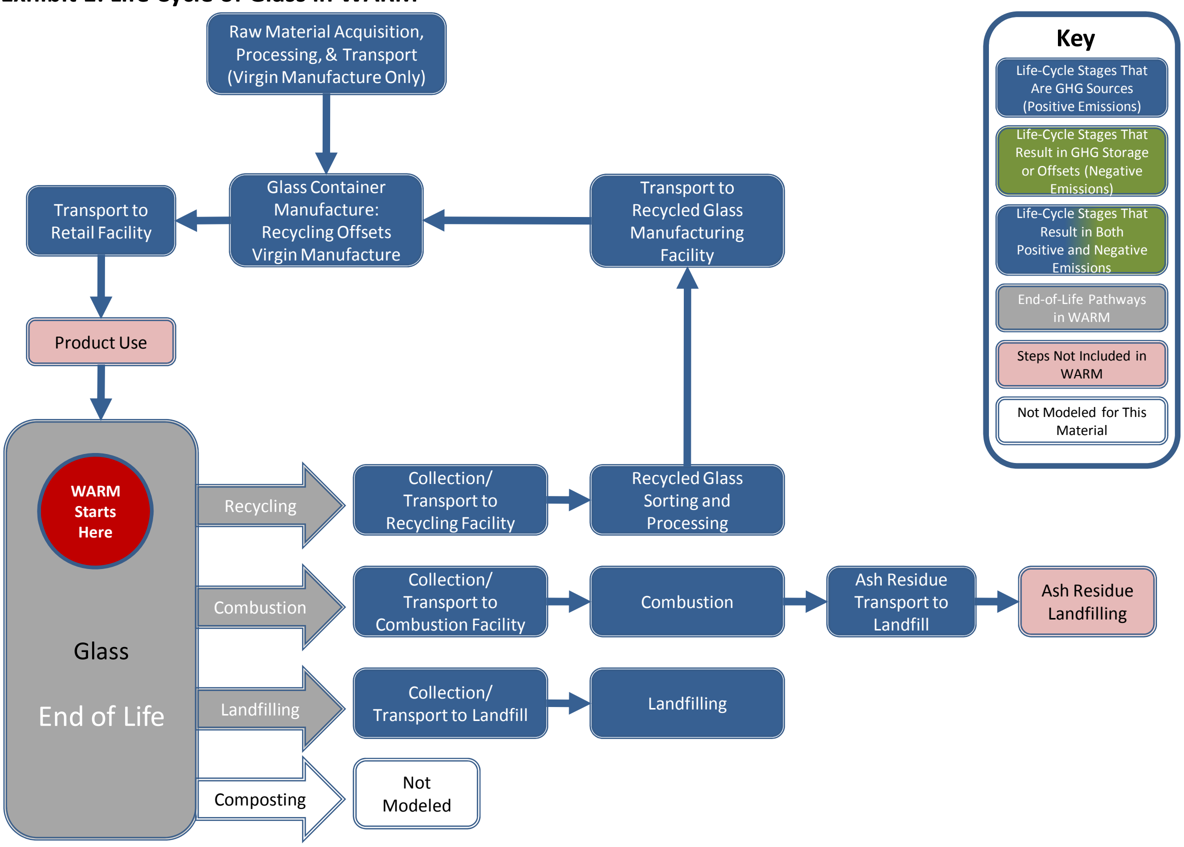
GLASS

1. INTRODUCTION TO WARM AND GLASS

This chapter describes the methodology used in EPA's Waste Reduction Model (WARM) to estimate streamlined life-cycle greenhouse gas (GHG) emission factors for glass, beginning at the point of waste generation. The WARM GHG emission factors are used to compare the net emissions associated with glass in the following four materials management alternatives: source reduction, recycling, landfilling and combustion. Exhibit 1 shows the general outline of materials management pathways for glass in WARM. For background information on the general purpose and function of WARM emission factors, see the Introduction & Overview chapter. For more information on Source Reduction, Landfilling and Combustion, see the chapters devoted to those processes. WARM also allows users to calculate results in terms of energy, rather than GHGs. The energy results are calculated using the same methodology described here but with slight adjustments, as explained in the Energy Impacts chapter.

