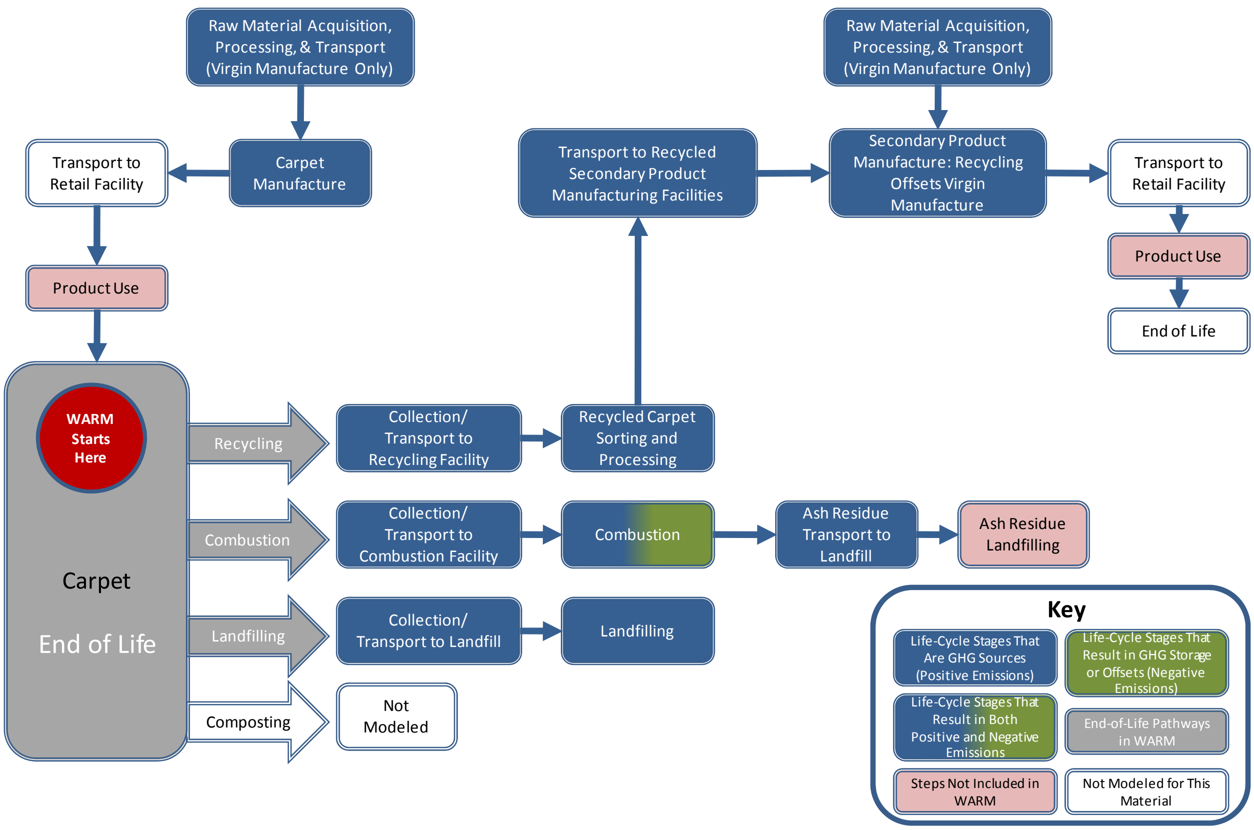
CARPET

1 INTRODUCTION TO WARM AND CARPET

This chapter describes the methodology used in EPA's Waste Reduction Model (WARM) to estimate streamlined life-cycle greenhouse gas (GHG) emission factors for carpet beginning at the point of waste generation. The WARM GHG emission factors are used to compare the net emissions associated with carpet in the following four materials management alternatives: source reduction, recycling, landfilling and combustion. 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: Life Cycle of Carpet in WARM

