG emissions as further discussed in Part III of this study.

Table 1: CalRecycle Residuals Composition for California Mixed Waste MRFs

Table 18 - Estimated Residual Composition for California MRFs Receiving Mixed Waste, 2005

	Est. Pct.	+/-	Est. Tons
Paper	**33.1%**	**1.8%**	**2,213,130**
Uncoated Corrugated Cardboard	4.3%	0.4%	284,205
Paper Bags/Kraft	0.7%	0.1%	45,834
Newspaper	4.2%	0.5%	278,891
White Ledger	1.8%	0.3%	120,169
Colored Ledger	0.2%	0.0%	13,761
Computer Paper	0.0%	0.0%	1,676
Other Office Paper	2.5%	0.3%	166,522
Magazines/Catalogs	2.5%	0.4%	163,624
Phone Books/Directories	0.2%	0.1%	12,360
Other Misc. Paper	4.7%	0.4%	310,598
Remainder/Composite Paper	12.2%	1.1%	815,491
Glass	**1.9%**	**0.3%**	**128,415**
Clear Glass Bottles & Containers	0.8%	0.2%	54,896
Green Glass Bottles & Containers	0.2%	0.1%	15,722
Brown Glass Bottles & Containers	0.2%	0.1%	11,930
Other Colored Glass Bottles & Containers	0.0%	0.0%	519
Flat Glass	0.1%	0.0%	3,497
Mixed Cullet	0.4%	0.1%	25,861
Remainder/Composite Glass	0.2%	0.1%	15,991
Metal	**5.6%**	**0.8%**	**372,659**
Tin/Steel Cans	1.1%	0.2%	74,031
Major Appliances	0.2%	0.1%	10,799
Used Oil Filters	0.0%	0.0%	305
Other Ferrous	2.0%	0.5%	136,782
Aluminum Cans	0.3%	0.0%	18,331
Other Non-Ferrous	0.7%	0.2%	49,703
Remainder/Composite Metal	1.2%	0.3%	82,706
Electronics	**1.1%**	**0.3%**	**73,259**
Brown Goods	0.3%	0.1%	20,966
Computer-related Electronics	0.4%	0.1%	23,838
Other Small Consumer Electronics	0.4%	0.1%	28,122
TV's & Other CRTs	0.0%	0.0%	333
Plastic	**16.9%**	**1.1%**	**1,127,866**
PETE Bottles	0.7%	0.1%	43,746
Other PETE Containers	0.1%	0.0%	9,710
HDPE Natural Bottles	0.3%	0.1%	19,636
HDPE Colored Bottles	0.3%	0.1%	17,303
HDPE 5-gallon buckets (Food)	0.1%	0.0%	4,852
HDPE 5-gallon buckets (Non-Food)	0.3%	0.1%	21,262
Other HDPE Containers	0.1%	0.0%	6,097
#3-#7 Bottles	0.1%	0.0%	6,863
Other #3-#7 Containers	0.8%	0.1%	53,697
Plastic Trash Bags	1.3%	0.2%	87,248
Grocery/Merch. Bags	1.1%	0.2%	76,432
Non-bag Comm./Ind. Packaging Film	1.8%	0.4%	117,378
Film Products	0.1%	0.1%	8,592
Other Film	3.7%	0.4%	246,411
Durable Plastic Items	1.2%	0.2%	80,524
Remainder/Composite Plastic	4.9%	0.5%	328,115
Organic	**27.3%**	**2.4%**	**1,825,548**
Food	10.4%	1.3%	691,353
Leaves and Grass	7.9%	1.9%	530,628
Prunings & Trimmings	1.0%	0.3%	63,914
Branches & Stumps	0.3%	0.1%	22,940
Agricultural Crop	0.0%	0.0%	2,710
Manures	0.0%	0.0%	1,879
Textiles	2.4%	0.4%	163,550
Carpet	0.3%	0.1%	22,798
Remainder/Composite Organics	4.9%	0.7%	325,776
Construction & Demolition	**12.6%**	**2.0%**	**839,302**
Concrete	0.6%	0.2%	41,868
Asphalt Paving	0.0%	0.0%	215
Asphalt Roofing	0.2%	0.1%	12,605
Lumber	3.1%	0.6%	204,749
Treated Wood Waste	1.9%	0.4%	127,948
Gypsum Board	0.8%	0.3%	52,064
Rock, Soil, Fines	3.2%	0.6%	216,690
Remainder/Composite C&D	2.7%	0.8%	183,161
Household Hazardous Waste	**0.4%**	**0.1%**	**25,022**
Paint	0.0%	0.0%	1,232
Vehicle & Equip. Fluids	0.0%	0.0%	0
Used Oil	0.0%	0.0%	459
Batteries	0.3%	0.1%	19,319
Remainder/Composite HHW	0.1%	0.0%	4,012
Special Waste	**0.5%**	**0.4%**	**36,442**
Ash	0.0%	0.0%	1,111
Sewage Solids	0.0%	0.0%	0
Industrial Sludge	0.0%	0.0%	0
Treated Medical Waste	0.0%	0.0%	90
Bulky Items	0.0%	0.0%	0
Tires	0.0%	0.0%	1,566
Remainder/Composite Special Waste	0.5%	0.2%	33,675
Mixed Residue	**0.5%**	**0.2%**	**36,508**
Totals	**100.0%**		**6,678,151**
Sample count:	**120**		

Notes: Confidence intervals calculated at the 90% confidence level. Percentages for material types may not total 100% due to rounding.
Estimated Percentages calculated by weight as the average proportion of each material type to the total residual weight