Exhibit 1: Life Cycle of Glass in WARM



WARM assumes that all glass waste is in the form of containers and packaging, including beer and soft drink bottles, wine and liquor bottles, and food and other bottles and jars. The model does not account for glass waste that is a component of durable goods such as appliances, furniture and consumer electronics, or for other types of glass such as the flat or plate glass used in picture frames, mirrors or windows. Recent figures on glass container generation and recovery are shown in Exhibit 2.

Exhibit 2: U.S. Glass Container Generation and Recovery in 2008

Type of Product	Generation (Short Tons)	Recovery (Short Tons)	Total MSW Generation (Short Tons)	Glass as % of Total MSW
Glass Bottles and Jars	10,050,000	2,810,000	249,610,000	4.9%

Source: EPA (2009).

The recovery and subsequent recycling of glass is considered to be a closed-loop process (i.e., glass bottles and jars are remanufactured into more glass bottles and jars).

2. LIFE-CYCLE ASSESSMENT AND EMISSION FACTOR RESULTS

The streamlined life-cycle GHG analysis in WARM focuses on the waste generation point, or the moment a material is discarded, as the reference point and only considers upstream GHG emissions when the production of new materials is affected by materials management decisions.[1] Recycling and source reduction are the two materials management options that impact the upstream production of materials, and consequently are the only management options that include upstream GHG emissions. For more information on evaluating upstream emissions, see the chapters on Recycling and Source Reduction.

The overall life-cycle energy associated with manufacturing glass from virgin inputs and recycled inputs is shown in Exhibit 3.

Exhibit 3: Process and Transportation Energy for Manufacture of Glass Using Virgin and Recycled Inputs

Material/ Product	Virgin Manufacture			Recycled Manufacture		
	Process Energy per Short Ton Made from Virgin Inputs (Million Btu)	Transportation Energy per Short Ton Made from Virgin Inputs (Million Btu)	Total	Process Energy per Short Ton Made from Recycled Inputs (Million Btu)	Transportation Energy per Short Ton Made from Recycled Inputs (Million Btu)	Total
Glass	6.49	0.58	7.08	4.32	0.34	4.66

Source: RTI (2004).

As Exhibit 4 illustrates, most of the GHG sources relevant to glass in this analysis fall under the raw materials acquisition and manufacturing section of the life-cycle. The recycling and source reduction pathways are most relevant to glass since the upstream emissions associated with glass production are significant. Glass does not contain carbon and does not generate CH_4 emissions when landfilled. Therefore, the emissions associated with landfilling glass include only transportation- and landfill-equipment-related emissions. Glass cannot be composted and therefore this pathway is not considered in WARM.

Exhibit 4: Glass GHG Sources and Sinks from Relevant Materials Management Pathways

Materials Management Strategies for Glass	GHG Sources and Sinks Relevant to Glass		
	Raw Materials Acquisition and Manufacturing	Changes in Forest or Soil Carbon Storage	End of Life
Source Reduction	**Offsets** • Transport of raw materials and products • Virgin manufacture process energy • Virgin manufacture process non-energy	NA	NA

[1] The analysis is streamlined in the sense that it examines GHG emissions only and is not a comprehensive environmental analysis of all environmental impacts from municipal solid waste management options.

Recycling	**Emissions** • Transport of recycled materials • Recycled manufacture process energy • Recycled manufacture process non-energy **Offsets** • Transport of raw materials and products • Virgin manufacture process energy • Virgin manufacture process non-energy	NA	**Emissions** • Collection and transportation to recycling center • Sorting and processing energy
Composting	Not applicable since glass cannot be composted		
Combustion	NA	NA	**Emissions** • Transport to WTE facility • Energy required for combustion
Landfilling	NA	NA	**Emissions** • Transport to landfill • Landfilling machinery

NA = Not applicable.

WARM analyzes all of the GHG sources and sinks outlined in Exhibit 4 and calculates net GHG emissions per short ton of glass generated for each materials management alternative as shown in Exhibit 5. For additional discussion on the detailed methodology used to develop these emission factors, see sections 3 and 4 .

Exhibit 5: Net Emissions for Glass under Each Materials Management Option ($MTCO_2E$/Short Ton)

Material/ Product	Net Source Reduction (Reuse) GHG Emissions For Current Mix of Inputs	Net Recycling GHG Emissions	Net Composting GHG Emissions	Net Combustion GHG Emissions	Net Landfilling GHG Emissions
Glass	-0.53	-0.28	NA	0.05	0.04

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.
NA = This materials management option is not applicable to this material.