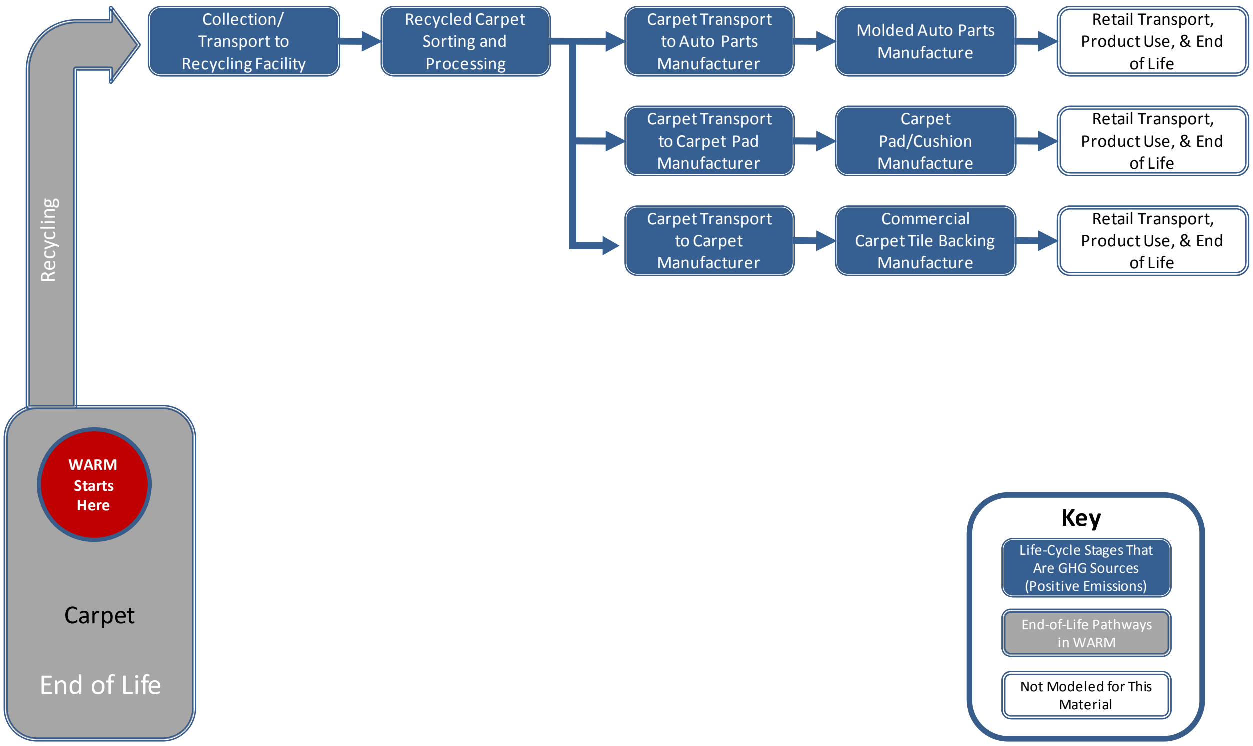


Roughly 79 percent of carpet is landfilled after entering the municipal solid waste stream, which means that landfilling is the most commonly selected waste management option for carpet. According to EPA (2009), 8.1 percent of carpet is recycled annually. Efforts by industry, EPA, and other organizations over the past few years have increased the fraction of waste carpet that is recycled.

Due to the great variability in the composition and uses of carpet, we limited our life-cycle study of GHG emissions from managing carpet waste to nylon broadloom residential carpet only. Other fibers used for carpet face fiber, such as wool or polyester, were not considered due to lack of data. Because the composition of commercial carpet is different than that of residential carpet, these emission factors only apply to broadloom residential carpet. The components of nylon broadloom residential carpet in this analysis include: face fiber, primary and secondary backing and latex used for attaching the backings.

Upon disposal, carpet can be recovered for recycling, sent to a landfill or combusted. Exhibit 1 shows the general outline of materials management pathways in WARM. Recycling carpet is an open-loop process, meaning that components are recycled into secondary materials such as carpet pad, molded products and carpet backing. Carpet is collected curbside and at special events, or individuals can bring it to designated drop-off sites. Once carpet has been collected for recycling, it is sent to material recovery facilities that specialize in separating and recovering materials from carpet. Building on Exhibit 1, a more detailed flow diagram of the recycling pathway for carpet is provided in Exhibit 2.

Exhibit 2: Detailed Recycling Flows for Carpet in WARM



2 LIFE-CYCLE ASSESSMENT AND EMISSION FACTOR RESULTS

The life-cycle boundaries in WARM start at the point of waste generation, or the moment a material is discarded, and only consider upstream emissions when the production of materials is affected by end-of-life materials management decisions. 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.

WARM includes source reduction, recycling, landfilling and combustion pathways for materials management of carpet. As Exhibit 3 illustrates, most of the GHG emissions from end-of-life management of carpet occur from waste management of this product, while most of the GHG savings occur from offsetting upstream raw materials acquisition and the manufacturing of other secondary materials that are recovered from carpet.

