Waste Reduction Model (WARM):

Materials Management and Alternatives for Recyclables (Recycling and Combustion)




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Outline

- Waste Reduction Model (WARM) overview
- Organic materials and management practices in WARM
- Anaerobic digestion
- Results comparison – organics management practices
- Overview– Recycling and Combustion (WTE)
- Results comparison - Recycling and Combustion (WTE)

WARM Overview

- In 1998, EPA created the Waste Reduction Model (WARM) to help solid waste planners and organizations track and voluntarily report greenhouse gas (GHG) emissions reductions from several different waste management practices.

- WARM calculates and totals GHG emissions of baseline and alternative waste management practices, including **source reduction**, **recycling**, **combustion**, **composting**, **anaerobic digestion** and **landfilling**.

- The model calculates emissions in metric tons of carbon equivalent (MTCE), metric tons of carbon dioxide equivalent (MTCO2E), and energy units (million BTU) across a wide range of material types commonly found in municipal solid waste (MSW).

- WARM recognizes **54 materials** from paper to plastic to organics

WARM Overview

1. **Describe the baseline generation and management for the waste materials listed below. If the material is not generated in your community or you do not want to analyze it, leave it blank or enter 0. Make sure that the total quantity generated equals the total quantity managed.**

2. **Describe the alternative management scenario for the waste materials generated in the baseline. Any decrease in generation should be entered in the Source Reduction column. Any increase in generation should be entered in the Source Reduction column as a negative value. Make sure that the total quantity generated equals the total quantity managed.**

Material	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Tons Anaerobically Digested	Tons Generated	Tons Source Reduced	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Tons Anaerobically Digested
Aluminum Cans				NA	NA	0.0					NA	NA
Aluminum Ingot				NA	NA	0.0					NA	NA
Steel Cans				NA	NA	0.0					NA	NA
Copper Wire				NA	NA	0.0					NA	NA
Glass				NA	NA	0.0					NA	NA
HDPE				NA	NA	0.0					NA	NA
LDPE	NA			NA	NA	0.0		NA			NA	NA
PET				NA	NA	0.0					NA	NA
LLDPE	NA			NA	NA	0.0		NA			NA	NA
PP	NA			NA	NA	0.0		NA			NA	NA
PS	NA			NA	NA	0.0		NA			NA	NA
PVC	NA			NA	NA	0.0		NA			NA	NA
PLA	NA				NA	0.0		NA				NA
Corrugated Containers				NA	NA	0.0					NA	NA
Magazines/Third-class Mail				NA	NA	0.0					NA	NA
Newspaper				NA	NA	0.0					NA	NA
Office Paper				NA	NA	0.0					NA	NA
Phonebooks				NA	NA	0.0					NA	NA
Textbooks				NA	NA	0.0					NA	NA
Dimensional Lumber				NA	NA	0.0					NA	NA
Medium-density Fiberboard				NA	NA	0.0					NA	NA
Food Waste (non-meat)	NA					0.0		NA				
Food Waste (meat only)	NA					0.0		NA				
Beef	NA					0.0		NA				
Poultry	NA					0.0		NA				
Grains	NA					0.0		NA				
Bread	NA					0.0		NA				
Fruits and Vegetables	NA					0.0		NA				
Dairy Products	NA					0.0		NA				
Yard Trimmings	NA					0.0	NA	NA				
Grass	NA					0.0	NA	NA				
Leaves	NA					0.0	NA	NA				
Branches	NA					0.0	NA	NA				
Mixed Paper (general)				NA	NA	0.0					NA	NA
Mixed Paper (primarily residential)				NA	NA	0.0					NA	NA
Mixed Paper (primarily from offices)				NA	NA	0.0					NA	NA
Mixed Metals				NA	NA	0.0					NA	NA
Mixed Plastics				NA	NA	0.0					NA	NA
Mixed Recyclables		1,000.0		NA	NA	1,000.0	NA			1,000.0	NA	NA
Food Waste	NA					0.0		NA				
Mixed Organics	NA					0.0	NA	NA				
Mixed MSW	NA			NA	NA	0.0	NA	NA			NA	NA
Carpet				NA	NA	0.0					NA	NA
Personal Computers				NA	NA	0.0					NA	NA
Clay Bricks	NA		NA	NA	NA	0.0		NA		NA	NA	NA
Concrete [1]			NA	NA	NA	0.0	NA			NA	NA	NA
Fly Ash [2]			NA	NA	NA	0.0	NA			NA	NA	NA
Tires [3]				NA	NA	0.0					NA	NA
Asphalt Concrete			NA	NA	NA	0.0				NA	NA	NA
Asphalt Shingles				NA	NA	0.0					NA	NA