3. RAW MATERIALS ACQUISITION AND MANUFACTURING

For glass, the GHG emissions associated with raw materials acquisition and manufacturing (RMAM) are (1) GHG emissions from energy used during the acquisition and manufacturing processes, (2) GHG emissions from energy used to transport materials, and (3) non-energy GHG emissions resulting from manufacturing processes. Process non-energy GHG emissions occur during the manufacture of certain materials and are not associated with energy consumption.

The typical composition of container glass is shown in Exhibit 6. The first step in glass manufacture is mining, transporting and processing the minerals that will be the glass inputs. The mining, transportation and processing steps use energy and emit energy-related GHGs. Once the glass inputs are transported to the glass manufacturing facility, the main processes in glass manufacture are batch preparation, melting and refining, forming and post forming (DOE, 2002).

Batch preparation. Varied quantities of raw ingredients are blended together, based on the type of glass being manufactured. Glass inputs must include: *formers*, the main component of the glass; *fluxes*, which lower the temperature at which the glass melts; and *stabilizers*, which make the glass more chemically stable and increase the strength of the finished product. The typical composition of container glass is shown in Exhibit 6; other ingredients such as colorants may be added. This manufacturing stage consumes fossil fuels used for energy production, resulting in energy-related GHG emissions (DOE, 2002).

Exhibit 6: Typical Composition of Modern Container Glass

Chemical	Purpose	Source	% Composition
Silica (SiO_2)	Former	Sand	72% to 73.5%
Soda (Na_2O)	Flux	Soda ash (Na_2CO_3) from trona ore	12% to 14%
Potash (K_2O)	Flux	Mined and processed potassium salts	0.6%
Lime (CaO)	Stabilizer	Limestone ($CaCO_3$)	9% to 12%
Magnesia (MgO)	Stabilizer	Impurity in limestone	1.2% to 2.0%
Alumina (Al_2O_3)	Stabilizer	Feldspar	1.2% to 2.0%

Source: DOE (2002).

Melting and refining. The glass is melted in a furnace to the correct temperature, and bubbles and other inclusions are removed. This manufacturing stage results in both energy emissions and non-energy process CO_2 emissions from the heating of carbonates (soda ash and limestone) (DOE, 2002).

Forming. The molten glass is formed into its final shape. The glass can be molded, drawn, rolled, cast, blown, pressed or spun into fibers. Commercial glass containers are formed using molds. This manufacturing stage consumes fossil fuels used for energy production, resulting in energy-related GHG emissions (DOE, 2002).

Post-Forming. Various processes may be applied to the formed glass, depending on the results desired, including curing, annealing, tempering, coating and cutting. Container glass is annealed and usually coated with scratch-resistant coatings consisting of a thin layer of tin or titanium oxide followed by a lubricant such as polyethylene. This manufacturing stage uses energy and results in energy-related GHG emissions (DOE, 2002).

The RMAM calculation in WARM also incorporates "retail transportation," which consists of the average truck, rail, water and other-modes transportation emissions required to get the glass from the manufacturing facility to the retail/distribution point. The energy and GHG emissions from retail transportation are presented in Exhibit 7, and are calculated using data on average shipping distances and modes from the U.S. Census Bureau (2007) and on typical transportation fuel efficiencies from EPA (1998). Transportation emissions from the retail point to the consumer are not included.

Exhibit 7: Retail Transportation Energy Use and GHG Emissions

Material/Product	Average Miles per Shipment	Retail Transportation Energy (Million Btu per Short Ton of Product)	Retail Transportation Emissions ($MTCO_2E$ per Short Ton of Product)
Glass	383	0.411	0.031

The total RMAM emissions for glass manufacturing are shown in the section on source reduction. The net emission factors for source reduction and recycling of glass include RMAM "upstream" emissions.

4. MATERIALS MANAGEMENT METHODOLOGIES

This analysis considers source reduction, recycling, landfilling and combustion pathways for materials management of glass. For glass, source reduction and recycling result in net negative emissions (i.e., a net reduction in GHG emissions), while combustion and landfilling result in slightly positive net emissions.

Glass is rarely manufactured from 100 percent virgin inputs or 100 percent recycled inputs. Exhibit 8 shows the range of recycled content used for manufacturing glass. Therefore "virgin" glass as referred to in the rest of this chapter is assumed to contain 5 percent recycled inputs.