Exhibit 3: Carpet GHG Sources and Sinks from Relevant Materials Management Pathways

Materials Management Strategies for Carpet	GHG Sources and Sinks Relevant to Carpet		
	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 • Virgin process non-energy • Transport of carpet to point of sale	NA	NA
Recycling	**Emissions** • Transport of recycled materials • Recycled process energy • Recycled process non-energy **Offsets** • Emissions from producing carpet pad, molded auto parts and commercial carpet tile backing from virgin material based on a weighted average of the various end uses	NA	**Emissions** • Collection of carpet and transportation to recycling center • Demanufacturing carpet
Landfilling	NA	NA	**Emissions** • Transport to landfill • Landfilling machinery
Combustion	NA	NA	**Emissions** • Transport to WTE facility • Combustion-related CO_2 **Offsets** • Avoided electric utility emissions

NA = Not applicable.

WARM analyzes all of the GHG sources and sinks outlined in Exhibit 3 and calculates net GHG emissions per short ton of carpet inputs. For more detailed methodology on emission factors, please see the sections below on individual materials management strategies.

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

Material/Product	Net Source Reduction (Reuse) GHG Emissions For Current Mix of Inputs[a]	Net Recycling Emissions	Net Composting Emissions	Net Landfilling Emissions	Net Combustion Emissions
Carpet	-4.02	-7.22	NA	0.66	0.04

[a] The current mix of inputs for carpet is considered to be 100% virgin material.

3 RAW MATERIALS ACQUISITION AND MANUFACTURING

The components of nylon broadloom residential carpet in this analysis include: face fiber, primary and secondary backing and latex used for attaching the backings. The face fiber used for nylon carpet is typically made of either Nylon 6 or Nylon 6,6 (face fiber rarely includes a mix of Nylon 6 and Nylon 6,6). However, for the purpose of developing an emission factor that represents “typical” nylon broadloom residential carpet, WARM reflects the market share of each material in the nylon carpet industry (45 percent Nylon 6 and 55 percent Nylon 6,6) (FAL, 2002). Carpet backing for broadloom carpet typically consists of polypropylene. For latex used to adhere carpet backings, EPA modeled styrene butadiene, the most common latex used for this purpose. Styrene butadiene latex is commonly compounded with a filler such as calcium carbonate (limestone). Inputs to the manufacture of nylon, polypropylene and styrene butadiene are crude oil and/or natural gas. Exhibit 5 provides the assumed material composition of the typical carpet used for this analysis (FAL, 2002).

Exhibit 5: Material Composition of One Short Ton of Carpet

Material/Product	Application	% of Total Weight	Weight (lbs.) (Assuming 2,000 lbs. of Carpet)
Nylon 6 resin	Face fiber	20.2%	410
Nylon 6,6 resin	Face fiber	24.7%	500
Polypropylene	Woven for backing	15.0%	304
Styrene butadiene latex	Carpet backing adhesive	8.1%	164
Limestone	Filler in latex adhesive	32.0%	648
Total		**100.0%**	**2,026 lbs.**[a]

[a] Note that these values total 2,026 pounds, which is greater than one short ton. This is because 26 pounds of the raw materials used to manufacture carpet are assumed to be "lost" during the manufacturing process. In other words, producing one short ton of carpet actually requires slightly more than one short ton of raw materials (FAL, 2002).

The process used to turn the components in Exhibit 5 into a finished carpet may include weaving, tufting, needlepunching and/or knitting. According to the Carpet and Rug Institute, 95 percent of carpet produced in the United States is tufted (CRI, 2010). During tufting, face pile yarns are rapidly sewn into a primary backing by a wide multineedled machine. After the face pile yarns are sewn into the primary backing, a layer of latex is used to secure a secondary backing, which adds strength and dimensional stability to the carpet.

4 MATERIALS MANAGEMENT METHODOLOGIES

This analysis considers source reduction, recycling, landfilling and combustion of carpet. It is important to note that carpet is not recycled into new carpet; instead, it is recycled in an open loop process. The life cycle assessment of carpet disposal must take into account the variety of second-generation products made from recycled carpet. Information on carpet recycling and the resulting second-generation products is sparse; however, EPA has modeled pathways for which consistent data are available for recycled carpet components. The second-generation products considered in this analysis are carpet pad, molded automobile products and carpet backing.