Source: http://www.calrecycle.ca.gov/WasteChar/WasteStudies.htm#2006MRF

Table 2: Residuals Composition by Material Type and Quantity

Work Days/Year	365	Important Note: Lower and Upper Bounds for Major Materials and Total Are the Sum of Detailed Materials, Not Separaty Calculated Bounds.		AVERAGE					UPPER AND LOWER BOUND				
Short Tons/Day	1000			Process Category (Daily Short Tons)					Lower/Upper 90% Bound (Daily Short Tons)				
Material Group	Material	TOTAL PERCENT	TOTAL DAILY TONS	Recyclables	DC	RDF	Landfill	Reject	Recyclables	DC	RDF	Landfill	Reject
Paper		**33.1%**	**331.4**	**4.6**	**49.7**	**277.1**	**0.0**	**0.0**	**4.1 - 5.0**	**44.6 - 54.8**	**248.4 - 305.8**	**0.0 - 0.0**	**0.0 - 0.0**
1	OCC (Recyclable)/Kraft	4.9%	49.4	2.0	7.4	40.0	0.0	0.0	1.8 - 2.1	6.8 - 8.0	36.7 - 43.4	0.0 - 0.0	0.0 - 0.0
2	Newspaper	4.2%	41.8	1.3	6.3	34.2	0.0	0.0	1.1 - 1.4	5.5 - 7.0	30.1 - 38.3	0.0 - 0.0	0.0 - 0.0
3	High Grade Office Paper	4.5%	45.2	1.4	6.8	37.1	0.0	0.0	1.2 - 1.5	6.1 - 7.4	33.6 - 40.6	0.0 - 0.0	0.0 - 0.0
4	Mixed Recyclable Paper	7.3%	72.9	0.0	10.9	61.9	0.0	0.0	0.0 - 0.0	10.1 - 11.8	57.0 - 66.8	0.0 - 0.0	0.0 - 0.0
5	Compostable Paper	8.9%	89.0	0.0	13.4	75.7	0.0	0.0	0.0 - 0.0	11.9 - 14.8	67.7 - 83.6	0.0 - 0.0	0.0 - 0.0
6	Non-Recyclable Paper	3.3%	33.1	0.0	5.0	28.1	0.0	0.0	0.0 - 0.0	4.1 - 5.8	23.3 - 33.0	0.0 - 0.0	0.0 - 0.0
Plastic		**16.9%**	**168.9**	**6.1**	**2.0**	**153.0**	**7.5**	**0.3**	**5.0 - 7.2**	**1.8 - 2.2**	**139.3 - 166.7**	**6.8 - 8.2**	**0.2 - 0.3**
7	#1 PET Bottles/Containers (Deposit)	0.7%	6.6	2.9	0.0	3.6	0.0	0.0	2.5 - 3.4	0.0 - 0.0	3.1 - 4.2	0.0 - 0.0	0.0 - 0.0
8	#1 PET Bottles/Containers (Non-Deposi	0.1%	1.5	0.7	0.0	0.8	0.0	0.0	0.7 - 0.7	0.0 - 0.0	0.8 - 0.8	0.0 - 0.0	0.0 - 0.0
9	#2 HDPE Bottles	0.6%	5.5	2.5	0.0	3.0	0.0	0.0	1.9 - 3.1	0.0 - 0.0	2.3 - 3.8	0.0 - 0.0	0.0 - 0.0
10	Other Bottles/Containers	1.4%	13.9	0.0	0.0	12.2	1.4	0.3	0.0 - 0.0	0.0 - 0.0	11.0 - 13.5	1.2 - 1.5	0.2 - 0.3
11	Plastic Film/Wrap	8.0%	80.3	0.0	2.0	78.3	0.0	0.0	0.0 - 0.0	1.8 - 2.2	72.0 - 84.5	0.0 - 0.0	0.0 - 0.0
12	Other Plastic Products	6.1%	61.2	0.0	0.0	55.1	6.1	0.0	0.0 - 0.0	0.0 - 0.0	50.2 - 59.9	5.6 - 6.7	0.0 - 0.0
Metals		**5.4%**	**54.2**	**37.5**	**0.2**	**5.8**	**10.6**	**0.0**	**29.3 - 45.8**	**0.2 - 0.3**	**4.5 - 7.2**	**8.2 - 12.9**	**0.0 - 0.0**
13	Aluminum Cans (Deposit)	0.3%	2.7	2.1	0.0	0.1	0.5	0.0	2.1 - 2.1	0.0 - 0.0	0.1 - 0.1	0.5 - 0.5	0.0 - 0.0
14	Aluminum Cans (Non-Deposit)	0.0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0
15	Tin Cans	1.1%	11.1	8.3	0.0	0.6	2.2	0.0	6.8 - 9.8	0.0 - 0.0	0.5 - 0.7	1.8 - 2.6	0.0 - 0.0
16	Other Ferrous Metals	2.0%	20.5	15.4	0.0	1.0	4.1	0.0	11.6 - 19.1	0.0 - 0.0	0.8 - 1.3	3.1 - 5.1	0.0 - 0.0
17	Other Non-Ferrous Metals	0.7%	7.4	5.6	0.0	0.4	1.5	0.0	4.1 - 7.1	0.0 - 0.0	0.3 - 0.5	1.1 - 1.9	0.0 - 0.0
18	Mixed Metals/Other Materials	1.2%	12.4	6.2	0.2	3.7	2.2	0.0	4.7 - 7.7	0.2 - 0.3	2.8 - 4.6	1.7 - 2.8	0.0 - 0.0
Glass		**1.9%**	**19.2**	**2.2**	**0.2**	**0.0**	**16.8**	**0.0**	**1.6 - 2.9**	**0.1 - 0.2**	**0.0 - 0.0**	**12.6 - 21.0**	**0.0 - 0.0**
19	Glass Bottles/Containers (Deposit)	0.8%	8.2	1.5	0.0	0.0	6.7	0.0	1.1 - 1.8	0.0 - 0.0	0.0 - 0.0	5.1 - 8.4	0.0 - 0.0
20	Glass Bottles/Containers (Non-Deposit)	0.4%	4.2	0.8	0.0	0.0	3.5	0.0	0.5 - 1.0	0.0 - 0.0	0.0 - 0.0	2.3 - 4.6	0.0 - 0.0
21	Other Glass	0.7%	6.8	0.0	0.2	0.0	6.6	0.0	0.0 - 0.0	0.1 - 0.2	0.0 - 0.0	5.2 - 8.0	0.0 - 0.0
Inorganics		**7.6%**	**75.9**	**0.0**	**0.0**	**9.7**	**66.2**	**0.0**	**0.0 - 0.0**	**0.0 - 0.0**	**8.3 - 11.1**	**52.5 - 79.8**	**0.0 - 0.0**
22	Other C&D	4.8%	48.4	0.0	0.0	9.7	38.7	0.0	0.0 - 0.0	0.0 - 0.0	8.3 - 11.1	33.1 - 44.4	0.0 - 0.0
23	Ceramics	0.0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0
24	Miscellaneous Inorganics	2.7%	27.4	0.0	0.0	0.0	27.4	0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	19.4 - 35.4	0.0 - 0.0
Durables		**0.2%**	**1.6**	**0.0**	**0.0**	**0.0**	**1.6**	**0.0**	**0.0 - 0.0**	**0.0 - 0.0**	**0.0 - 0.0**	**0.6 - 2.6**	**0.0 - 0.0**
25	Electrical/Household Appliances	0.2%	1.6	0.0	0.0	0.0	1.6	0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.6 - 2.6	0.0 - 0.0
26	Furniture	0.0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0
27	Mattresses	0.0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0
Green Waste		**8.9%**	**89.0**	**0.0**	**71.2**	**17.8**	**0.0**	**0.0**	**0.0 - 0.0**	**55.8 - 86.6**	**14.0 - 21.7**	**0.0 - 0.0**	**0.0 - 0.0**
28	Green/Yard Waste	8.9%	89.0	0.0	71.2	17.8	0.0	0.0	0.0 - 0.0	55.8 - 86.6	14.0 - 21.7	0.0 - 0.0	0.0 - 0.0
Wood		**5.3%**	**53.3**	**0.0**	**19.9**	**33.3**	**0.0**	**0.0**	**0.0 - 0.0**	**15.9 - 23.9**	**26.3 - 40.3**	**0.0 - 0.0**	**0.0 - 0.0**
29	Untreated Wood	3.1%	30.7	0.0	12.3	18.4	0.0	0.0	0.0 - 0.0	9.9 - 14.7	14.8 - 22.0	0.0 - 0.0	0.0 - 0.0
30	Treated Wood	1.9%	19.2	0.0	7.7	11.5	0.0	0.0	0.0 - 0.0	6.1 - 9.3	9.1 - 13.9	0.0 - 0.0	0.0 - 0.0
31	Pallets	0.0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0
32	Stumps	0.3%	3.4	0.0	0.0	3.4	0.0	0.0	0.0 - 0.0	0.0 - 0.0	2.4 - 4.4	0.0 - 0.0	0.0 - 0.0
Organics		**18.1%**	**180.9**	**0.0**	**159.2**	**21.7**	**0.0**	**0.0**	**0.0 - 0.0**	**137.9 - 180.5**	**18.0 - 25.4**	**0.0 - 0.0**	**0.0 - 0.0**
33	Food	10.4%	103.5	0.0	103.5	0.0	0.0	0.0	0.0 - 0.0	90.5 - 116.5	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0
34	Disposable Diapers	0.0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0
35	Textiles and Leathers	2.4%	24.5	0.0	9.8	14.7	0.0	0.0	0.0 - 0.0	8.2 - 11.4	12.3 - 17.1	0.0 - 0.0	0.0 - 0.0
36	Rubber	0.0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0
37	Carpet	0.3%	3.4	0.0	1.4	2.0	0.0	0.0	0.0 - 0.0	1.0 - 1.8	1.4 - 2.6	0.0 - 0.0	0.0 - 0.0
38	Miscellaneous Organics	4.9%	49.5	0.0	44.5	4.9	0.0	0.0	0.0 - 0.0	38.2 - 50.8	4.2 - 5.6	0.0 - 0.0	0.0 - 0.0
HHW/Special Waste		**1.2%**	**11.8**	**0.0**	**0.0**	**0.0**	**0.0**	**11.8**	**0.0 - 0.0**	**0.0 - 0.0**	**0.0 - 0.0**	**0.0 - 0.0**	**8.9 - 14.6**
39	Pesticides/Herbicides	0.0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0
40	Paints/Adhesives/Solvents	0.0%	0.2	0.0	0.0	0.0	0.0	0.2	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.2 - 0.2
41	Household Cleaners	0.0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0
42	Automotive Products	0.0%	0.1	0.0	0.0	0.0	0.0	0.1	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.1 - 0.1
43	Other HHW/Special Waste	1.2%	11.5	0.0	0.0	0.0	0.0	11.5	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	8.7 - 14.4
Problem Materials		**1.4%**	**13.9**	**0.0**	**0.0**	**0.0**	**0.0**	**13.9**	**0.0 - 0.0**	**0.0 - 0.0**	**0.0 - 0.0**	**0.0 - 0.0**	**9.9 - 17.9**
44	Batteries	0.3%	2.9	0.0	0.0	0.0	0.0	2.9	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	1.9 - 3.9
45	Lead-Acid Batteries	0.0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0
46	CRTs	0.0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0
47	Other Computer Equipment	0.4%	3.6	0.0	0.0	0.0	0.0	3.6	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	2.6 - 4.6
48	Cell Phones	0.4%	4.2	0.0	0.0	0.0	0.0	4.2	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	3.2 - 5.2
49	Other Electronics	0.3%	3.1	0.0	0.0	0.0	0.0	3.1	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	2.1 - 4.1
50	Mercury Containing Products	0.0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0
51	Sharps	0.0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0	0.0 - 0.0
TOTAL		**100.0%**	**1,000.0**	**50.4**	**302.5**	**518.4**	**102.7**	**25.9**	**40.1 - 60.8**	**256.4 - 348.6**	**458.8 - 578.1**	**80.9 - 124.6**	**19.1 - 32.8**
	Process Percent			**5.0%**	**30.2%**	**51.8%**	**10.3%**	**2.6%**					