Exhibit 8: Typical Glass Recycled Content Values in the Marketplace

Material	Recycled Content Minimum	Recycled Content Maximum
Glass	5%	30%

Glass is most frequently manufactured using "virgin" inputs, or a very low percentage of recycled inputs. However, it is also manufactured using higher amounts of recycled inputs than in "virgin" production. The current mix of production from recycled and "virgin" inputs used for manufacturing glass is shown in Exhibit 9.

Exhibit 9: Current Mix of Production from Virgin and Recycled Inputs for Glass Manufacturing

Product	% of Current Production from Recycled Inputs	% of Current Production from "Virgin" Inputs
Glass	23%	77%

Note: Rounded to nearest percentage.

The emission factors for source reduction and recycling are affected by the mix of inputs used for the manufacturing process. The emission factor for glass produced from the current mix of virgin and recycled inputs is calculated using a weighted average of virgin and recycled glass production data, based on the values in Exhibit 9. WARM also calculates an emission factor for producing glass from "virgin" inputs, assuming a recycled content of 5 percent (the industry minimum recycled content). GHG implications and emission factors for glass in each pathway are discussed in sections 4.1 through 4.5.

4.1 SOURCE REDUCTION

When a material is source reduced, GHG emissions associated with making the material and managing the post-consumer waste are avoided. As discussed previously, under the measurement convention used in this analysis, source reduction for glass has negative raw material and manufacturing GHG emissions (i.e., it avoids baseline emissions attributable to current production) and zero materials management GHG emissions. For more information, please refer to the module on Source Reduction.

Exhibit 10 outlines the GHG emission factor for source reducing glass. GHG benefits of source reduction are calculated as the emissions savings from avoided raw materials acquisition and manufacturing (see section 3) of glass produced from a "current mix" of virgin and recycled inputs or from glass produced from "100-percent virgin" inputs.[2]

[2] The "100 percent virgin" inputs emission factor assumes a minimum recycled content of 5 percent, since glass is rarely manufactured from entirely virgin inputs.

Exhibit 10: Source Reduction Emission Factors for Glass ($MTCO_2E$/Short Ton)

Material	Raw Material Acquisition and Manufacturing for Current Mix of Inputs	Raw Material Acquisition and Manufacturing for 100% Virgin Inputs	Forest Carbon Sequestration for Current Mix of Inputs	Forest Carbon Sequestration for 100% Virgin Inputs	Net Emissions for Current Mix of Inputs	Net Emissions for 100% Virgin Inputs
Glass	-0.53	-0.60	NA	NA	-0.53	-0.60

NA = Not applicable.

Post-consumer emissions are the emissions associated with materials management pathways that could occur at end of life. When source reducing glass, there are no post-consumer emissions because production of the material is avoided in the first place, and the avoided glass never becomes post-consumer. Forest carbon storage is not applicable to glass, and thus does not contribute to the source reduction emission factor.

4.1.1 Developing the Emission Factor for Source Reduction of Glass

To produce glass, substantial amounts of energy are used both in the acquisition of raw materials and in the manufacturing process itself. In general, the majority of energy used for these activities is derived from fossil fuels. Combustion of fossil fuels results in emissions of CO_2. In addition, manufacturing glass also results in process non-energy CO_2 emissions from the heating of carbonates (soda ash and limestone). Hence, the RMAM component consists of process energy, non-process energy and transport emissions in the acquisition and manufacturing of raw materials, as shown in Exhibit 11.

Exhibit 11: Raw Material Acquisition and Manufacturing Emission Factor for Virgin Production of Glass ($MTCO_2E$/Short Ton)

(a) Material/Product	(b) Process Energy	(c) Transportation Energy	(d) Process Non-Energy	(e) Net Emissions (e = b + c + d)
Glass	- 0.37	-0.07	-0.16	-0.60

Source: RTI (2004).

To calculate this factor, EPA obtained an estimate of the amount of energy required to acquire and produce one short ton of glass, which is reported as 6.49 million Btu (RTI, 2004). Next, we determined the fuel mix that comprises this Btu estimate (RTI, 2004) and then multiplied the fuel consumption (in Btu) by the fuel-specific carbon content. The sum of the resulting GHG emissions by fuel type comprises the total process energy GHG emissions, including both CO_2 and CH_4, from all fuel types used in glass production. The process energy used to produce glass and the resulting emissions are shown in Exhibit 12.

