U.S. Environmental Protection Agency
Office of Resource Conservation and Recovery

Documentation for Greenhouse Gas Emission and Energy Factors Used in the Waste Reduction Model (WARM)

Tires

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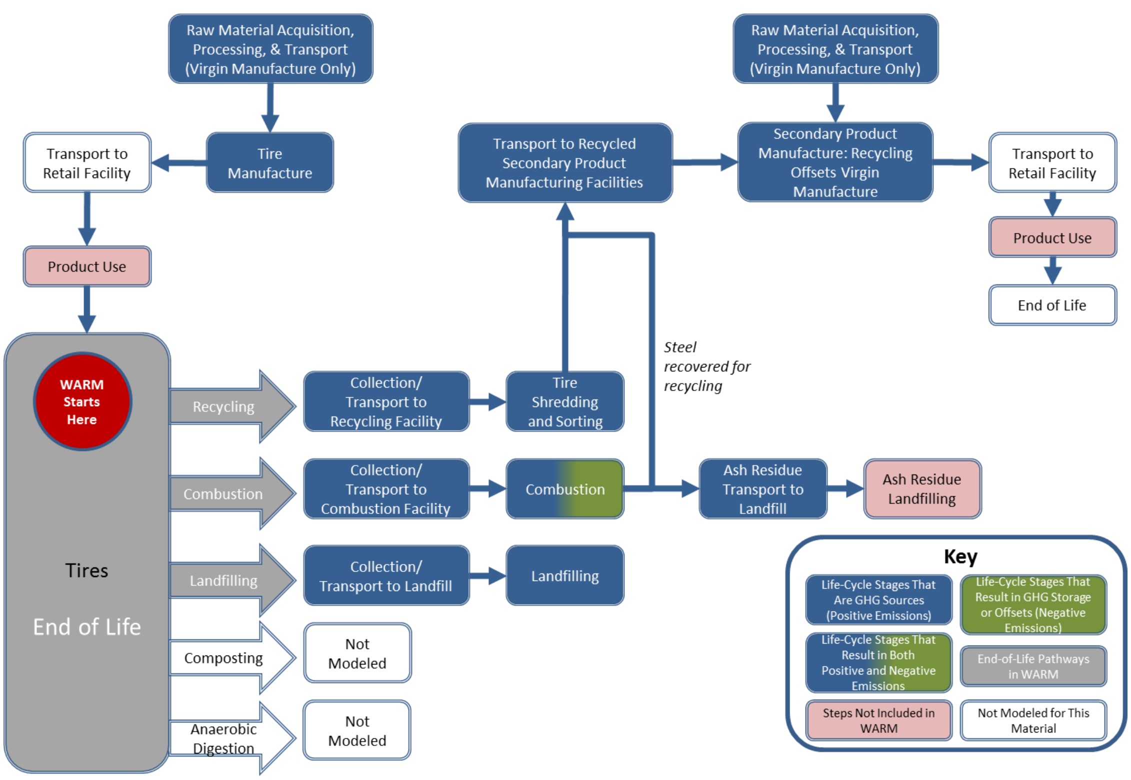
1 TIRES