The data source used to develop these emissions factors is a 2002 report published by Franklin Associates Limited (FAL) on energy and GHG emission factors for the manufacture and end-of-life management of carpet (FAL, 2002). These data were based on a number of industry and academic data sources dating from the 1990's and 2000's.

Recycling leads to the largest reduction in GHG emissions for carpet,[1] while source reducing carpet leads to greater reductions than combustion and landfilling since it reduces energy-intensive product manufacturing. Combustion has a positive net emission factor that is driven by the CO_2 emissions associated with combusting carpet, while landfilling has a slightly positive emission factor due to the emissions from landfill operation equipment.

[1] While for most materials and products in WARM, greater GHG benefits are realized from source reduction than recycling, this is not the case for carpet as currently modeled. Recycling is more beneficial for carpet because the secondary products that carpet is recycled into are more GHG-intensive to manufacture than the carpet itself.

4.1 SOURCE REDUCTION

Source reduction activities reduce the amount of carpet that is produced, thereby reducing GHG emissions from carpet production. Source reduction of carpet can be achieved through using less carpeting material per square foot (i.e., thinner carpet) or by finding a way to make existing carpet last longer through cleaning or repair. For more information on this practice, see the Source Reduction chapter.

Exhibit 6 outlines the GHG emission factor for source reducing carpet. GHG benefits of source reduction are calculated as the avoided emissions from raw materials acquisition and manufacturing (RMAM) of new carpet.

Exhibit 6: Source Reduction Emission Factor for Carpet ($MTCO_2E$/Short Ton)

Material/ Product	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
Carpet	-4.02	-4.02	NA	NA	-4.02	-4.02

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

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

4.1.1 Developing the Emission Factor for Source Reduction of Carpet

To calculate the avoided GHG emissions for carpet, EPA looks at three components of GHG emissions from RMAM activities: process energy, transportation energy and process non-energy GHG emissions. Exhibit 7 shows the results for each component and the total GHG emission factor for source reduction. More information on each component making up the final emission factor is provided in the remainder of this section.

Exhibit 7: Raw Material Acquisition and Manufacturing Emission Factor for Virgin Production of Carpet ($MTCO_2E$/Short Ton)

(a) Material/Product	(b) Process Energy	(c) Transportation Energy	(d) Process Non-Energy	(e) Net Emissions (e = b + c + d)
Carpet	-3.41	-0.10	-0.51	-4.02

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

FAL (2002) reports the amount of energy required to produce one short ton of carpet as 60.32 million Btu. FAL (2002) also provided the fuel mix that makes up this energy estimate. To estimate GHG emissions, EPA multiplied the fuel consumption (in Btu) by the fuel-specific carbon contents. Summing the resulting GHG emissions, by fuel type, gives the total process energy GHG emissions, including both CO_2 and CH_4, from all fuel types used in carpet manufacture (Exhibit 8).

Exhibit 8: Process Energy GHG Emissions Calculations for Virgin Production of Carpet

Material/Product	Process Energy per Short Ton Made from Virgin Inputs (Million Btu)	Process Energy GHG Emissions ($MTCO_2E$/Short Ton)
Carpet	60.32	3.41

Transportation energy emissions come from fossil fuels used to transport carpet raw materials and intermediate products. The methodology for estimating these emissions is the same as the one for process energy emissions. Based upon estimated total carpet transportation energy in Btu, EPA calculates the total emissions using fuel-specific carbon coefficients (Exhibit 9).

Exhibit 9: Transportation Energy Emissions Calculations for Virgin Production of Carpet

Material/Product	Transportation Energy per Short Ton Made from Virgin Inputs (Million Btu)	Transportation Energy GHG Emissions ($MTCO_2E$/Short Ton)
Carpet	1.36	0.10

Note: The transportation energy and emissions in this exhibit do not include retail transportation.

Process non-energy GHG emissions occur during manufacture but are not related to combusting fuel for energy. For carpet, non-energy GHGs are emitted in the use of solvents or chemical treatments. FAL provided data on GHG emissions from non-energy-related processes in units of pounds of native gas (2002). We convert pounds of gas per 1,000 lbs of carpet to metric tons of gas per short ton of carpet and then multiply that by the ratio of carbon to gas to produce the emission factor in $MTCO_2E$ per short ton of carpet, as detailed in the example below, showing the calculation of CH_4 process emissions for carpet. Exhibit 10 shows the components for estimating process non-energy GHG emissions for carpet.

$$2.72 \text{ lbs } CH_4/1{,}000 \text{ lbs carpet} \times 2{,}000 \text{ lbs carpet}/1 \text{ short ton carpet} \times 1 \text{ metric ton } CH_4/2{,}205 \text{ lbs } CH_4 \times 21 \text{ MTCO2E/metric ton } CH_4 = 0.05 \text{ } MTCO_2E\text{/short ton carpet}$$

Exhibit 10: Process Non-Energy Emissions Calculations for Virgin Production of Carpet

Material/Product	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)
Carpet	0.01	0.00	–	–	0.00	0.51

– = Zero emissions.