Exhibit 12: Process Energy GHG Emissions Calculations for Virgin Production of Glass

Product/Material	Process Energy per Short Ton Made from Virgin Inputs (Million Btu)	Process Energy GHG Emissions ($MTCO_2E$/Short Ton)
Glass	6.49	0.37

Source: RTI (2004).

Transportation energy emissions occur when fossil fuels are used to transport raw materials and intermediate products for glass production. The methodology for estimating these emissions is the same as the one used for process energy emissions. Based on estimated total glass transportation energy (RTI, 2004), EPA calculates the total emissions using fuel-specific carbon coefficients. The calculations for estimating the transportation energy emission factor for glass are shown in Exhibit 13.

Exhibit 13: Transportation Energy Emissions Calculations for Virgin Production of Glass

Product/Material	Transportation Energy per Short Ton Made from Virgin Inputs (Million Btu)	Transportation Energy GHG Emissions ($MTCO_2E$/Short Ton)
Glass	0.58	0.04

Note: The transportation energy and emissions in this exhibit do not include retail transportation, which is presented separately in Exhibit 7.

Non-energy GHG emissions occur during manufacturing but are not related to consuming fuel for energy. For glass, non-energy CO_2 emissions (based on data from ICF (1994)) are emitted in the virgin glass manufacturing process during the melting and refining stages from the heating of carbonates (soda ash and limestone). Exhibit 14 shows the components for estimating process non-energy GHG emissions for glass.

Exhibit 14: Process Non-Energy Emissions Calculations for Virgin Production of Glass

Product/Material	CO_2 Emissions (MT/Short Ton)	CH_4 Emissions (MT/Short Ton)	CF_4 Emissions (MT/Short Ton)	C_2F_6 Emissions (MT/Short Ton)	N_2O Emissions (MT/Short Ton)	Non-Energy Carbon Emissions ($MTCO_2E$/Short Ton)
Glass	0.16	–	–	–	–	0.16

– = Zero emissions.

4.2 RECYCLING

When a material is recycled, it is used in place of virgin inputs in the manufacturing process, rather than being disposed of and managed as waste. According to EPA, 28 percent of glass containers and packaging in the U.S. municipal solid waste stream are recycled each year (EPA 2009). Glass, like most of the materials in WARM, is modeled as being recycled in a closed loop. This section describes the development of the recycling emission factor for glass, which is shown in the final column of Exhibit 15. For more information, please refer to the Recycling chapter.

Exhibit 15: Recycling Emission Factor for Glass ($MTCO_2E$/Short Ton)

Material	Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Materials Management Emissions	Recycled Input Credit[a] Process Energy	Recycled Input Credit[a] – Transportation Energy	Recycled Input Credit[a] – Process Non-Energy	Forest Carbon Sequestration	Net Emissions (Post-Consumer)
Glass	–	–	-0.12	-0.02	-0.14	–	-0.28

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.
[a] Includes emissions from the initial production of the material being managed.

4.2.1 Developing the Emission Factor for the Recycling of Glass

EPA calculates the GHG benefits of recycling glass by comparing the difference between the emissions associated with manufacturing a short ton of glass from recycled materials and the emissions from manufacturing the same ton from virgin materials, after accounting for losses that occur in the recycling process. This difference is called the “recycled input credit” and represents the net change in GHG emissions from process energy, transportation energy and process non-energy sources in recycling glass relative to virgin production of glass.

To calculate each component of the recycling emission factor, EPA follows six steps, which are described in detail below.

Step 1. *Calculate emissions from virgin production of one short ton of glass.* We apply fuel-specific carbon coefficients to the process and transportation energy use data for virgin RMAM of glass (RTI, 2004). This estimate is then summed with the emissions process non-energy emissions (ICF, 1994) to calculate the total emissions from virgin production of glass. The calculations for virgin process, transportation and process non-energy emissions for glass are presented in Exhibit 12, Exhibit 13, and Exhibit 14, respectively.

Step 2. *Calculate GHG emissions for recycled production of glass.* WARM applies the same fuel-specific carbon coefficients to the process and transportation energy use data from RTI (2004) for the production of recycled glass, as shown in Exhibit 16 and Exhibit 17,. There were no process non-energy emissions from recycled production of glass. These sources are summed to calculate the total emissions from the production of recycled glass.