PART III: EMISSIONS ANALYSES AND ASSUMPTIONS

SECTION 4: GHG EMISSIONS ANALYSIS FOR BASELINE SCENARIO – LANDFILL TRANSPORT AND DISPOSAL

Emissions calculated for the landfill transport and disposal operation included three sources of emissions: (1) refuse transportation truck-related emissions; (2) emissions from equipment used in daily landfill disposal operations (e.g., compacting, etc.); and (3) emissions from buried waste. Methodologies for estimating GHG emissions from each source are described below and in more detail in Appendix 1.

Refuse Transportation Truck Emissions

California state and local governments use the Air Resources Board (ARB)-developed EMFAC2011 model to calculate emissions from on-road vehicles. The California Emissions Estimator Model (CalEEMod), developed collectively by air districts throughout California, incorporates EMFAC2011 in its module to calculate emissions from on-road vehicles and off-road equipment. CalEEMod is used as a uniform platform to quantify potential criteria pollutants and GHG emissions associated with construction and operations from various statewide land uses. The model quantifies direct emissions from construction and operations (including vehicle and off-road equipment use), as well as indirect emissions such as GHG emissions from energy use, solid waste disposal, vegetation planting and/or removal, and water use. The CalEEMod model considers future truck fleets with better emissions controls, such as using alternative fuel or low carbon fuel to power refuse transport trucks.

Landfill Disposal Emissions

The CalEEMod model was also used to estimate emissions from landfill operations such as construction of landfill cells and daily cover operations. The model includes future landfill equipment with better emissions controls.

The following assumptions were used in the analysis of emissions from refuse transfer truck trips and landfill operation:

- Project period: 1/1/2014 – 12/31/2038 (25 years)
- Work day: 7 days per week
- Amount of refuse to landfill: 1,000 tons per day
- Average trip distance for refuse (based on average distance to closest out-of-County landfills in Ventura, San Bernardino, Riverside, and Orange counties) and worker vehicles: 47 miles/one way trip
- Number of daily trucks: 45 trucks
- Daily acreage of landfill disturbed: 1 acre
- Equipment used in landfill operations: 1 loader, 1 scraper, 1 water truck, 1 bulldozer, and 2 compactors

Buried Refuse Emissions

The major sources of GHG emissions are the landfill gases generated from decomposition of buried refuse. In this study, the U.S. EPA LandGEM model (v3.02) was used to estimate GHG emissions from the disposal of 1,000 tpd of refuse over a 25-year period. LandGEM is based on a first-order decomposition rate equation to estimate annual gas generation. The model is recommended by the U.S. EPA as documented in the Climate Leader Greenhouse Gas Inventory Protocol "Direct Emissions from Municipal Solid Waste Landfilling, October 2004."

The various input factors for LandGEM were based on values specifically used for local Southern California landfills, not national averages, to better represent the emissions of biogenic and non-biogenic carbon dioxide (CO_2) and methane (CH_4). The GWP factor in the LandGEM model was updated to reflect the most current values (at the time of the analysis in 2013) stated in the IPCC, Fifth Assessment Report. Landfill emissions for the Baseline Scenario were calculated for the 1,000 tpd of post-recycled residuals from a mixed waste MRF disposed for 25 years, plus an additional 100 years to account for the long-term decomposition of the buried waste due to a low decay factor in Southern California's arid weather conditions. The decay factor is influenced by the amount of moisture/water in refuse when buried which is affected by rainfall (low for Southern California) during disposal operations.

The following assumptions were used in the analysis:

- Project period: 1/1/2014 – 12/31/2138 (125 years)
- Methane generation rate (k): 0.020 year-1, based on a Southern California case
- Potential methane generation capacity (Lo): 100 m3/Mg (USEPA and CARB GHG inventory methodologies default value)
- Non-methane organic compounds (NMOC) concentration: 600 ppmv as Hexane
- Methane content: 50% v/v
- Landfill cap methane oxidation rate: 10%
- Landfill gas capture efficiency: 83% (CARB default value)

Assumptions for input factors to LandGEM can vary for every landfill depending on site specific conditions for type and composition of waste and landfill gas system efficiency. An analysis of a second LFG-to-energy scenario using a higher methane generation capacity (L_o) of 114 m3/Mg (site specific value) and a lower landfill gas capture efficiency of 70% was conducted to assess the model sensitivity of estimated GHG emissions. The results showed a total of net emissions of approximately 3.88 million metric tons of CO_2 equivalent, whereas, the Baseline Scenario analysis was estimated to generate 1.64 million metric tons of CO_2 equivalent. The use of a higher Lo and a lower gas capture efficiency contributed to a much higher estimate of overall GHG emissions. Detailed data of the second analysis, landfill with LFG-to-energy, can be found in Appendix 1.

The analysis also included two simulated scenarios for GHG emissions:

- Scenario one: Landfill with cap and flare
- Scenario two: Landfill with cap and LFG-to-energy facility, which was assumed to be 7.65 MW capacity (see Appendix C of Appendix 1 for emissions factor assumptions)

The results of the Baseline Scenario GHG emissions analysis are presented in Part IV of this study (scenario two) and in Appendix 1.

SECTION 5: GHG EMISSIONS ANALYSIS FOR ALTERNATIVE SCENARIO – INTEGRATED MRF WITH CONVERSION TECHNOLOGIES

Overview of GHG Emissions Modeling

A combination of models and actual facility processing engineering data was utilized to calculate the GHG emissions for the Integrated MRF with Conversion Technologies. The Entreprises pour l'Environment "Protocol for the Quantification of Greenhouse Gases Emissions from Waste Management Activities", Version 4.0 – June 2010 (EpE), and the U.S. EPA's Waste Reduction Model WARM were utilized. Actual facility emissions data and process engineering modeling from a commercially operating thermal gasification facility were also utilized. This approach was necessary because no single GHG emissions calculation model was able to address all of the GHG emissions of the various components of the study's model Integrated MRF with Conversion Technologies.

The WARM model does not calculate GHG emissions for "preprocessing" or mechanical and biological pre-treatment nor does it have the capability of calculating the GHG emissions for anaerobic digestion or thermal processing by gasification. The EpE model has a module for the calculation of GHG emissions for "preprocessing" and a module for the calculation of GHG emissions for anaerobic digestion. Both models had GHG calculation modules for incineration, but no modules for GHG emissions calculation for thermal process by gasification and ash melting.

In order to enable the calculation of GHG emissions for all of the components which are part of the study's Integrated MRF with Conversion Technologies, it was necessary to deconstruct the WARM model and EpE model and utilize the individual GHG emissions modules for each of the operational components of the Integrated MRF with Conversion Technologies and then compile the individual operational components. Updated GWP factors were substituted for factors which had not been updated in the models.

In order to calculate the GHG emissions for the thermal gasification processing component of the study's Integrated MRF with Conversion Technologies, the reference California post-recycled mixed waste MRF residual composition data was used as the feedstock composition in a proprietary process engineering model from an existing commercial scale operating gasification reference facility.