1.1 INTRODUCTION TO WARM AND TIRES

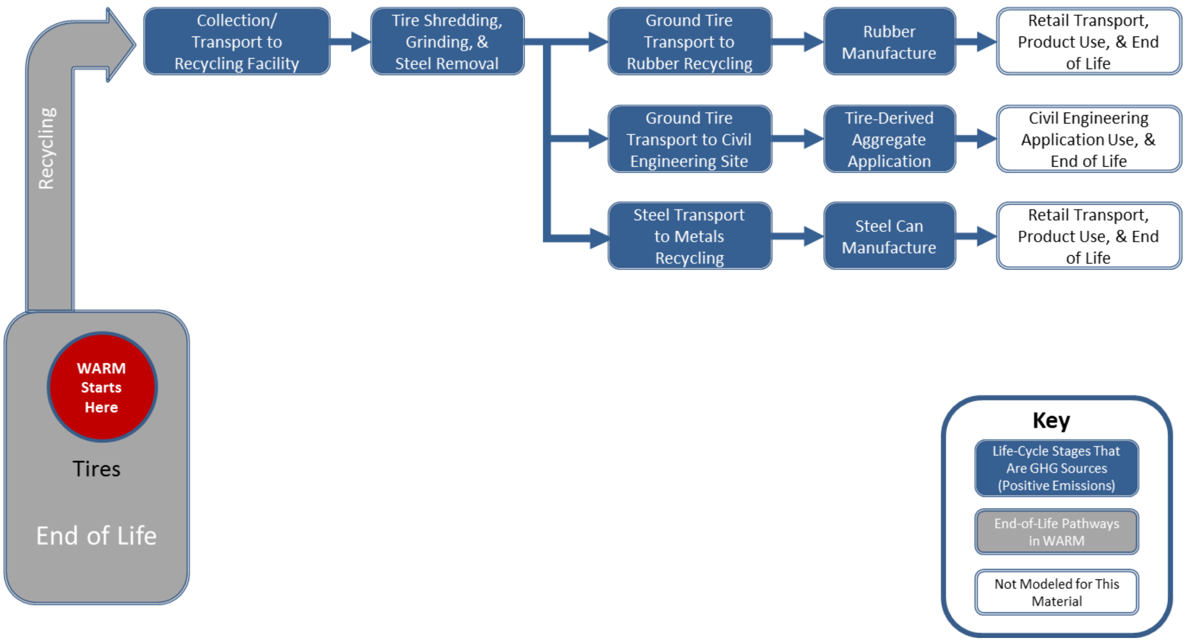
This chapter describes the methodology used in EPA's Waste Reduction Model (WARM) to estimate streamlined life-cycle greenhouse gas (GHG) emission factors for passenger vehicle tires beginning at the waste generation reference point.[1] The WARM GHG emission factors are used to compare the net emissions associated with scrap passenger tires in the following four materials management alternatives: source reduction, recycling, landfilling and combustion (with energy recovery). Exhibit 1-1 shows the general materials management pathways (life cycle) for tires 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, Recycling, 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 1-1: Life Cycle of Tires in WARM



Scrap tires have several end uses in the U.S. market. Scrap tires used as a fuel, as construction materials in civil engineering applications, and in various ground rubber applications such as running tracks and molded products represented more than 90 percent of the scrap tire market in the United States in 2007 (RMA, 2009b) and therefore are the three uses modeled by WARM. Exhibit 2-2 shows the open-loop recycling pathways of tires wherein the recycling of tires results in a new raw material used in rubber manufacture, aggregate application, and steel can manufacture.

Exhibit 1-2: Detailed Recycling Flows for Tires in WARM



1.2 LIFE-CYCLE ASSESSMENT AND EMISSION FACTOR RESULTS

The streamlined life-cycle GHG analysis in WARM uses the waste generation point (the point where a material is discarded), as the reference point. As Exhibit 1-3 shows, most of the GHG sources relevant to tires in this analysis are contained in the end-of-life management section of the life-cycle assessment, with the exception of recycling tires and transporting the recycled products.

WARM analyzes all of the GHG sources and sinks presented in Exhibit 1-3 and calculates net GHG emissions per short ton of tire inputs. More detailed methodology on emission factors are provided in the sections below on individual waste management strategies.

Upstream GHG emissions are only considered when the production of new materials is affected by materials management decisions[2], specifically recycling and source reduction. For more information on evaluating upstream emissions, see the chapters on Recycling and Source Reduction. WARM does not consider composting or anaerobic digestion for the tires category.

[2] 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.

Exhibit 1-3: Tires GHG Sources and Sinks from Relevant Waste Management Pathways

Materials Management Strategies for Tires	GHG Sources and Sinks Relevant to Tires: Raw Materials Acquisition and Manufacturing	Changes in Forest or Soil Carbon Storage	End of Life
Source Reduction	**Offsets** • Transport of raw materials and intermediate products • Virgin process energy • Transport of tires to point of sale	NA	NA
Recycling	**Emissions** • Transport of recycled materials • Recycled ground rubber and TDA[a] manufacture process energy **Offsets** • Transport of virgin ground rubber and soil/sand • Virgin ground rubber and soil/sand manufacture process energy	NA	**Emissions** • Collection of tires and transportation to recycling center • Production of ground rubber and rubber for civil engineering applications **Offsets** • Steel recovery from steel-belted radial tires
Composting	Not applicable since tires cannot be composted		
Combustion	NA	NA	**Emissions** • Transport to combustion facilities • Combustion-related CO_2 and N_2O **Offsets** • Avoided utility emissions • Steel recovery
Landfilling	NA	NA	**Emissions** • Transport to landfill • Landfilling machinery
Anaerobic Digestion	Not applicable since tires cannot be anaerobically digested		

NA = Not applicable.
[a] Tire-derived aggregate (TDA) is used in civil engineering applications.