Organics Management Practices in WARM

Management Practice	Food Waste	Yard Trimmings	Mixed Organics
Source Reduction	Modeled specifically for all food waste types	Not modeled – does not apply for yard trimmings	
Anaerobic Digestion	Assuming weighted average food waste properties for all food types	Modeled based on specific properties for grass, leaves, and branches	Weighted average of food waste, grass, leaves, and branches
Composting	Assuming weighted average food waste properties for all food types	Assuming weighted average green waste properties	Weighted average of food waste and yard trimmings
Combustion	Assuming weighted average food waste properties for all food types	Assuming weighted average green waste properties	Weighted average of food waste and yard trimmings
Landfilling	Assuming weighted average food waste properties for all food types	Modeled based on specific properties for grass, leaves, and branches	Weighted average of food waste and yard trimmings
Donation	In development; guidance available to estimate avoided landfilling	Not modeled – does not apply for yard trimmings	

Anaerobic Digestion – Introduction

- EPA added AD module in 2016 as part of WARM Version 14.
- An anaerobic digestion (AD) facility generates biogas via the anaerobic degradation of organic materials.
- Degradable materials are digested in a reactor in the absence of oxygen to produce biogas that is 50-70% methane.
- WARM assumes biogas generated during AD is used in an internal combustion engine to generate electricity.
- The resulting solid and liquid digestates are then recovered or treated.