4.2 RECYCLING

This section describes the development of the recycling emission factor, which is shown in the final column of Exhibit 11. For more information on recycling in general, please see the Recycling chapter.

Exhibit 11: Recycling Emission Factor for Carpet ($MTCO_2E$/Short Ton)

Material/ Product	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 Sequest-ration	Net Emissions (Post-Consumer)
Carpet	–	–	-5.42	-0.06	-1.74	-	-7.22

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

WARM models carpet as being recycled in an open loop into the following secondary materials: carpet pad, molded products and carpet backing (Exhibit 12). Carpet pad is used as a cushion layer between the carpet and the floor that provides thermal and acoustical insulation, and resilience. Molded products for automobiles are used in a wide range of applications, from air intake assemblies to headrests. The carpet backing produced from recycled carpet is generally used to secure the yarn and provide dimensional stability to commercial carpeting.

The recycled input credits shown in Exhibit 11 include all of the GHG emissions associated with collecting, transporting, processing and recycling or remanufacturing carpet into secondary materials. None of the upstream GHG emissions from manufacturing the carpet in the first place are 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 end-of-life carpet are included in the recycling credit calculation. Since carpet does 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 below.

Exhibit 12: Fate of Recycled Carpet

Secondary Product from Recycled Carpet	% Composition of Original Carpet, by Weight
Carpet Pad/Cushion	67%
Molded Products (Auto Parts)	25%
Backing for Commercial Carpet Tiles	8%

Source: FAL (2002).

4.2.1 Developing the Emission Factor for Recycling of Carpet

EPA calculates the GHG benefits of recycling carpet by comparing the difference between the emissions associated with manufacturing a short ton of each of the secondary products from recycled carpet 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 the distribution shown in Exhibit 12 to obtain a composite emission factor for recycling one short ton of carpet. This recycled input credit is composed of GHG emissions from process energy, transportation energy and process non-energy.

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

Step 1. *Calculate emissions from virgin production of one short ton of secondary product.*

We apply fuel-specific carbon coefficients to the data for virgin RMAM of each secondary product (FAL, 2002). This estimate is then summed with the emissions from transportation and process non-energy emissions to calculate the total emissions from virgin production of each secondary product. The calculations for virgin process, transportation and process non-energy emissions for the secondary products are presented in Exhibit 13, Exhibit 14 and Exhibit 15, respectively.

Exhibit 13: Process Energy GHG Emissions Calculations for Virgin Production of Carpet Secondary Products

Material/Product	Process Energy per Short Ton Made from Virgin Inputs (Million Btu)	Energy Emissions ($MTCO_2E$/Short Ton Carpet)
Carpet Pad/Cushion	107.46	6.11
Molded Products (Auto Parts)	113.75	6.47
Backing for Commercial Carpet Tiles	46.54	2.64

Exhibit 14: Transportation Energy Emissions Calculations for Virgin Production of Carpet Secondary Products

Material/Product	Transportation Energy per Short Ton Made from Virgin Inputs (Million Btu)	Transportation Emissions ($MTCO_2E$/Short Ton Carpet)
Carpet Pad/Cushion	2.15	0.15
Molded Products (Auto Parts)	1.51	0.11
Backing for Commercial Carpet Tiles	1.36	0.09

Exhibit 15: Process Non-Energy Emissions Calculations for Virgin Production of Carpet Secondary Products

Material/Product	CO_2 Emissions (MT/Short Ton Carpet)	CH_4 Emissions (MT/Short Ton Carpet)	CF_4 Emissions (MT/Short Ton Carpet)	C_2F_6 Emissions (MT/Short Ton Carpet)	N_2O Emissions (MT/Short Ton Carpet)	Non-Energy Carbon Emissions ($MTCO_2E$/Short Ton)
Carpet Pad/Cushion	0.02	0.00	–	–	0.01	1.89
Molded Products (Auto Parts)	0.02	0.00	–	–	0.01	1.89
Backing for Commercial Carpet Tiles	–	0.01	–	–	–	0.11

– = Zero emissions.