The net emissions for tires under each materials management option are presented in Exhibit 1-4.

Exhibit 1-4: Net Emissions for Tires under Each Materials Management Option ($MTCO_2E$/Short Ton)

Material	Net Source Reduction (Reuse) Emissions for Current Mix of Inputs	Net Recycling Emissions	Net Composting Emissions	Net Combustion Emissions	Net Landfilling Emissions	Net Anaerobic Digestion Emissions
Tires	(4.30)	(0.38)	NA	0.50	0.02	NA

1.3 RAW MATERIALS ACQUISITION AND MANUFACTURING

Exhibit 1-5 provides the characteristics of tires as modeled in WARM.

Exhibit 1-5: Tire Characteristics (RMA, 2009a; RMA, 2010b; CIWMB, 1992; NIST, 1997)

Tire Weight	22.5 lb
Energy Content	13,889 Btu/lb
Material Composition (by Weight):	
Rubber	74%
Steel Wire	11%
Polyester Fiber	15%

Tire manufacturing starts out with the extraction of petroleum, which is processed into synthetic rubber, polyester fiber, oils and carbon black; the mining and manufacture of steel, which is made into steel cords; and the mining and processing of silica. These materials are transported to the tire manufacturer, who selects several types of rubber, along with special oils, carbon black, silica and other additives for production. The various raw materials are mixed into a homogenized material that is sent for further processing to manufacture the different components of the tire (i.e., sidewalls, treads, etc.), each requiring additional energy inputs. The tire is then assembled by adding the inner liner, the polyester and steel and then molded into the final shape before being cured at a high temperature. According to RMA (RMA 2010a), the tire manufacturing process requires approximately 74 million Btu of energy per short ton of tire produced.

In addition to manufacturing, the raw materials acquisition and manufacturing (RMAM) calculation in WARM also incorporates "retail transportation," which includes the average truck, rail, water and other-modes transportation emissions required to transport plastics from the manufacturing facility to the retail/distribution point, which may be the customer or a variety of other establishments (e.g., warehouse, distribution center, wholesale outlet). The energy and GHG emissions from retail transportation are presented in Exhibit 1-6.

Exhibit 1-6: Retail Transportation Energy Use and GHG Emissions (BTS, 2013; EPA, 1998; NREL, 2015)

Material	Average Miles per Shipment	Transportation Energy per Short Ton of Product (Million Btu)	Transportation Emission Factors ($MTCO_2E$/ Short Ton)
Tires	497	0.54	0.04

1.4 MATERIALS MANAGEMENT METHODOLOGIES

This analysis considers source reduction, recycling, landfilling and combustion pathways for management of tires. It is important to note that tires modeled in WARM are not recycled into new tires; rather, they are recycled into new materials/products (i.e., open loop recycling). Therefore, assessing the impacts of their disposal must take into account the secondary products made from recycled tires. While information on tire recycling and the resulting secondary products is limited, EPA has modeled the pathways that the majority (approximately 93 percent in 2007) of recycled tires follows, and for which consistent life-cycle assessment data are available (RMA, 2009b). The secondary products considered in this analysis are shredded tires (also known as tire-derived aggregate or TDA) for civil engineering applications and for ground rubber.

The data source used to develop these emission factors is a 2004 report by Corti and Lombardi that compares four end-of-life pathways for tires. While these data are based on research from several studies in the 1990s and 2000s in Europe, EPA believes there are similar energy requirements for processing tires in the United States.

The emission factors show that source reduction leads to the largest reduction in GHG emissions for tires, since the manufacturing tires is energy intensive. Recycling tires leads to greater reductions in GHG emissions than combustion and landfilling, since recycling reduces energy-intensive secondary product manufacturing. Combustion with energy recovery results in positive net GHG emissions, driven primarily by the combustion of carbon compounds found in the rubber portion of the tires. Landfilling results in minor GHG emissions due to the use of fossil fuels in transporting tires to the landfill and the use of landfilling equipment.