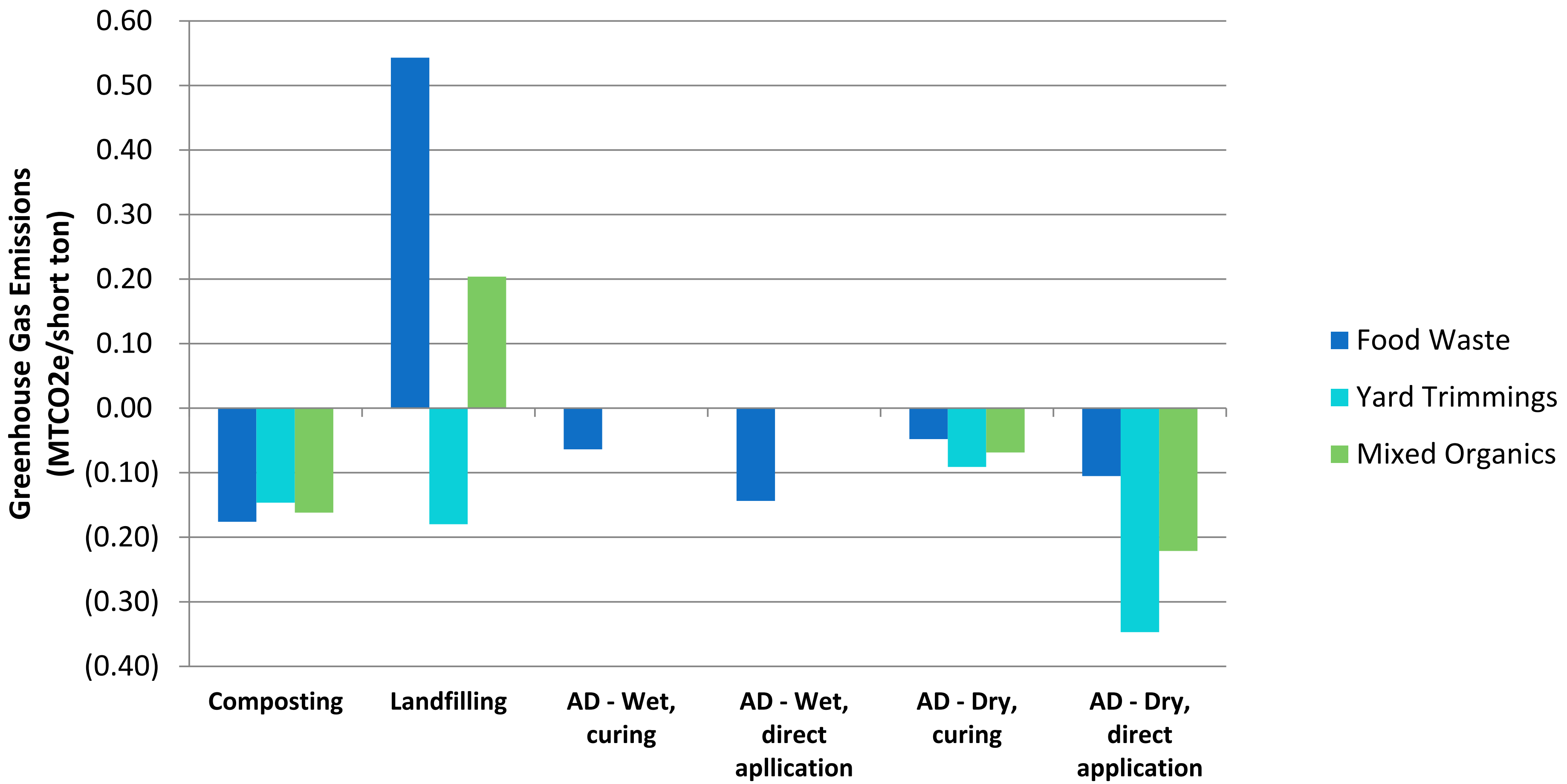
Modeling Approach

- Two digester configuration options modeled
- Wet digester
  - Continuous, single-stage, mesophilic digester
  - Accepts only food waste materials in WARM
- Dry digester
  - Single-stage, mesophilic digester
  - Accepts all organic materials in WARM (food waste, yard trimmings, mixed organics)
- Two digestate treatment options:
  - Aerobic curing before land application (default)
  - Direct land application without curing