This technical approach enabled the project team to calculate the GHG emissions of the various components of the Integrated MRF with Conversion Technologies on a feedstock specific basis (for California), and when combined with the transportation and landfill emissions calculations gave a reasonable estimate of the overall GHG emissions for purposes of comparing the Baseline and Alternative Scenarios.

Pre-Processing MRF, Anaerobic Digestion, and Composting Emissions

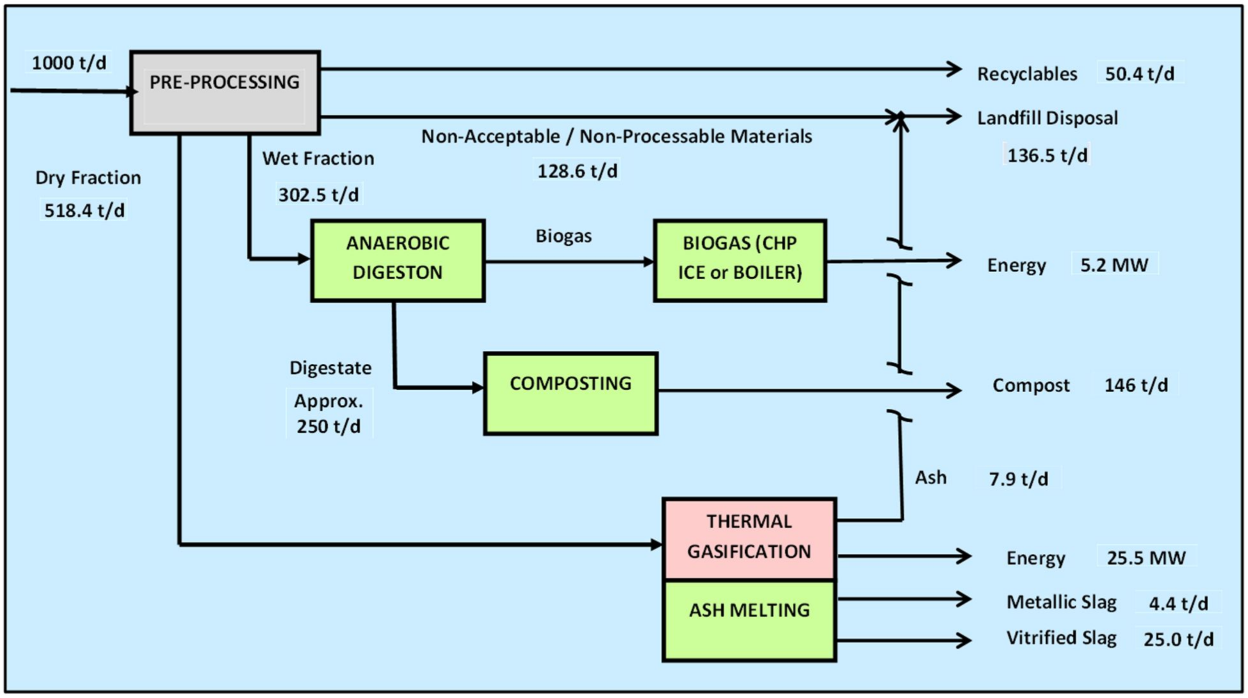
For the mechanical and biological process emissions calculations, a European-based commercial facility provided a full process flow diagram detailing the unit process equipment and the additional MRF processing of 1,000 tpd of post-recycled mixed waste MRF residuals based on the CalRecycle statewide composition. The specific MRF pre-processing unit equipment and process flow diagrams are included in Appendices 3 and 4. Project Team members reviewed and vetted this process flow diagram and concluded it best fit the study's model design, met current regulatory processing requirements, and proposed compost and digestate land application standards.

The front end pre-processing MRF was modeled to illustrate the recovery of additional recyclables from the mixed waste MRF residuals, remove non-processable materials, and separate the mixed waste stream into a wet fraction and a dry fraction. The readily digestible organic materials are concentrated in the wet fraction. The wet fraction was modeled to be further processed to remove inorganic materials and other non-readily digestible materials and potential contaminants that are further processed to become the feedstock for the anaerobic digestion process. The anaerobic digestion process selected for the study analysis is a traditional, wet low solids (12% to 15% solids) anaerobic digestion fermentation technology (with concrete tanks).

The dry fraction (along with the non-digestible materials from the wet fraction) was modeled to become the feedstock for the thermal gasification process. Digestate from the anaerobic digestion process is composted aerobically and assumed to be land-applied in Scenario 1 and gasified in Scenario 2. A second scenario was evaluated assuming no market for land application of compost. Scenario 1 is used in the study results presented in Section 7 and the results assuming Scenario 2 are included in Appendix 7. Scenario 2 is an option in which additional energy from the digestate is extracted. This scenario was provided as an alternative to the digestate to compost because the integrated waste management hierarchy places the compost option at a higher preferred waste management option. The ash from the thermal gasification process is assumed to be melted into a glassy slag for potential beneficial use. Metal is assumed to be recovered for recycling. A small amount of fly ash would be generated and may potentially be used to manufacture concrete (or disposed). Markets for these recyclables exist in Japan, and the specifications would have to meet standards in the U.S. for use as recyclable products.

For this study, the model process mass balance for the incoming 1,000 tpd of post-recycled mixed waste MRF residuals, and its allocation into wet and dry fractions in tpd, is shown in Figure 5 below.

Figure 5: Mass Balance of Integrated MRF with Conversion Technologies



Note: Mass balance presents general mass flow of tons of mixed waste MRF residuals material into system and resulting tonnage to disposal, recyclables, compost and slag. Mass Balance does not show input tons of coke, process water, chemicals, supplemental chemicals for emissions control and control of viscosity of slag, etc.

A summary of the EpE modeling results for the pre-processing MRF, anaerobic digestion, and composting processes are presented below in Table 3 as well as in Part IV of this study and in Appendix 5.

Table 3. Summary of the EpE Modeling Results for MRF Pre-Processing, Anaerobic Digestion and Composting (GHG emissions in MTCO2E)

Process	Total Emissions	Biogenic Emissions	Non-Biogenic Emissions	Avoided Emissions	Net Emissions (biogenic and non-biogenic)	Net Emissions (only non-biogenic emissions)
MRF pre-processing	0	-	-	1,646,938	(1,646,938)	(1,646,938)
Anaerobic Digestion (Digestate to Composting)	842,815	740,338	102,477	563,389	279,426	(460,912)
Composting of Digestate	342,436	177,942	164,493	9,667	332,768	154,826

Thermal Gasification Emissions

The dry fraction waste composition resulting from the pre-processing MRF was provided to the gasification facility operators and process design engineers to calculate the potential GHG emissions, recycled metal/slag, and energy, based on current operational RDF gasification facilities (summary of gasification technology and calculations included in Appendix 6). The gasification technology selected for comparison purposes was used, in part, due to the availability of very detailed mass, energy and emission data. It should be noted that the heat source for the gasifier is coke and coke combustion emissions are included in the GHG calculations. The use of other heat sources (i.e., wood biomass as charcoal) and air pollution control equipment that would have to meet South Coast Air Quality Management District (SCAQMD) requirements for a facility in Los Angeles County would likely result in lower GHG emissions.

The dry fraction waste composition makeup was separately reviewed by the Project Team using WARM (v12, February 2012) GHG model to provide an independent cross-check of the gasification facility operator's calculations of GHG emissions.

WARM accepts specific material categories, which did not always correspond directly to the RDF composition categories. To input the data, the RDF composition categories were assigned to WARM material categories listed in Table 2. For combustion, WARM accounts for GHG emissions generated by the waste management practice as well as the avoided electricity-related emissions resulting from electricity generated by the facility. WARM contains two options for estimating the avoided electricity-related emissions – a national average mix of electric generation or a state-specific mix. The California mix of electricity generation was used for this analysis. Facility operation was assumed at full capacity, 365 days per year for 25 years.

Since the main purpose of WARM is to allow for comparing various waste management options, it requires input of a Baseline and an Alternative Scenario. The Baseline Scenario (landfilling) was not utilized for the results presented in this study, but was required input for WARM. The reason it was not used for the Baseline Scenario is that the LandGEM model allows for customized variable input specific to Southern California and the WARM model does not allow for year-to-year variable calculations. The GHG emissions information used in this analysis corresponds to the WARM-calculated value for Total GHG Emissions from Alternative MSW Generation and Management.