1.4.1 Source Reduction

Source reduction activities reduce the number of tires manufactured, thereby reducing GHG emissions from tire production. Extending the life of tires by purchasing long-life tires is an example of source reduction. For more background on source reduction, see the Source Reduction chapter.

Exhibit 1-7 outlines the components of the GHG emission factors for source reduction of tires. The GHG benefits of source reduction are from avoided (RMAM) emissions.

Exhibit 1-7: Source Reduction Emission Factors for Tires ($MTCO_2E$/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
Tires	(4.30)	(4.46)	NA	NA	(4.30)	(4.46)

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.
NA = Not applicable.

To calculate the avoided GHG emissions for tires, EPA looks at three components of GHG emissions from RMAM activities: process energy, transportation energy and process non-energy GHG emissions for tires made from 100 percent virgin material, as shown in Exhibit 2-8. In WARM, there is also an option to select source reduction based on the current mix of recycled and virgin material, as shown in Exhibit 1-9. EPA calculates the RMAM emission factors for the current mix of material inputs by weighting the emissions from manufacturing tires from 100 percent virgin material and the emissions from manufacturing tires from 100 percent recycled material by an assumed recycled content. More information on each component making up the final emission factor is provided in Exhibit 1-7. The source reduction emission factor for tires includes only emissions from RMAM, since no forest carbon sequestration is associated with tire manufacture.

Exhibit 1-8: Raw Material Acquisition and Manufacturing Emission Factor for Virgin Production of Tires ($MTCO_2E$/Short Ton)

(a) Material	(b) Process Energy	(c) Transportation Energy[a]	(d) Process Non-Energy	(e) Net Emissions (e = b + c + d)
Tires	4.42	0.04	–	4.46

– = Zero Emissions.
Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.
[a] The transportation energy and emissions in this exhibit do not include retail transportation, which is presented separately in Exhibit 1-6.

Exhibit 1-9: Recycled Content Values in Tire Manufacturing (RMA, 2009a)

Material	Recycled Content Minimum (%)	Recycled Content for "Current Mix" in WARM (%)	Recycled Content Maximum (%)
Tires	0%	5%	5%

Data on energy used to manufacture a new passenger tire from Atech Group (2001), passenger tire weights from RMA (2009a), and data on fuel consumption from the Energy Information Administration's (EIA) *2006 Manufacturing Energy Consumption Survey* (EIA, 2009) were used to estimate avoided process energy. By using EIA (2009) data, EPA assumes that tire manufacturing uses the same mix of fossil fuels as does the entire synthetic rubber manufacturing industry as a whole. Exhibit 1-10 provides the process energy requirement and associated emissions for tires.

Exhibit 1-10: Process Energy GHG Emissions Calculations for Virgin Production of Tires

Material	Process Energy per Ton Made from Virgin Inputs (Million Btu)	Energy Emissions ($MTCO_2E$/Short Ton)
Tires	73.79	4.42

1.4.2 Recycling

WARM models tires as being recycled in an open loop into the following secondary materials: TDA for civil engineering applications and ground rubber (Exhibit 1-11). Eighty-three percent of the tires recovered in 2007 for recycling were used as TDA in civil engineering applications or as ground rubber. Since these pathways account for the majority of recycling processes, the tire recycling emission factor is a weighted average of the life-cycle emissions from ground rubber and TDA end uses. For more information on recycling in general, please see the Recycling chapter.

Exhibit 1-11: Fate of Recycled Tires (RMA, 2009a)

Recycled Tire Material	Virgin Product Equivalent	% Composition of Modeled Market
TDA for Civil Engineering Applications	Sand	42%
Ground Rubber	Synthetic Rubber	58%

Preparing tires for these secondary end uses requires shredding the tires and removing any metal components. Further grinding of tire is accomplished through ambient grinding or cryogenic grinding. Ambient grinding involves using machinery to size the crumb rubber particles. In cryogenic grinding, shredded rubber chips are frozen using liquid nitrogen and ground in a series of milling devices. Freezing causes the rubber to become brittle, which allows it to break down more easily and aids in the creation of smaller-sized particles (Nevada Automotive Test Center, 2004, p. 11; Praxair, 2009). For this analysis, EPA assumes that tires will be converted into ground rubber by ambient grinding because, according to Corti and Lombardi (2004), the ambient grinding process is used to prepare tires for combustion, the most common waste management option used for tires.