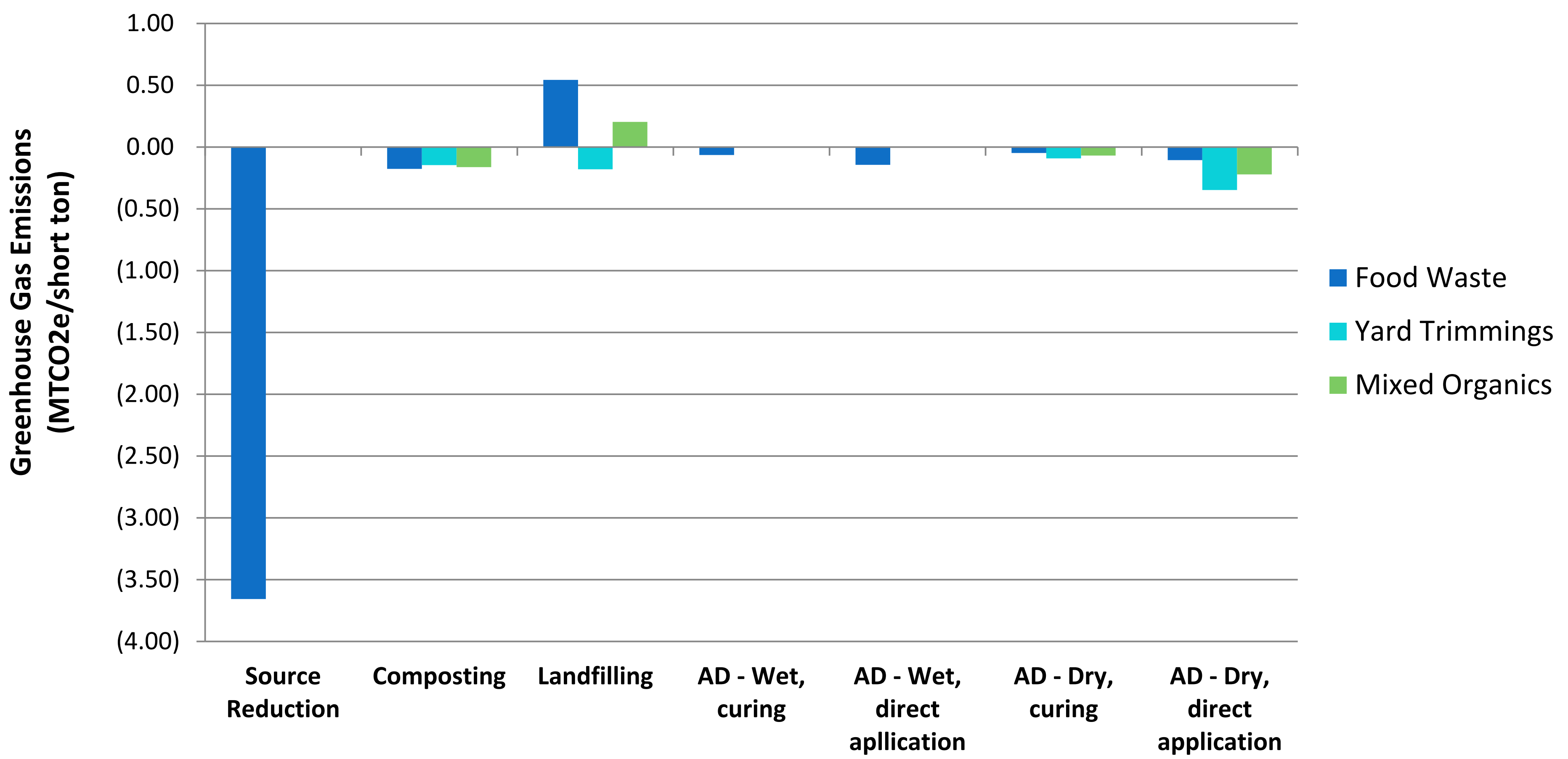
Composting Organics in WARM

- Modeled for food waste, yard trimmings, mixed organics, and PLA
- Energy and emissions sources
  - Transport to composting facility
  - Equipment use (turning)
  - Fugitive CH_4 and N_2O emissions
- Emissions offsets
  - Soil carbon storage after land application
- Uses same soil carbon storage model and assumptions as for land application of anaerobic digestion digestate

Organics Results - Comparison



Organics Results – With Source Reduction



Overview: Recycling and Combustion

WARM definition of **Recycling**: A material or finished product that has served its intended use and has been diverted or recovered from waste destined for disposal, having completed its life as a consumer item.

- Open vs. closed-loop recycling is material specific
- Loss rates are material specific

Combustion: WARM models "mass burn" combustion facilities, which generate electricity (or steam) through combustion of municipal solid waste.

Net combustion emissions = gross CO_2 and N_2O emissions
– CO2 emissions avoided through displaced electricity
– combustion facility recycling (calculated the same as recycling)

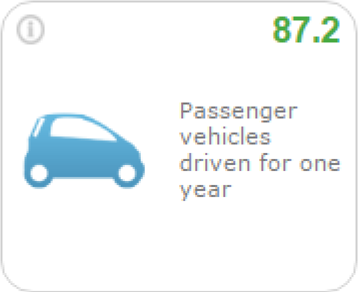
Comparing Combustion and Landfilling in WARM (1,000 tons)

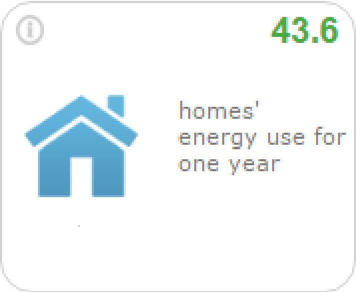
Mixed Municipal Solid Waste: Baseline is Landfill. Alternative is Combustion.

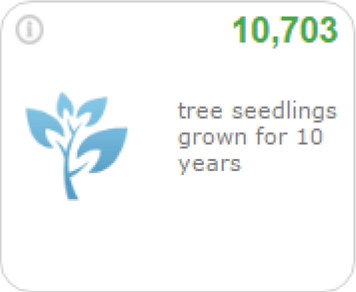
Total GHG Emissions from Baseline MSW Generation and Management ($MTCO_2E$):	347
Total GHG Emissions from Alternative MSW Generation and Management ($MTCO_2E$):	(66)
Incremental GHG Emissions ($MTCO_2E$):	(413)

$MTCO_2E$ = metric tons of carbon dioxide equivalent

The net benefit (national average) of combusting mixed municipal solid waste rather than landfilling is equivalent to:







Mixed Recyclables: Baseline is Landfill. Alternative is Combustion.