Step 2. *Calculate emissions from recycled production of one short ton of the secondary product.*

EPA then applies the same carbon coefficients to the energy data for the production of the secondary products from recycled carpet. FAL (2002) indicated that no non-energy process emissions occur in recycled production of secondary products from carpet. Exhibit 16 and Exhibit 17 present the emission calculation components for recycled secondary product process energy emissions and transportation energy emissions, respectively.

Exhibit 16: Process Energy GHG Emissions Calculations for Recycled Production of Carpet Secondary Products

Material/Product	Process Energy per Short Ton Made from Recycled Inputs (Million Btu)	Energy Emissions ($MTCO_2E$/Short Ton)
Carpet Pad/Cushion	2.14	0.13
Molded Products (Auto Parts)	20.24	1.18
Backing for Commercial Carpet Tiles	23.27	1.36

Exhibit 17: Transportation Energy GHG Emissions Calculations for Recycled Production of Carpet Secondary Products

Material/Product	Transportation Energy per Short Ton Made from Recycled Inputs (Million Btu)	Transportation Emissions ($MTCO_2E$/Short Ton)
Carpet Pad/Cushion	1.05	0.07
Molded Products (Auto Parts)	1.05	0.08
Backing for Commercial Carpet Tiles	1.05	0.08

Note: The transportation energy and emissions in this exhibit do not include retail transportation.

Step 3. *Calculate the difference in emissions between virgin and recycled production.*

To calculate the GHG reductions associated with replacing virgin production with recycled production of secondary products, we then subtract the emissions from recycled production (Step 2) from the emissions from virgin production (Step 1). These results are shown in Exhibit 19.

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

	Product Manufacture Using 100% Virgin Inputs ($MTCO_2E$/Short Ton)			Product Manufacture Using 100% Recycled Inputs ($MTCO_2E$/Short Ton)			Difference Between Virgin and Recycled Manufacture ($MTCO_2E$/Short Ton)		
Material/Product	**Process Energy**	**Transpor-tation Energy**	**Process Non-Energy**	**Process Energy**	**Transpor-tation Energy**	**Process Non-Energy**	**Process Energy**	**Transpor -tation Energy**	**Process Non-Energy**
Carpet Pad/Cushion	6.11	0.15	1.89	0.13	0.07	–	-5.99	-0.08	-1.89
Molded Products (Auto Parts)	6.47	0.11	1.89	1.18	0.08	–	-5.26	-0.03	-1.88
Backing for Commercial Carpet Tiles	2.64	0.09	0.11	1.36	0.08	–	-1.28	-0.02	-0.11

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.*

For almost every material that gets recycled, some portion of the recovered material is unsuitable for use as a recycled input. This portion is discarded either in the recovery stage or in the manufacturing stage. Consequently, less than one ton of new material is typically made from one ton of recovered materials. Material losses are quantified and translated into loss rates. In the case of carpet, no data were available on recovery-stage losses, so EPA assumed no losses during this stage. For the recycling stage, data indicated a loss rate for molded products of 0.5 percent. Zero loss rates were reported for the other two secondary products (carpet pad and backing for commercial carpet tiles). Since losses occur in both the recovery and manufacturing stages, the net retention rate was calculated as the product of the recovery and manufacturing retention rates, as shown in Exhibit 20. The differences in emissions from process energy, transportation energy and non-energy processing are then adjusted to account for the loss rates by multiplying the final three columns of Exhibit 19 by the retention rates in column (d) of Exhibit 20.

Exhibit 19: Calculation of Adjusted GHG Savings for Carpet Recycled into Secondary Products

(a) Material/Product	(b) Recovered Materials Retained per Short Ton Carpet Collected	(c) Short Tons Product Produced per Short Ton Recycled Inputs (%)	(d) Short Tons Product Made per Short Ton Carpet Collected (d = b × c)
Carpet Pad/Cushion	100%	100%	100%
Molded Products (Auto Parts)	100%	99.5%	99.5%
Backing for Commercial Carpet Tiles	100%	100%	100%

Source: FAL (2002).