The recycled input credits shown in Exhibit 1-12 include all of the GHG emissions associated with collecting, transporting, processing and manufacturing tires into secondary materials, and recovering steel for reuse. As discussed earlier in this section, the upstream GHG emissions from manufacturing the tire are not included; instead, WARM calculates a "recycled input credit" by assuming that the recycled material avoids—or offsets—the GHG emissions associated with producing the same amount of secondary materials from virgin inputs. Consequently, GHG emissions associated with management (i.e., collection, transportation and processing) of tires are included in the recycling credit calculation. Because tires do not contain any wood products, there are no recycling benefits associated with forest carbon sequestration. The GHG benefits from the recycled input credits are discussed further in the next section.

Exhibit 1-12: Recycling Emission Factor for Tires (MTCO2E/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)
Tires	–	–	(0.46)	0.08	–	–	(0.38)

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.
– = Zero emissions.
NA = Not applicable.
[a] Includes emissions from the virgin production of secondary materials.

1.4.2.1 Developing the Emission Factor for Recycling of Tires

EPA calculates the GHG benefits of recycling tires by calculating the difference between the emissions associated with manufacturing a short ton of each of the secondary products from recycled tires and the emissions from manufacturing the same ton from virgin materials, after accounting for losses that occur in the recycling process. These results are then weighted by their percent contribution to tire recycling to obtain a composite emission factor for recycling one short ton of tires. This recycled input credit is composed of GHG emissions from process energy and transportation energy. EPA does not model any non-energy process emissions for the virgin or recycled production of tires.

Civil engineering applications for tires offset the use of soil or sand; therefore, a recycling credit for this end use can be applied using the difference between extracting and processing sand and creating TDA. Ground rubber applications for tires offset the use of virgin rubber; therefore, a recycling credit for this end use can be applied using the difference between creating ground rubber from synthetic rubber and creating ground tire rubber. Additionally, a recovered steel credit is estimated based on the process energy recycling credit for steel cans (see the Metals chapter for details) and the amount of steel recovered through ambient grinding of tires.

To calculate each component of the recycling emission factor, EPA follows six steps:

Step 1. *Calculate emissions from virgin production of secondary products.* Data on sand from the Athena Institute (Venta and Nesbit, 2000) report, "Life Cycle Analysis of Residential Roofing Products," were used to estimate the GHG emissions associated with sand extraction and processing, which is the virgin alternative to TDA. Because sand is generally produced locally, EPA assumes that its haul distance is approximately 20 miles by truck with no back haul. This information on transportation energy is included in the Athena Institute (Venta and Nesbit, 2000) data. There are no process non-energy emissions from extracting and processing sand for civil engineering applications.

EPA uses data from the International Rubber Research and Development Board, as found in Pimentel et al. (2002), along with EIA (2009) fuel consumption percentages for the synthetic rubber industry, to estimate the GHG emissions associated with synthetic rubber production. Pimentel et al. (2002) include process energy and transportation energy for synthetic rubber manufacture; therefore,, no transportation-specific emissions are estimated for synthetic rubber. EPA also assumes that there are no process non-energy emissions from manufacturing synthetic rubber.

The calculations for virgin process and transportation for secondary products are presented in Exhibit 1-13. Note that each product's energy requirements were weighted by their contribution to the recycled tire market modeled in WARM and that the transportation energy and emissions are included in the process energy data.

Exhibit 1-13: Process and Transportation Energy GHG Emissions Calculations for Virgin Production of Tire Secondary Products

Material	Process and Transportation Energy per Short Ton Made from Virgin Inputs (Million Btu)	Energy Emissions ($MTCO_2E$/Short Ton)
Sand	2.13	0.19
Synthetic Rubber	9.91	0.78
Weighted Sum of Virgin Secondary Materials	**6.67**	**0.53**

Note: The transportation energy and emissions in this exhibit do not include retail transportation, which is presented separately in Exhibit 1-6.