Total GHG Emissions from Baseline MSW Generation and Management ($MTCO_2E$):	42
Total GHG Emissions from Alternative MSW Generation and Management ($MTCO_2E$):	(444)
Incremental GHG Emissions ($MTCO_2E$):	(486)

$MTCO_2E$ = metric tons of carbon dioxide equivalent

Comparing Combustion (WTE) and Recycling using WARM (1,000 tons)

Baseline is combustion. Alternative is recycling.

Total GHG Emissions from Baseline MSW Generation and Management ($MTCO_2E$):	(444)
Total GHG Emissions from Alternative MSW Generation and Management ($MTCO_2E$):	(2,825)
Incremental GHG Emissions ($MTCO_2E$):	(2,381)

$MTCO_2E$ = metric tons of carbon dioxide equivalent

The benefit (national average) of recycling 1,000 tons of recyclable material rather than combusting 1,000 tons of the same material is equal to:

503 Passenger vehicles driven for one year

251 homes' energy use for one year

61,706 tree seedlings grown for 10 years

WARM Documentation and Website

Documentation Chapters

Any material or waste management option that is modeled in WARM can be found in our chapters.

In each chapter, you will find emission factors, assumptions, limitations, offsets and life-cycle emissions.

Materials Chapters (March 2015)

Management Practices Chapters (February 2016)

WARM Model History

https://www.epa.gov/warm

Each Version includes a paragraph on any major updates.

The current version is WARM Version 14.

Combustion Documentation

Exhibit 5-1: Gross GHG Emissions from MSW Combustion ($MTCO_2E$/Short Ton of Material Combusted)

(a) Material	(b) Combustion CO_2 Emissions From Non-Biomass per Short Ton Combusted	(c) Combustion N_2O Emissions per Short Ton Combusted	(d) Transportation CO_2 Emissions per Short Ton Combusted	(e) Gross GHG Emissions per Short Ton Combusted (e = b + c + d)
Aluminum Cans	–	–	0.01	0.01

Exhibit 5-2: Avoided Utility GHG Emissions from Combustion at WTE Facilities

(a) Material Combusted	(b) Energy Content (Million Btu Per Ton)	(c) Mass Burn Combustion System Efficiency (%)	(d) RDF Combus-tion System Efficiency (%)	(e) Emission Factor for Utility-Generated Electricity[a] ($MTCO_2E$/ Million Btu of Electricity Delivered)	(f) Avoided Utility GHG Emissions per Ton Combusted at Mass Burn Facilities[a] ($MTCO_2E$) (f = b × c × e)	(g) Avoided Utility CO_2 per Ton Combusted at RDF Facilities ($MTCO_2E$) (g = b × d × e)
Aluminum Cans	-0.67[b]	17.8%	16.3%	0.22	-0.03	-0.02

Exhibit 5-7: Net National Average GHG Emissions from Combustion at WTE Facilities

(a) Material Combusted	(b) Gross GHG Emissions per Ton Combusted ($MTCO_2E$/ Short Ton)	(c) Avoided Utility GHG Emissions per Ton Combusted at Mass Burn Facilities ($MTCO_2E$ / Short Ton)[a]	(d) Avoided Utility GHG Emissions per Ton Combusted at RDF Facilities ($MTCO_2E$ / Short Ton)	(e) Avoided CO_2 Emissions per Ton Combusted Due to Steel Recovery ($MTCO_2E$ / Short Ton)	(f = b – c – e) Net GHG Emissions from Combustion at Mass Burn Facilities ($MTCO_2E$ / Short Ton)	(g = b – d – e) Net GHG Emissions from Combustion at RDF Facilities ($MTCO_2E$ / Short Ton)
Aluminum Cans	0.01	-0.03	-0.02	–	0.04	0.03
Aluminum Ingot	0.01	-0.03	-0.02	–	0.04	0.03
Steel Cans	0.01	-0.02	-0.02	1.60	-1.57	-1.57
Copper Wire	0.01	-0.02	-0.02	–	0.03	0.03
Glass	0.01	-0.02	-0.02	–	0.03	0.03
HDPE	2.80	1.58	1.44	–	1.23	1.36
LDPE	2.80	1.57	1.43	–	1.24	1.37
PET	2.05	0.84	0.76	–	1.21	1.29

Questions?

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