Step 5. *Weight the results by the percentage of recycled carpet that the secondary product makes up.*

Using the percentages provided in Exhibit 12, EPA weights the individual GHG differences from Step 4 for each of the secondary products. In the case of molded products, the emission factor estimates from Step 3, as modified by the loss rates in Step 4, were weighted by the percentage of recycled carpet converted to molded products (25 percent), as shown below:

Process Energy: -5.26 $MTCO_2E$/short ton x 25 % = -1.32 $MTCO_2E$ /short ton
Transportation Energy: -0.03 $MTCO_2E$ /short ton x 25 % = -0.01 $MTCO_2E$ /short ton

Process Non-energy: -1.88 $MTCO_2E$ /short ton x 25 % = -0.47 $MTCO_2E$ /short ton

Each product's process energy, transportation energy and process non-energy emissions are weighted by the percentages in Exhibit 12 and then they are summed as shown in the final column of Exhibit 21.

Exhibit 20: Carpet Recycling Emission Factors ($MTCO_2E$/Short Ton)

	Recycled Input Credit for Recycling One Short Ton of Carpet			
Material/Product	**Weighted Process Energy ($MTCO_2E$/Short Ton Product)**	**Weighted Transport Energy ($MTCO_2E$/Short Ton Product)**	**Weighted Process Non-Energy ($MTCO_2E$/Short Ton Product)**	**Total ($MTCO_2E$/Short Ton Product)**
Carpet Pad/Cushion	-3.99	-0.05	-1.26	-3.99
Molded Products (Auto Parts)	-1.32	-0.01	-0.47	-1.32
Backing for Commercial Carpet Tiles	-0.11	-0.00	-0.01	-0.11
Carpet Total	**NA**	**NA**	**NA**	**-1.74**

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

4.3 COMPOSTING

Carpet is not subject to aerobic bacterial degradation and therefore cannot be composted. As a result, WARM does not consider GHG emissions or storage associated with composting.

4.4 COMBUSTION

Combustion results in both direct and indirect emissions: direct emissions from the combustion process itself and indirect emissions associated with transportation to the combustor. To the extent that carpet combusted at waste-to-energy (WTE) facilities produces electricity, combustion offsets GHG emissions that would have otherwise been produced from non-baseload power plants feeding into the national electricity grid. These components make up the combustion factor calculated for carpet. The tables presented here are based on the national average grid mix, rather than on any of the regional grid mixes also available in the Excel version of WARM.

For further information on combustion, see the Combustion chapter. Because WARM's analysis begins with materials at end-of-life, emissions from RMAM are zero. Exhibit 22 shows the components of the emission factor for combustion of carpet. Further discussion on the development of each piece of the emission factor is discussed below.

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

Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Transportation to Combustion	CO_2 from Combustion	N_2O from Combustion	Avoided Utility Emissions	Steel Recovery	Net Emissions (Post-Consumer)
–	0.03	1.72	–	-1.09	–	0.66

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

4.4.1 Developing the Emission Factor for Combustion of Carpet

EPA estimates that carpet has a carbon content of 53 percent and that 98 percent of that carbon is converted to CO_2 during combustion. This carbon is contained within the plastics and the limestone in carpet. The resulting direct CO_2 emissions from combustion of carbon in carpet are presented in Exhibit 23.

Exhibit 22: Carpet Combustion Emission Factor Calculation

Components	% of Total Weight	Carbon Content	Carbon Content % of Total Weight	Carbon Converted to CO_2 during Combustion	Total $MTCO_2E$/Short Ton
Styrene-butadiene (latex)	8%	90%	7%	98%	0.22
Limestone	32%	12%	4%	98%	0.11
Polypropylene	15%	86%	13%	98%	0.40
Nylon	45%	64%	29%	98%	0.95
Carpet (Sum)	**NA**	**NA**	**53%**	**98%**	**1.72**

Sources: Styrene-butadiene carbon content calculated from chemical formula; limestone carbon content (Kantamaneni, 2002); polypropylene and nylon carbon contents (EPA, 2001, Ch. 7).
Totals may not sum due to independent rounding.
NA = Not applicable.

EPA estimates CO_2 emissions from transporting carpet to the WTE plant and transporting ash from the WTE plant to the landfill using data provided by FAL (2002). Transportation-related CO_2 emissions were estimated to be 0.03 $MTCO_2E$ per short ton of carpet combusted.

Most utility power plants use fossil fuels to produce electricity, and the electricity produced at a WTE plant reduces the demand for fossil-derived electricity. As a result, the combustion emission factor for carpet includes avoided GHG emissions from utilities. We calculate the avoided utility CO_2 emissions based on the energy content of carpet, the combustion efficiency of the WTE plant including transmission and distribution losses, and the national average carbon-intensity of electricity produced by non-baseload power plants. Exhibit 24 shows the estimated utility offset from combustion of carpet.