Step 2. *Calculate GHG emissions for recycled production of one short ton of the secondary product.* The recycled secondary product emission factor is based on life-cycle inventory data for the ambient grinding. TDA pieces are on average 2–12 inches and EPA uses energy data from Corti and

Lombardi (2004) on grinding tires to aggregate greater than 16mm in size for the TDA process energy. For ground rubber produced from tires, EPA uses LCI data on the mechanical grinding of tires to less than 2mm in diameter from Corti and Lombardi (2004).

According to RMA (2010b) tires are transported by truck in batches of 1,000–1,200 tires to facilities no greater than 200 miles away to be shredded and ground. To develop this portion of the emission factor, EPA assumes an average of 1,100 tires constituting a batch that is then transported 200 miles by a diesel truck to be shredded or ground. Exhibit 1-14 and Exhibit 1-15 present the results for process-related energy emissions for recycled products and transportation energy emissions, respectively. EPA assumes there are no process non-energy emissions associated with manufacturing.

Exhibit 1-14: Process Energy GHG Emissions Calculations for Recycled Production of Tire Secondary Products

Material	Process Energy per Short Ton Made from Recycled Inputs (Million Btu)	Energy Emissions ($MTCO_2E$/Short Ton)
TDA	0.44	0.02
Ground Rubber	2.93	0.14
Weighted Sum of Recycled Secondary Materials	**1.89**	**0.09**

Exhibit 1-15: Transportation Energy GHG Emissions Calculations for Recycled Production of Tire Secondary Products

Material	Transportation Energy per Short Ton Made from Recycled Inputs (Million Btu)	Transportation Emissions ($MTCO_2E$/Short Ton Product)
TDA	0.85	0.06
Ground Rubber	0.85	0.06
Weighted Sum of Recycled Secondary Materials	**0.85**	**0.06**

Note: The transportation energy and emissions in this exhibit do not include retail transportation, which is presented separately in Exhibit 1-6.

Step 3. *Calculate the difference in emissions between virgin and recycled production.* EPA subtracts the recycled product emissions (Step 2) from the virgin product emissions (Step 1) to determine the GHG emissions savings. These results are shown in Exhibit 1-16.

Exhibit 1-16: Differences in Emissions between Recycled and Virgin Tire Manufacture ($MTCO_2E$/Short Ton)

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	Transportation Energy	Process Non-Energy	Process Energy	Transportation Energy	Process Non-Energy	Process Energy	Transportation Energy	Process Non-Energy
Tires	4.42	0.04	–	0.09	0.10	–	(4.33)	0.06	–

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.
– = Zero emissions.

Step 4. *Adjust the emissions differences to account for recycling losses.* The Corti and Lombardi (2004) report assumes nearly 90 percent recovery of rubber and steel during ambient grinding in Europe, while RMA assumes 80 percent recovery in the United States (RMA, 2010b). To adjust the European data reported by Corti and Lombardi to account for differing practices in the United States, EPA scales down the amount of rubber and steel recovered so that the recovery rate for each is 80 percent. The resulting weighted process energy, transportation energy, process non-energy and total emission factors are presented in Exhibit 1-17.

Exhibit 1-17: Tires Recycling Emission Factors Adjusted for Recycling Losses ($MTCO_2E$/Short Ton)

Material	Recycled Input Credit for Recycling One Short Ton of Tires			
	Weighted Process Energy	Weighted Transport Energy	Weighted Process Non-Energy	Total
Tires	(0.36)	0.08	–	(0.27)

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.
– = Zero emissions.

Step 5. *Factor in the GHG emission credit from steel recovery.* EPA assumes that 80 percent of the total steel available in tires is recovered at the end of life and is recycled into steel sheet. As a result, an additional recycling input credit from steel recovery is added to the tires recycling process energy emission factor. The recycling input credit for process energy from recycling steel, found in the Metals chapter, is weighted by the relative amount of steel recovered from recycling tires. Exhibit 1-18 shows how the steel recovery credit is calculated and Exhibit 1-19 provides the final calculated recycling emission factor for tires by adding that credit to the tires process energy credit.