Exhibit 16: Process Energy GHG Emissions Calculations for Recycled Production of Glass

Product/Material	Process Energy per Short Ton Made from Recycled Inputs (Million Btu)	Energy Emissions ($MTCO_2E$/Short Ton)
Glass	4.32	0.23

Exhibit 17: Transportation Energy GHG Emissions Calculations for Recycled Production of Glass

Product/Material	Transportation Energy per Ton Made from Recycled Inputs (Million Btu)	Transportation Emissions ($MTCO_2E$/Short Ton)
Glass	0.34	0.02

Note: The transportation energy and emissions in this exhibit do not include retail transportation, which is presented separately in Exhibit 7.

Step 3. *Calculate the difference in emissions between virgin and recycled production.* To calculate the GHG emissions savings from recycling one short ton of glass, WARM subtracts the recycled product emissions (calculated in Step 2) from the virgin product emissions (calculated in Step 1) to get the GHG savings. These results are shown in Exhibit 19.

Exhibit 18: Differences in Emissions between Recycled and Virgin Glass Manufacture ($MTCO_2E$/Short Ton)

Product/ Material	Product Manufacture Using 100% Virgin Inputs ($MTCO_2E$/Short Ton)			Product Manufacture Using 100% Recycled Inputs ($MTCO_2E$/Short Ton)			Difference Between Recycled and Virgin Manufacture ($MTCO_2E$/Short Ton)		
	Process Energy	Transpor-tation Energy	Process Non-Energy	Process Energy	Transpor-tation Energy	Process Non-Energy	Process Energy	Transpor-tation Energy	Process Non-Energy
Glass	0.37	0.07	0.16	0.23	0.06	–	-0.14	-0.02	-0.16

Step 4. *Adjust the emissions differences to account for recycling losses.* Material losses occur in both the recovery and manufacturing stages of recycling. The loss rate represents the percentage of end-of-life glass collected for recycling that is lost during the recovery or remanufacturing process, and ultimately disposed of. WARM applies a 2.4 percent loss rate for glass (FAL, 2003; RTI, 2004). The differences in emissions from virgin versus recycled process energy, transportation energy and non-energy processing are adjusted to account for the loss rates by multiplying the final three columns of Exhibit 19 by 97.6 percent, the amount of material retained after losses (i.e., 100 percent input – 2.4 percent lost = 97.6 percent retained).

4.3 COMPOSTING

Glass is not subject to aerobic bacterial degradation, and therefore, cannot be composted. Consequently, WARM does not include composting as an end-of-life pathway for glass.

4.4 COMBUSTION

WARM estimates (1) gross emissions of CO_2 and N_2O from MSW combustion (including emissions from transportation of waste to the combustor and ash from the combustor to a landfill) and (2) CO_2 emissions avoided due to displaced electric utility generation. WARM subtracts GHG emissions avoided from energy recovery from direct combustion GHG emissions to obtain an estimate of the net GHG emissions from MSW.

Glass, however, cannot be combusted, and instead absorbs a small amount of heat during MSW combustion that could otherwise be recovered and used to produce electricity. Consequently, Exhibit 20 shows that the emission factor for combusting glass includes transportation to the facility and a small increase in utility emissions for power generation that would otherwise have been avoided if the glass were not sent to the combustor.

Exhibit 19: Components of the Combustion Net Emission Factor for Glass ($MTCO_2E$/Short Ton)

Material	Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Transportation to Combustion	CO_2 from Combustion	N_20 from Combustion	Avoided Utility Emissions	Steel Recovery	Net Emissions (Post-Consumer)
Glass	–	0.03	–	–	0.02	–	0.05

– = Zero emissions.

4.4.1 Developing the Emission Factor for Combustion of Glass

Raw Material Acquisition and Manufacturing: Since WARM takes a materials-management perspective (i.e., starting at end-of-life disposal of a material), RMAM emissions are not included for this materials management pathway.

Transportation to Combustion: GHG emissions from transportation energy use were estimated to be 0.03 $MTCO_2E$ for one short ton of glass (FAL, 1994).