Exhibit 23: Utility GHG Emissions Offset from Combustion of Carpet

(a) Material/Product	(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 × c × d)
Carpet	26.8	17.8%	0.23	1.09

4.5 LANDFILLING

Typically, the emission factor for landfilling is composed of four parts: landfill CH_4; CO_2 emissions from transportation and landfill equipment; landfill carbon storage; and avoided electric utility emissions. However, as with other non-biodegradable materials in WARM, there are zero landfill methane emissions, landfill carbon storage or avoided utility emissions associated with landfilling carpet, as shown in Exhibit 25. Greenhouse gas emissions associated with RMAM are not included in WARM's landfilling emission factors. As a result, the emission factor for landfilling carpet represents only the transportation emissions associated with collecting the waste and operating the landfill equipment. For more information on landfilling, refer to the Landfilling chapter.

Exhibit 24: Landfilling Emission Factor for Carpet ($MTCO_2E$/Short Ton)

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)
–	0.04	–	–	–	0.04

NA Not applicable.
– = Zero emissions.

5 LIMITATIONS

As outlined in the Recycling section (4.2), the open-loop recycling process is a complicated end-of-life process for carpet. There are some limitations associated with modeling the GHG emissions from open-loop carpet recycling, including limited availability of representative life-cycle inventory (LCI) data for carpet and the materials recovered from them.

Given the complex open loop recycling process and a lack of consistent and up-to-date information on carpet recycling, the recycling factor for carpet is subject to important limitations. A primary data gap is the availability of representative LCI data for carpet in the closed-loop recycling process, and the materials recovered from them in the open-loop recycling process. For this analysis, we utilize an LCI from 2001 for carpet (FAL, 2002) and assume that these data are representative of the current processes used to collect and recover materials from carpet in the United States. This source was selected because it offered consistent and sufficient LCI data to produce an emission factor, but improved LCI data in at least three areas could have important effects on our results.

First, the recycling pathway for carpet does not currently include all end products of open-loop recycling. Since the WARM carpet emission factor was initially developed, manufacturers have increased their capacity to recycle nylon 6 and nylon 6,6 carpet into different end products including new carpet, plastic pellets, molded plastics and carpet padding. According to the CARE Annual Report for 2009, 47 percent of carpet recovered for recycling is used to manufacture new carpet. EPA is investigating the availability of data necessary to develop a more representative open-loop recycling emission factor for carpet.

Second, the share of carpet recycled by each open-loop pathway, as shown in Exhibit 12, has changed since the WARM carpet emission factor was initially developed. In addition to being recycled into new carpet, end-of-life carpet is also recycled into plastic pellets, which are later used to manufacture auto parts and other molded products. In 2009, 47 percent of carpet recovered for recycling was used to manufacture new carpet, 35 percent was used to manufacture plastic pellets, 13 percent was used to manufacture carpet padding, and 5 percent was used to manufacture molded or extruded plastics (CARE, 2009).

Finally, the open-loop recycling pathways for each carpet type vary significantly (Realff, 2010a). WARM currently assumes that the same average mix of carpet types is recycled by each of the three open-loop recycling pathways, since at the time the emission factors were created, no further information was available. However, more recent data show that some carpet types are rarely or never recycled into some open-loop products. For example, nylon 6 carpet is exclusively recycled into new nylon 6 carpet, PET carpet is exclusively recycled into new carpet padding, and nylon 6,6 carpet is only recycled into new nylon 6,6 carpet and plastic pellets (CARE, 2009).

In the combustion pathway, the current analysis in WARM assumes that carpet has a relatively high BTU content (million BTU/short ton). However, recent literature suggests that a lower BTU content of 17.6 million BTU/short ton is more representative of carpet (Realff, 2010b). Thus, GHG emissions from the combustion of carpet will likely decrease if the emission factor is revised to take this new information into account.

Emissions associated with retail transport of carpet from manufacturing to point of sale were not developed in the original WARM analysis as the representative transportation mode/distance data were not available. EPA is investigating the availability of these data through the U.S. Census and will likely incorporate emissions from retail transport in the next version of the carpet emission factor in WARM.

For the source reduction pathway, the LCI data to estimate GHG emissions from the manufacture of carpet from virgin materials are slightly outdated. EPA is investigating the availability of updated life cycle data and will revise the source reduction emission factor accordingly in WARM.

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