Exhibit 1-18: Steel Recovery Emission Factor Calculation ($MTCO_2E$/Short Ton)

Material	Amount of Steel Recovered (MT/Short Ton Product)	Avoided CO_2 Emissions per Ton of Steel Recovered ($MTCO_2E$/Short Ton)	Steel Recovery Emissions ($MTCO_2E$/Short Ton Product)
Tires	0.06	1.80	0.10

Exhibit 1-19: Final Tires Recycling Emission Factors ($MTCO_2E$/Short Ton)

Material	Recycled Input Credit for Recycling One Short Ton of Tires			
	Process Energy	Transport Energy	Process Non-Energy	Total
Tires	(0.46)	0.08	–	(0.38)

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.
– = Zero emissions.

1.4.3 Composting

Because tires are not subject to aerobic bacterial degradation, they cannot be composted. As a result, WARM does not consider GHG emissions or storage associated with composting.

1.4.4 Combustion

Tires used as fuel made up about 60 percent of the entire scrap tire market in 2007 (RMA, 2009b). About 84 percent of those tires went to pulp and paper mills, cement kilns and utility boilers. WARM models the combustion of tires based on these three facility types. Exhibit 1-20 provides the assumed percent of tires used as fuel that go to each type of facility.

Exhibit 1-20: Percent of Tires Used as Fuel at the Three Modeled Facility Types (RMA, 2009b)

Facility	Share Used as Fuel
Pulp and Paper Mills	51%
Cement Kilns	32%
Utility Boilers	17%

GHG emissions from combusting tires result from the combustion process as well as from indirect emissions from transporting tires to the combustor. Combustion also produces energy that can be recovered to offset electricity and GHG emissions that would have otherwise been produced from non-baseload power plants feeding into the national electricity grid. Finally, many of the facilities where tires are used as fuel recycle steel that is left after combustion, resulting in offsets for the production of steel from other virgin and recycled inputs. Exhibit 1-21 shows the components of the emission factor for combustion of tires. Because WARM's analysis begins with materials at end of life, emissions from RMAM are zero.

For further information on combustion, see the Combustion chapter. Further discussion on the development of each piece of the emission factor is discussed below.

Exhibit 1-21: Components of the Combustion Net Emission Factor for Tires ($MTCO_2E$/Short Ton)

Material	Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Transportation to Combustion	CO_2 from Combustion	N_2O from Combustion	Utility Emissions	Steel Recovery	Net Emissions (Post-Consumer)
Tires	–	0.01	2.20	–	(1.57)	(0.13)	0.50

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice.
– = Zero emissions.

1.4.4.1 *Developing the Emission Factor for Combustion of Tires*

EPA calculates CO_2 emissions from combusting tires based on the energy content of tires from CIWMB (1992) and the estimated tire carbon coefficient from Atech Group (2001).

Exhibit 1-22: Tires CO_2 Combustion Emission Factor Calculation

Material	Energy Content (Million Btu/Short Ton Product)	$MTCO_2E$ from Combustion per Million Btu	Combustion CO_2 Emissions ($MTCO_2E$/Short Ton Product)
Tires	27.78	0.08	2.20

EPA estimates CO_2 emissions from transporting tires to pulp and paper mills, cement kilns and utility boilers assuming that the distance the tires need to travel is similar to the distance involved in transporting MSW to waste-to-energy facilities. To calculate the emissions, WARM relies on assumptions from FAL (1994) for the equipment emissions and NREL's US Life Cycle Inventory Database (USLCI) (NREL, 2015). The NREL emission factor assumes a diesel, short-haul truck.

Most power plants use fossil fuels to produce electricity, and the electricity produced at the various facilities where tires are used as fuel reduces the demand for conventional, fossil-derived electricity. As a result, the combustion emission factor for tires includes avoided GHG emissions from facilities that would otherwise be using conventional electricity. EPA calculates the avoided facility CO_2 emissions from electricity production based on (1) the energy content of tires and (2) the carbon-intensity of default (offset) fuel mix at each facility. These avoided GHG emissions are weighted based on the percent of tires used for combustion across three types of facilities (Exhibit 1-20). Exhibit 1-23 shows the electricity offset from combustion of tires.