For the purposes of this study, the following emissions definitions are used:

Direct Emissions – Emissions directly related to solid waste management activities. In this study, direct emissions are further divided into biogenic and non-biogenic [CO_2] emissions.

Biogenic [CO_2] Emissions – Emissions resulting from production, harvest, combustion, digestion, fermentation, decomposition, and processing of biologically based materials or biomass, such as combustion of biogas collected from biological decomposition of waste in landfills or combustion of the biological fraction of municipal solid waste or biosolids. Biogenic [CO_2] emissions are carbon neutral and have zero GHG impact.

Non-Biogenic [CO_2] Emissions – Emissions that are not considered biogenic CO_2 emissions, such as emissions from combustion of fossil fuels, of materials of fossil fuel origin (e.g., plastics) and from other non-combustion processes, such as fugitive methane emissions from landfill operation or oil and gas production. Methane emissions are not carbon neutral and regardless of source (biogenic or non-biogenic), are considered non-biogenic [CO_2] emissions in this study.

Indirect Emissions – Emissions from purchased electricity, heat, or steam.

Avoided Emissions – Emissions avoided due to displacing purchase of power generated by fossil-fuel combustion or from emissions avoided by recycling (e.g., reduction in emissions associated with processing virgin materials)

Total Emissions = biogenic + non-biogenic

Net Emissions = total emissions – avoided emissions

The net GHG emissions results calculated in this study are based on non-biogenic emissions (i.e., fugitive methane emissions from landfills and emissions from combustion of fossil fuels) pursuant to the Intergovernmental Panel on Climate Change (IPCC) guidelines, and industry accepted GHG models such as EPA Waste Reduction Model (WARM), European Union's EpE model and California Air Resources Board models. Biogenic emissions are not included in the study conclusions, as these emissions naturally cycle through the atmosphere by processes such as photosynthesis, and are therefore carbon neutral and do not impact GHG emissions.

The daily RDF to be gasified was input to WARM for each scenario and the results calculated. It should be noted that WARM only provides an emissions value for an incinerator. The WARM-calculated results are presented in Table 4 that provides results assuming anaerobic digestion digestate is not gasified but aerobically composted and land applied (due to that use being higher on the integrated waste management hierarchy). A second scenario analyzed for anaerobic digestion digestate being gasified (assuming no market availability for compost/land application) is included in Appendix 2. Scenario 2 provides additional GHG emission reduction due to additional offset of fossil fuels with energy extracted from the digestate. The results for the WARM estimated net GHG emissions for thermal gasification were compared to the reference facility data modeling results.

Table 4: Comparison of Reference Operating Facility and WARM Estimated Net GHG Emissions for Thermal Gasification, MTCO2E Over 25 Years

Table 4: DRY FRACTION ONLY TO GASIFICATION (Anaerobic Digestion Digestate Composted / Land Applied)						
Source	**Total Emissions**	**Biogenic Emissions**	**Non-Biogenic Emissions**	**Avoided Emissions**	**Net Emissions, Total**	**Net Emissions, Non-Biogenic**
Reference Operating Facility	7,728,236	4,537,816	2,987,587	1,668,485	6,059,751	1,521,935
WARM	8,178,161	4,019,707	4,158,454	2,726,834	5,451,327	1,431,620

After cross-checking the results, the Project Team determined that the reference gasification facility operator's emissions calculations were within an acceptable comparison range compared with the WARM results. Since the facility's calculations are based on actual plant operations, the Project Team used this data in the comparative analysis, as it most closely reflects the gasification technology assumed for this study (see results comparison and discussion in Part IV of this study). All of the reference operating gasification facility calculations are included in Appendix 6.

An additional preliminary emissions study using CalRecycle's defined feedstock was completed using operating data from another commercial facility in Europe for modeling the emissions that would result from 1,000 tpd being processed at an integrated MRF that includes recycling, anaerobic digestion, composting, and incineration. That study resulted in net negative emissions for direct emissions minus avoided emissions for an integrated MRF with recycling and conversion technologies and is available upon request.

An expanded summary table of all the GHG emissions calculations developed for this study is presented in Appendix 7.

SECTION 6: SUMMARY OF OTHER POLLUTANTS

In California, local air quality management districts or air pollution control districts are responsible for air quality in their respective jurisdictional areas. The study scenarios are assumed to be located in Los Angeles County, which is under the jurisdiction of the SCAQMD. SCAQMD's responsibilities include monitoring air pollution and promulgating rules and regulations that limit and permit the emissions of certain air pollutants. This study air emissions analysis included the following subset of pollutants regulated by SCAQMD: GHG, SO_2, NO_x, dioxins, and furans. Particulate matter (PM) pollutants were also considered but PM data was not available for each of the processes analyzed in this study comparative analysis. Appendix 1 includes PM calculations for the Baseline Scenario landfill transport and operations.

Landfill Transport and Operations

Emissions of criteria air pollutants and dioxins/furans from refuse transfer trucks, landfill operations, and flare or LFG-to-energy were calculated for the two landfill scenarios and landfilling of residuals from post-Integrated MRF with Conversion Technologies (included in Appendix 1). The results are summarized below in Table 5.

Table 5: Other Air Pollutant Emissions for the Baseline Scenario

[Treatment of 1,000 Tons per Day (for 25 Years) of Post-Recycled MRF Residuals
Emissions in metric tons (Years 2014 to 2138)]

TRANSPORTATION AND LANDFILL OPERATIONS (1,000 TPD)	**NO_x**	**SO_2**	**Dioxin/Furan**
Transportation to Landfill (25-yr Landfill Operation)	93	0.3	Not Available
Landfill Operations (with cap/flare) including transportation related emissions	255	45	1.72E-06
Landfill Operations (with cap/LFG-to-energy) including transportation related emissions	266	22	1.27E-06
LANDFILL OF POST-INTEGRATED MRF WITH CT RESIDUALS (136 TPD)	**NO_x**	**SO_2**	**Dioxin/Furan**
Transportation to Landfill (25-yr Landfill Operation)	12	0	Not Available
Landfill Operations (with cap/flare) including transportation related emissions	12	0	3.93E-09

Conversion Technology Facility

SO_2, NO_x, and dioxin/furan emissions are a function of the type of gasification and combustion processes that will be used, as well as the composition of the RDF. In lieu of estimating emissions for a specific type of gasification and combustion process, emissions information from various confidential vendor proposals and actual operating facilities was collected, reviewed, and used to calculate emissions estimates (four U.S. Demonstration Facilities and three Japanese Facilities), as shown in Tables 6 and 7. The four US Demonstration Facilities were projects that explored the use of gasification to process various feedstock sources and reflect companies that provided information in the context of remaining confidential to retain their process as proprietary. It should be noted that there is a wide variation in the values for these facilities used for comparison due to the different: 1) types of gasification technologies used, 2) capacities of the facilities, 3) air pollution control devices applied, and 4) feedstocks.

Table 6: Stack Test Data / Expected Emissions – U.S. EPA Typical Units

Pollutant	Units	Tokyo, Japan Facility	US Demo Facility 1	US Demo Facility 2	US Demo Facility 3	Chiba, Japan Facility	US Demo Facility 4	Japanese Reference Facility
NO_x (as NO_2)	ppm @ 7% O_2	7.8	6	12	11	5.2	92.6	57.7
SO_2	ppm @ 7% O_2	1.6	3	12	3	0.26	9.7	1.5
Dioxin/furan	ng/dscm @ 7% O_2	0.030	NA	2.2	NA	0.0007	NA	0.0050

NOTES:
NA = Not Available
ppm = parts per million, dry volume basis
d = dry
s = standard (20ºC – 68ºF, 1atm)
The USEPA currently regulates dioxin furan emissions from MWCs on a total mass basis rather than a TEQ basis. While there is no exact conversion factor between TEQ and total mass, EPA indicates that the 40 CFR Part 60, Subpart Eb limit of 13 ng/dscm total mass value corresponds to 0.1 to 0.3 ng/dscm TEQ. For purposes of this analysis, an average value of 0.2 ng/dscm TEQ corresponding to 13 ng/dscm total mass was used.
Where applicable, the ng/dscm values for NO_x and SO_2 were converted to ppm values using conversion factors from 40 CFR Part 60, Appendix A, Method 19.