CO_2 from Combustion and N_2O from Combustion: Glass does not contain any C or N, so the emission factors for CO_2 and N2O from combustion are estimated to equal zero.[3]

Avoided Utility Emissions: Most waste-to-energy (WTE) plants in the United States produce electricity. Only a few cogenerate electricity and steam. In this analysis, EPA assumed that the energy recovered with MSW combustion would be in the form of electricity, and thus estimated the avoided electric utility CO_2 emissions associated with combustion of waste in a WTE plant. Avoided utility emissions for glass, however, are positive. This means that, instead of being avoided, emissions increase slightly due to the presence of glass in MSW at combustion facilities. EPA developed these estimates from data on the specific heat of glass (Incropera and DeWitt, 1990), and calculated the energy required to raise the temperature of glass from ambient temperature to the temperature found in a combustor (about 750° Celsius). Therefore, the amount

[3] At the relatively low combustion temperatures found in MSW combustors, most of the nitrogen in N_2O emissions is derived from the waste, not from the combustion air. Because glass does not contain nitrogen, EPA concluded that running these materials through an MSW combustor would not result in N_2O emissions.

of energy absorbed by one ton of glass in an MSW combustor would have resulted in less than 0.02 $MTCO_2E$ of avoided utility CO_2, if the glass had not been sent to the combustor,.

Steel Recovery: There are no steel recovery emissions associated with glass because it does not contain steel.

Because transportation and avoided utility emissions are positive emission factors, net GHG emissions for combustion are positive for glass.

4.5 LANDFILLING

WARM considers the CH_4 emissions, transportation-related CO_2 emissions and carbon storage that will result from landfilling each type of organic waste and mixed MSW. Because glass is not an organic material, it does not generate CH_4 or sequester any carbon when landfilled. The only emissions associated with landfilling glass are those from transporting glass to the landfills and moving waste around in the landfills. Transportation of waste materials results in anthropogenic CO_2 emissions due to the combustion of fossil fuels in the vehicles used to haul the wastes. For further information, please refer to the chapter on Landfilling. Exhibit 21 provides the net emission factor for landfilling glass.

Exhibit 20: Landfilling Emission Factor for Glass ($MTCO_2E$/Short Ton)

Material	Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Transportation to Landfill	Landfill CH_4	Avoided CO_2 Emissions from Energy Recovery	Landfill Carbon Sequestration	Net Emissions (Post-Consumer)
Glass	–	0.04	–	–	–	0.04

– = Zero emissions.

5. LIMITATIONS

EPA did not consider glass contained in durable goods as part of this analysis, due to the lack of relevant data.

6. REFERENCES

DOE. (2002). *Energy and Environmental Profile of the U.S. Glass Industry*. Washington, DC: U.S. Department of Energy, Office of Industrial Technologies. April.

EPA. (2010). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2008. (EPA publication no. EPA 430-R-10-006.) U.S. Environmental Protection Agency, Office of Atmospheric Programs. April. Retrieved from: http://epa.gov/climatechange/emissions/usinventoryreport.html.

EPA. (2009). *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2008*. Washington DC: U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. Retrieved from: http://www.epa.gov/wastes/nonhaz/municipal/pubs/msw2008rpt.pdf.

EPA. (1998). *Greenhouse Gas Emissions from the Management of Selected Materials*. (EPA publication no. EPA530-R-98-013.) Washington, DC: U.S. Environmental Protection Agency, Municipal and Industrial Solid Waste Division.

FAL. (2003). Loss rates provided by in-house data from Franklin Associates, Ltd., Prairie Village, KS.

FAL. (1994). *The Role of Recycling in Integrated Solid Waste Management to the Year 2000*. Franklin Associates, Ltd. (Stamford, CT: Keep America Beautiful, Inc.), September, pp. I-24.

ICF. (1994). Memorandum: "Detailed Analysis of Greenhouse Gas Emissions Reductions from Increased Recycling and Source Reduction of Municipal Solid Waste," July 29. Page 48 of the Appendix prepared by Franklin Associates, Ltd., July 14.

Incropera, F. P., & DeWitt, D. P. (1990). *Introduction to Heat Transfer*. Second Edition. New York: John Wiley & Sons. pp. A3–A4.

RTI. (2004). Unpublished database developed jointly by the Research Triangle Institute and the U.S. Environmental Protection Agency Office of Research and Development.

U.S. Census Bureau. (2007). *Commodity Flow Survey*. Washington, DC: United States Census Bureau. Retrieved from http://www.census.gov/prod/ec02/02tcf-usp.pdf.