Exhibit 1-23: Utility GHG Emissions Offset from Combustion of Tires

(a) Material	(b) Energy Content (Million Btu per Short Ton)	(c) Combustion System Efficiency (%)	(d) Emission Factor for Utility-Generated Electricity ($MTCO_2E$/ Million Btu of Electricity Delivered)	(e) Avoided Utility GHG per Short Ton Combusted ($MTCO_2E$/Short Ton) ($e = b \times c \times d$)
Tires	27.8	NA	NA	1.57

NA = Not applicable.

The combustion of tires at pulp and paper mills and utility boilers also includes steel recovery and recycling processes. Recovered steel from cement kilns is used to replace iron used in the cement-making process; therefore, there is no steel recovery credit for tire use at cement kilns. The recycling credit is weighted for two of the three facilities modeled. Because some steel in tires is lost during combustion, the percent of tires that is steel (Exhibit 1-5) is multiplied by a ferrous recovery factor of 98 percent.

Exhibit 1-24: Steel Production GHG Emissions Offset from Steel Recovered from Combustion of Tires

Material	Short Tons of Steel Recovered per Short Ton of Waste Combusted	Avoided CO_2 Emissions per Ton of Steel Recovered ($MTCO_2E$/Short Ton)	Avoided CO_2 Emissions per Ton of Waste Combusted ($MTCO_2E$/Short Ton)
Tires	0.06	1.80	0.10

1.4.5 Landfilling

In WARM, landfill emissions comprise landfill CH_4 and CO_2 from transportation and the use of landfill equipment. WARM also accounts for landfill carbon storage, and avoided utility emissions from landfill gas-to-energy recovery. However, since tires do not contain biogenic carbon and do not decompose in landfills, there are zero emissions from landfill CH_4, zero landfill carbon storage, and zero avoided utility emissions associated with landfilling tires, as shown in Exhibit 1-25. Greenhouse gas emissions associated with RMAM are not included in WARM's landfilling emission factors. As a result, the emission factor for landfilling tires represents only the emissions associated with collecting the waste and operating the landfill equipment.

Exhibit 1-25: Landfilling Emission Factor for Tires ($MTCO_2E$/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)
Tires	–	0.02	–	–	–	0.02

– = Zero emissions.
NA = Not applicable.

For more information, refer to the Landfilling chapter.

1.4.6 Anaerobic Digestion

Because of the nature of tire components, tires cannot be anaerobically digested, and thus, WARM does not include an emission factor for the anaerobic digestion of tires.

1.5 LIMITATIONS

There are several limitations to this analysis, which is based on several assumptions from expert judgment. The limitations associated with the source reduction and recycling emission factors include:

- Tire percent composition by material may not be accurate. EPA uses two data sources for estimating the percent fiber and percent steel content of tires. Upon expert review, RMA (2010b) notes that today there is less fiber in tires than estimated by NIST (1997). The percent steel content is believed to be accurate, but because of the possibly high fiber content, the percent rubber by weight may be underestimated. Simultaneously, RMA (2010b) reports that tires produced recently may contain non-negligible amounts of silica, whereas the data used here assume that any silica content is negligible. If this is the case, the amount of rubber may be overestimated, so it is also possible that the changing trends in fiber and silica content effectively cancel each other out.
- This analysis assumes that the fuel mix used to manufacture tires is the same as the one used to manufacture synthetic rubber. If tire manufacturers use a different fuel mix, the resulting

difference in carbon-intensity would influence the carbon emissions produced by manufacturing tires from virgin materials.

- Upon expert review, RMA (2010b) reported that the amount of energy required to produce a tire is outdated and that the tire manufacturing process has changed considerably since 2001, the year of the data that WARM relies on for the process energy requirements. The difference in the energy requirements for tire manufacture today would change the associated process energy emissions for source reduction; however, EPA has been unable to find more recent, publicly available data to update the analysis.
- By using European process data from Corti and Lombardi (2004), EPA assumes that tire recycling processes in the United States and Europe are similar. This may or may not be the case.
- The assumption that, when scaling down the amount of steel and rubber recovered during the recycling process from the 90 percent from Corti and Lombardi (2004) based on European data to an industry estimate of 80 percent recovery of tires (RMA, 2010b), the 80 percent recovery is applicable to both steel and rubber. The average recovery between the two materials was assumed to be 80 percent. Any difference in the amount of rubber or steel recoverable during recycling would change the recycling input credits for process energy and steel recovery, respectively.

1.6 REFERENCES

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