Table 7: Stack Test Data / Expected Emissions – Mass in Metric Tons / 25 Years of Operation

Pollutant	Tokyo, Japan Facility	US Demo Facility 1	US Demo Facility 2	US Demo Facility 3	Chiba, Japan Facility	US Demo Facility 4	Japanese Reference Facility
NO_x (as NO_2)	441	339	678	622	294	5235	3261
SO_2	126	236	943	236	20	762	120
Dioxin/furan	8.87E-08	n/a	6.50E-05	n/a	2.07E-08	n/a	1.48E-07

The emissions information used was based on volume, parts per million dry volume (ppmdv) corrected to seven percent oxygen and nanograms per dry standard cubic meter ng/dscm corrected to seven percent oxygen). For this analysis, these concentration values were converted to mass emissions values. This was done using the concentration value, the anticipated RDF heat content (BTU/lb), and Equation 19-1 and the Fd factor for MSW combustion from Table 19-2 of 40 CFR Part 60, Appendix A-7, Method 19. Using the total stack flow for digestate to land application (composting) to calculate emissions amounts in metric tons from ppm, the results are shown above in Table 7 for comparison purposes.

Based on the four factors discussed above, the Japanese Reference Facility was judged to be the most representative of the type of facility being analyzed in this study. Tables 8 and 9 on the following pages show the emissions calculation method, using the Japanese Reference Facility emissions factors, for the two dry fraction scenarios: Scenario 1- anaerobic digestion digestate composted aerobically and land applied (not gasified); and Scenario 2 - anaerobic digestion digestate gasified. The Japanese Reference Facility was also used for the GHG analysis results presented in Table 4.

TABLE 8: SO_2, NO_x, Dioxin/Furan, and GHG Emissions
Scenario 1 - Anaerobic Digestion Digestate Land Applied

LA County
CT White Paper
Gasification Emission Calculations
Digestate to Land Application

Gasifier RDF Throughput:	519	tpd	Anaergia - "20131218_LA_County_-_BFD_(Scenario_2_-_Cake_to_Composting).pdf"
	4,735,875	tons over 25 year period	Based on 365 days per year operation
RDF Heat Content:	17.80	MJ/kg	JFE - "LQ1092_WB_A23_A000-001_MASS_BALANCE_r2.pdf"
	7659	Btu/lb	Calculated
Total Heat Input:	7950	MMBtu/day	Calculated
RDF F_d:	9570	dscf/MMBtu	40 CFR Part 60, Appendix A-7, Table 19-2, factor for MSW
Exhaust Flow:	114,395,087	dscf per day @ 7% O2	Calculated

Pollutant	Emission Factors		lb/day*	lb/ton RDF	Emissions over 25 years of operation: tons	lbs	metric tons
NOx	57.7	ppm @ 7% O2	788	1.52	3595		3261
SO2	1.5	ppm @ 7% O2	29.0	0.056	132.1		120
Dioxin/Furan	0.005	ng/dscm @ 7% O2	3.58E-08	6.90E-11		3.27E-04	1.48E-07

		metric tons/day	metric ton/ton RDF	
Net GHG as CO2e	WARM Output	157	0.302	1,431,620
Avoided GHG as CO2e	Calculated using WARM Avoided Pacific Utility Emissions	299	0.576	2,726,834
Nonbiogenic GHG as CO2e	Net GHG Plus Avoided GHG			4,158,454
Biogenic GHG as CO2e	Obtained from JFE Biogenic Calculations			4,019,707
Gross GHG as CO2e	Nonbiogenic Plus Biogenic			8,178,161

NOTES:
F_d = Volume of combustion components per unit of heat content, dry basis.
ppm = parts per million, dry volume basis
d = dry
s = standard (20°C - 68°F, 1 atm).
The GHG emissions estimated by WARM include only anthropogenic emissions of carbon dioxide.

* Calculated using conversion factors obtained from 40 CFR Part 60, Appendix A-7, Table 19-1.

TABLE 9: SO_2, NO_x, Dioxin/Furan, and GHG Emissions
Scenario 2 – Anaerobic Digestion Digestate Gasified

LA County
CT White Paper
Gasification Emission Calculations
Digestate to Gasifier

Gasifier RDF Throughput:	589	tpd	Anaergia - "20131213_LA_County_-_BFD_(Scenario_1_-_Cake_to_RDF).pdf"
	5,374,625	tons over 25 year period	Based on 365 days per year operation
RDF Heat Content:	17.00	MJ/kg	JFE - "LQ1092_WB_A23_A000-001_MASS_BALANCE_r2.pdf"
	7315	Btu/lb	Calculated
Total Heat Input:	8617	MMBtu/day	Calculated
RDF F_d:	9570	dscf/MMBtu	40 CFR Part 60, Appendix A-7, Table 19-2, factor for MSW
Exhaust Flow:	123,989,305	dscf per day @ 7% O2	Calculated

Pollutant	Emission Factors		lb/day*	lb/ton RDF	Emissions over 25 years of operation: tons	lbs	metric tons
NOx	57.7	ppm @ 7% O2	854	1.45	3896		3535
SO2	1.5	ppm @ 7% O2	31.4	0.053	143.2		130
Dioxin/Furan	0.005	ng/dscm @ 7% O2	3.88E-08	6.59E-11		3.54E-04	1.61E-07

		metric tons/day	metric ton/ton RDF	metric tons
Net GHG as CO2e	WARM Output	133	0.226	1,215,826
Avoided GHG as CO2e	Calculated using WARM Avoided Pacific Utility Emissions	327	0.555	2,981,608
Nonbiogenic GHG as CO2e	Net GHG Plus Avoided GHG			4,197,434
Biogenic GHG as CO2e	Obtained from JFE Biogenic Calculations			5,165,959
Gross GHG as CO2e	Nonbiogenic Plus Biogenic			9,363,393

NOTES:
F_d = Volume of combustion components per unit of heat content, dry basis.
ppm = parts per million, dry volume basis
d = dry
s = standard (20°C - 68°F, 1 atm).
The GHG emissions estimated by WARM include only anthropogenic emissions of carbon dioxide.

* Calculated using conversion factors obtained from 40 CFR Part 60, Appendix A-7, Table 19-1.

Summary of Other Pollutants

Table 10 compares the additional air pollutants (NO_x, SO_2, dioxins and furans) analyzed for the landfill transport and operations scenario and the gasification conversion technology reference facility.

Table 10: Comparison of Other Air Pollutant Emissions for Baseline and Alternative Scenarios

[Treatment of 1,000 Tons per Day (for 25 Years) of Post-Recycled MRF Residuals Emissions in metric tons (Years 2014 to 2138)]

BASELINE SCENARIO: TRANSPORTATION AND LANDFILL OPERATIONS	**NO_x**	**SO_2**	**Dioxin/Furan**
Transportation to Landfill (25-yr Landfill Operation)	93	0.3	Not Available
Landfill Operations (with cap/flare) including transportation related emissions	255	45	1.72E-06
Landfill Operations (with cap/LFG-to-energy) including transportation related emissions	266	22	1.27E-06
ALTERNATIVE SCENARIO: INTEGRATED MRF WITH CONVERSION TECHNOLOGIES	**NO_x**	**SO_2**	**Dioxin/Furan**
TOTAL OF INTEGRATED MRF AND CONVERSION TECHNOLOGIES COMPONENTS			
Japanese Reference Facility – Digestate Land Applied	3261	120	1.48E-07
LANDFILL OF POST INTEGRATED MRF RESIDUALS (136 TPD)			
Transportation to Landfill (25-yr Landfill Operations)	12	0	Not Available
Landfill Operations (with cap/flare) including transportation related emissions	12	0	3.93E-09

The dry fraction only to gasification scenario (assumes Scenario 1 - anaerobic digestion digestate land applied or composted) was used for the conversion technology comparison.

The NO_x and SO_2 comparison shows higher emissions for the Alternative Scenario than the Baseline Scenario, while dioxin and furan emissions were lower for the Alternative Scenario than the Baseline Scenario. It should be noted that a facility in Los Angeles County would need to meet strict SCAQMD advanced air pollution control and permit requirements which would likely result in lower emissions than that calculated for the Japanese reference facility. For example, the reference facility assumes electricity generation through combustion in an internal combustion engine which may not be permitted by SCAQMD and a coke-fired furnace would likely not be permitted. Wood biomass as charcoal may be used instead of coke which would reduce emissions.

PART IV: RESULTS AND CONCLUSIONS

SECTION 7: SUMMARY RESULTS OF GHG EMISSIONS FOR THE WASTE MANAGEMENT SCENARIOS

This section summarizes the results of the study analysis of GHG emissions and other criteria pollutants for two waste management scenarios. The Baseline Scenario evaluated the 125-year cumulative GHG emissions for transport and disposal of 1,000 tpd (for 25 years) of post-recycled residuals from a mixed waste MRF to a landfill with a cap, a landfill gas collection system, and a LFG-to-energy facility (standard for most landfills in Southern California). The results include GHG emissions for the Baseline Scenario of landfill gas generation from the buried waste over a period of 125 years to account for GHG emissions continuing to be generated from decomposing waste due to low decay factors in arid Southern California weather conditions. The Alternative Scenario evaluated sending the 1,000 tpd (for 25 years) of post-recycled residuals from a mixed waste MRF to an Integrated MRF with Conversion Technologies.

Since the single largest source of GHG emissions from an Integrated MRF with Conversion Technologies is from the thermal gasification component, significant effort was expended to review these emissions calculations and to cross-check results based on operating facilities using a separate WARM analytical model. The WARM-calculated results are presented in Table 11 (included in Section 5 as Table 4, and duplicated below for ease of reference) for thermal gasification of the dry fraction under the scenario of the anaerobic digestion digestate being composted aerobically and land applied, not gasified. These results were compared with the reference facility data modeling results.

Table 11: Comparison of Reference Operating Facility and WARM Estimated Net GHG Emissions for Thermal Gasification, $MTCO_2E$ Over 25 Years

(Identified in Section 5 as Table 4)

DRY FRACTION ONLY TO GASIFICATION (Anaerobic Digestion Digestate Land Applied / Composted)						
Source	**Total Emissions**	**Biogenic Emissions**	**Non-Biogenic Emissions**	**Avoided Emissions**	**Net Emissions, Total**	**Net Emissions, Non-Biogenic**
Reference Operating Facility	7,728,236	4,537,816	2,987,587	1,668,485	6,059,751	1,521,935
WARM	8,178,161	4,019,707	4,158,454	2,726,834	5,451,327	1,431,620

Definitions:

<u>Direct Emissions</u> – Emissions directly related to solid waste management activities. In this comparative study, direct emissions are further divided into biogenic and non-biogenic [CO_2] emissions.

<u>Biogenic [CO_2] Emissions</u> – Emissions resulting from production, harvest, combustion, digestion, fermentation, decomposition, and processing of biologically based materials or biomass, such as combustion of biogas collected from biological decomposition of waste in landfills or combustion of the biological fraction of municipal solid waste or biosolids. Biogenic [CO_2] emissions are carbon neutral and have zero GHG impact.

<u>Non-Biogenic [CO_2] Emissions</u> – Emissions that are not considered biogenic CO_2 emissions, such as emissions from combustion of fossil fuels, of materials of fossil fuel origin (e.g., plastics) and from other non-combustion processes, such as fugitive methane emissions from landfill operation or oil and gas production. Methane emissions are not carbon neutral and regardless of source (biogenic or non-biogenic), are considered non-biogenic [CO_2] emissions in this study.

<u>Indirect emissions</u>: emissions from purchased electricity, heat or steam.
<u>Avoided emissions</u>: emissions avoided due to power generation (replacing fossil fuels) or from emissions avoided by recycling (e.g., energy savings)
<u>Total emissions</u> = biogenic + non-biogenic emission
<u>Net emissions total</u> = total emissions – avoided emissions

Expanded GHG emissions calculations using various databases were used to cross-check emissions data from operating facilities. A comprehensive summary is included in Appendix 7.

The GHG emissions model used to cross-check the gasification and ash melting emissions indicated that the operating facilities-based calculations are within the range of values projected by the Project Team's WARM analysis. The operating facilities' data is used for the comparative analysis summarized in Table 12 as it models the emissions based on a California-specific waste composition, is more reflective of the model facility being analyzed for this study (including gasification and ash melting), and is based on actual facility operations.

Table 12: Comparative Greenhouse Gas Emissions for Years 2014 to 2138 for the Treatment of 1,000 Tons per Day (for 25 Years) of Post-Recycled MRF Residuals (in metric tons of carbon dioxide equivalent, $MTCO_2E$)

SCENARIO	EMISSIONS (Years 2014 TO 2138): 125 Years						
BASELINE SCENARIO: POST RECYCLED RESIDUAL TO LANDFILL (1000 TPD)	**TOTAL EMISSIONS**	**BIOGENIC EMISSIONS**	**NON-BIOGENIC EMISSIONS**	**INDIRECT EMISSIONS**	**AVOIDED EMISSIONS**	**NET EMISSIONS (biogenic and non-biogenic)**	**NET EMISSIONS (only non-biogenic emissions)**
TOTAL OF TRANSPORTATION AND LANDFILL OPERATONS EMISSIONS (Cap / LFG-to-Energy)	**5,357,275**	**2,479,735**	**2,877,540**	**0**	**1,241,000**	**4,116,275**	**1,636,540**
Transportation to Landfill (25-yr Landfill Operation) (EMFAC2011)	25,946	-	25,946			25,946	25,946
Landfill Operation (with cap/LFG-to-energy) (CalEEMod, LandGEM) Lo = 100, Capture rate = 83%	5,331,329	2,479,735	2,851,594		1,241,000	4,090,329	1,610,594
ALTERNATIVE SCENARIO: INTEGRATED MRF WITH CONVERSION TECHNOLOGY	**TOTAL EMISSIONS**	**BIOGENIC EMISSIONS**	**NON-BIOGENIC EMISSIONS**	**INDIRECT EMISSIONS**	**AVOIDED EMISSIONS**	**NET EMISSIONS (biogenic and non-biogenic)**	**NET EMISSIONS (only non-biogenic emissions)**
TOTAL OF INTEGRATED MRF AND CONVERSION TECHNOLOGY COMPONENTS	**8,931,770**	**5,462,299**	**3,266,635**	**202,835**	**4,135,493**	**4,796,277**	**(666,022)**
MRF Preprocessing (Anaergia EpE) [a]	0	-	-	-	1,646,938	(1,646,938)	(1,646,938)
Anaerobic Digestion (Digestate to Composting) (EpE) [a]	842,815	740,338	102,477	-	563,389	279,426	(460,912)
Composting of Digestate (Anaergia EpE) [a]	342,435	177,942	164,493	-	9,667	332,768	154,826
RDF (Average) Gasification and Ash Melting	7,728,236	4,537,816	2,987,584	202,835	1,668,485	6,059,751	1,521,935
RDF, Slag and Metal Recycling from Ash Melting Process (Average) (WARM)	Included in Process	Included in Process	Included in Process	Included in Process	247,014	(247,014)	(247,014)
Landfill of Post Integrated MRF Residuals							
Transportation to Landfill (25-yr Landfill Operation) (EMFAC2011)	4,404		4,404			4,404	4,404
Landfill Operation (with cap/flare) (CalEEMod, LandGEM)	13,880	6,202	7,678			13,880	7,678

Definitions:

Direct Emissions - Emissions directly related to solid waste management activities such as at a landfill site. In this comparative study, direct emissions are further divided into biogenic and non-biogenic [CO_2] emissions.

Biogenic [CO_2] Emissions – Emissions resulting from production, harvest, combustion, digestion, fermentation, decomposition, and processing of biologically based materials or biomass, such as combustion of biogas collected from biological decomposition of waste in landfills or combustion of the biological fraction of municipal solid waste or biosolids. Biogenic [CO_2] emissions are carbon neutral and has zero GHG impact.

Non-Biogenic [CO_2] Emissions – Emissions that are not considered as biogenic CO_2 emissions, such as emissions from combustion of fossil fuels, of materials of fossil fuel origin (e.g., plastics) and from other non-combustion processes, such as fugitive methane emissions from landfill operation or oil and gas production. Methane emissions is not carbon neutral, regardless of its source, biogenic or non-biogenic, it is considered as non-biogenic [CO_2] emission in this study .

Indirect Emissions – Emissions from purchased electricity, heat, or steam

Avoided Emissions – Emissions avoided due to power generation (replacing fossil fuels) or from emissions avoided by recycling (e.g., energy savings)

Total Emissions = Direct (Biogenic + Non-Biogenic) + Indirect Emissions

Net Emissions = Total Emissions – Avoided Emissions

a. All Source 2 Emissions, all Avoided Emissions and Scope 1 Natural Gas Emissions were derived from factors which were CO2 Equivalent factors, rather than factors for CO2, CH4 and N2O individually, so these numbers could not be updated to Global Warming Potentials based on the 5th Assessment Report or modified to California Grid numbers. Only Scope 1 Emissions were updated.

b. Landfill numbers are based on US EPA WARM Model which could not be updated to Fifth Assessment Report GWP factors, and Biogenic could not be separated from Non-Biogenic. Pacific Region was used for calculations.

It should be noted that the gasification reference facility GHG emissions are likely higher than would be for a facility in Southern California which would likely require the use of a heat source other than coke and would have to comply with strict SCAQMD air pollution control requirements. Technologies that do not include an ash melting process to form metal slag for recycling potential would also have a lower emission profile.

Over the 125-year period, the Baseline Scenario of hauling 1,000 tpd (for 25 years of disposal) to a landfill, with a cover cap and recovery of LFG-to-energy, results in net GHG emissions of 1.64 million $MTCO_2E$ as shown in Table 12. The Alternative Scenario shows a net *avoided* GHG emissions amount of (0.67) million $MTCO_2E$. For the purposes of this study, "avoided emissions" is the amount of GHG emissions avoided due to power generation (replacing fossil fuels) and recycling (energy savings).

For Table 12, the total emissions, not accounting for avoided emissions, for the Alternative Scenario is significantly higher than the Baseline Scenario primarily due to the biogenic emissions. The biogenic emissions are much higher for the Alternative Scenario due to the gasification process which converts biogenic components of RDF (e.g. wood, paper, leather, branches, and other naturally occurring organics) to carbon dioxide and water. The non-biogenic emissions are similar for both scenarios (representing fugitive methane emissions from landfills and carbon dioxide from the gasification process). Indirect emissions are accounted for in the gasification and ash melting process but not for the MRF preprocessing and anaerobic digestion process because they are accounted for as part of the parasitic loading in the anaerobic digestion process module.

The most significant difference between the two scenarios is that the avoided emissions are much greater for the Alternative Scenario. This is due to the energy generated from anaerobic digestion and gasification, which would replace fossil fuels, as well as the additional Integrated MRF recycling in the Alternative Scenario. The avoided emissions in the Baseline Scenario are due to LFG-to-energy replacing the use of fossil fuels.

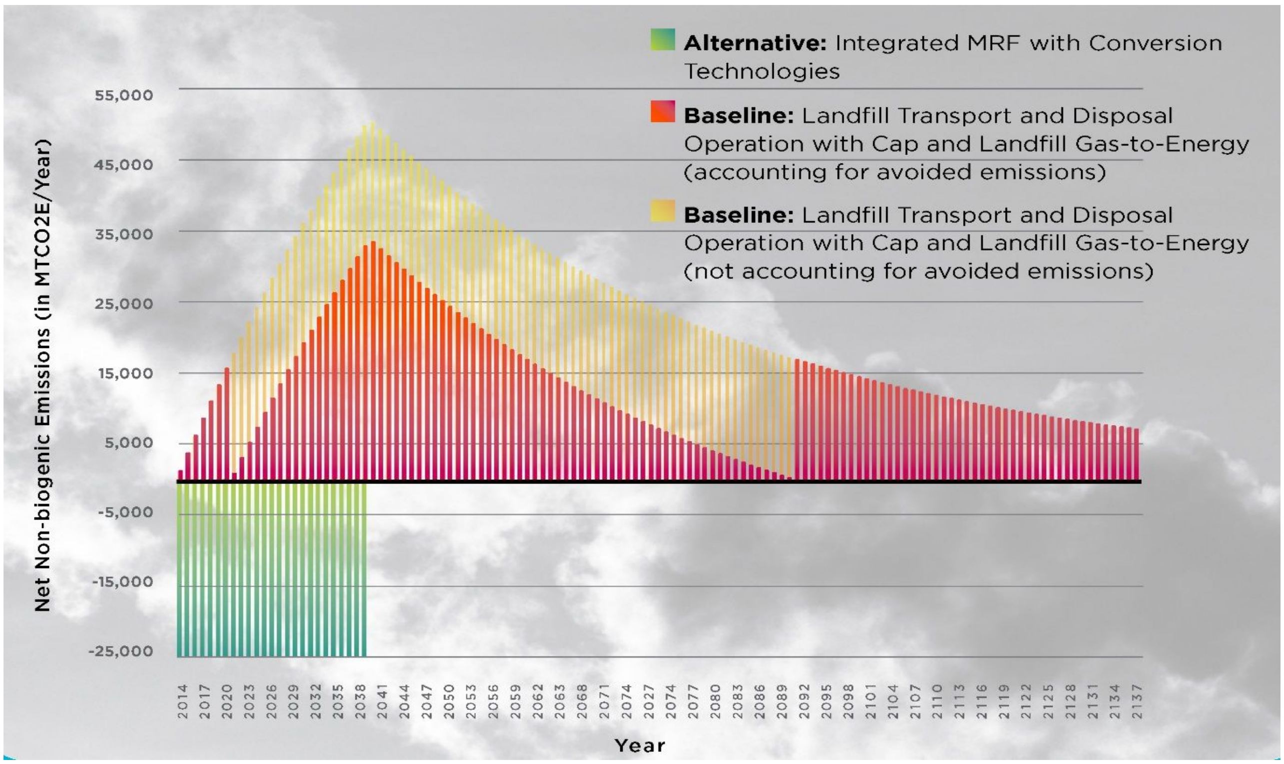
The GHG emissions of the transport and disposal of post Integrated MRF with Conversion Technologies residuals (136.5 tpd) was analyzed assuming a landfill with a cap and flare (residuals have very low organic content and thus low landfill gas generation from those residuals is not sufficient for LFG-to-energy). Those emissions are insignificant (12,082 $MTCO_2E$) and would be lower if a cap and LFG-to-energy facility was assumed. It should also be noted that a portion of the residuals is E-waste and special waste, which would likely have longer travel distances to appropriate receiving facilities so would have higher transport emissions but would also result in reduced disposal emissions at the landfill. These factors are not on a scale to have a material effect on the emissions for the Alternative Scenario results.

The analysis boundary did not include transport of compost and slag (175.4 tpd) to receiving facilities that is anticipated to be on the same order of magnitude as transport of post Integrated

MRF with Conversion Technologies residuals (136.5 tpd) to a distant landfill (4,404 $MTCO_2E$) which is not on a scale to have a material effect on the analysis results.

Figure 6 below illustrates graphically the results of the study analysis with 1.64 million $MTCO_2E$ net GHG emissions for the Baseline Scenario and (.67) million $MTCO_2E$ net GHG emissions for the Alternative Scenario. In southern California, most landfills are equipped with LFG-to-energy facilities.

Figure 6: Net Non-Biogenic GHG Emissions Over Time for Baseline and Alternative Scenarios



Although not the main focus of this study, other pollutants were also evaluated herein, including NO_x, SO_2 and dioxins/furans. The results found that NO_x and SO_2 emissions were higher while dioxins/furans emissions were lower for the Alternative Scenario as compared with the Baseline Scenario. Advanced air pollution control equipment such as selective catalytic reduction, non-selective catalytic reduction, dry scrubbers, and other best available control equipment may be feasible to lower these emissions. However, the feasibility of these controls would be part of the permitting, engineering and design for each specific project.

The model Integrated MRF with Conversion Technologies, analyzed herein, would result in recovering additional recyclables, compost, and energy from the anaerobic digestion and thermal gasification processes and in recovered slag and metal, which could potentially be beneficially used. It was compared to traditional transport and disposal of waste at a modern sanitary landfill that converts landfill gas to energy.

This study concludes that an Integrated MRF with Conversion Technologies comprised of a combination of proven technologies will achieve a net reduction in cumulative GHG emissions as compared to landfill transport and disposal due to higher avoided emissions for energy generation replacing fossil fuels, and energy savings from additional recycling.

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