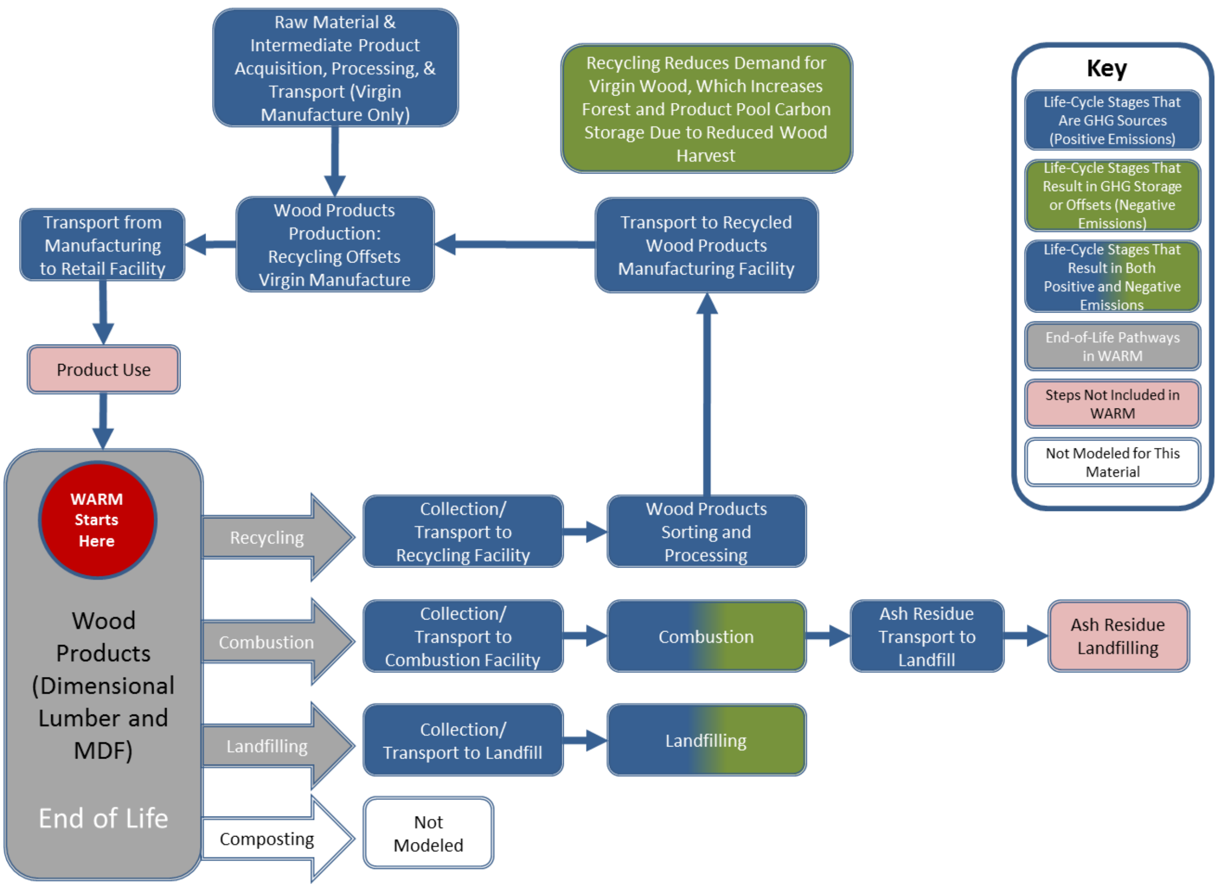
WOOD PRODUCTS

1. INTRODUCTION TO WARM AND WOOD PRODUCTS

This chapter describes the methodology used in EPA's Waste Reduction Model (WARM) to estimate streamlined life-cycle greenhouse gas (GHG) emission factors for wood products beginning at the point of waste generation. The WARM GHG emission factors are used to compare the net emissions associated with wood products in the following four materials management alternatives: source reduction, recycling, landfilling, and combustion. Exhibit 1 shows the general outline of materials management pathways 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, Combustion, and Landfilling, 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 Wood Products in WARM



The category "wood products" in WARM comprises dimensional lumber and medium-density fiberboard (MDF). Dimensional lumber includes wood used for containers, packaging and buildings and includes crates, pallets, furniture and lumber such as two-by-fours (EPA, 2014b). Fiberboard, including MDF, is a panel product that consists of wood chips pressed and bonded with a resin and is used primarily to make furniture (EPA, 1995). At end of life, wood products can be recovered for recycling, sent to a landfill or combusted.

2. LIFE-CYCLE ASSESSMENT AND EMISSION FACTOR RESULTS

The life-cycle boundaries in WARM start at the point of waste generation—the point at which a material is discarded—and only consider upstream (i.e., material acquisition and manufacturing) GHG emissions when the production of new materials is affected by 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.

Composting is not included as a materials management pathway due to a lack of information on the GHG implications of composting wood products.[1] Exhibit 2 illustrates the GHG sources and offsets that are relevant to wood products in this analysis.

Exhibit 2: Wood Products GHG Sources and Sinks from Relevant Materials Management Pathways

MSW Management Strategies for Wood Products	GHG Sources and Sinks Relevant to Wood Products		
	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 wood products to point of sale	**Losses** • Decrease in carbon storage in products **Offsets** • Increase in forest carbon storage	NA
Recycling	**Emissions** • Transport of recycled materials • Recycled process energy **Offsets** • Transport of raw materials and intermediate products • Virgin process energy • Transport of wood products to point of sale	**Losses** • Decrease in carbon storage in products **Offsets** • Increase in forest carbon storage	**Emissions** • Collection of wood products and transportation to recycling center
Composting	Not Modeled in WARM		
Combustion	NA	NA	**Emissions** • Transport to WTE facility • Combustion-related N_2O **Offsets** • Avoided utility emissions
Landfilling	NA	NA	**Emissions** • Transport to landfill • Landfilling machinery **Offsets** • Carbon storage • Energy recovery

NA = Not applicable.

WARM analyzes all of the GHG sources and sinks outlined in Exhibit 2 and calculates net GHG emissions per short ton of inputs, shown in Exhibit 3 for the four materials management pathways. For

[1] The composting factor in WARM, described in the Composting chapter, assumes a generic compost mix, rather than looking at materials in isolation. It is not currently known what effect adding large amounts of wood would have at a composting site, whether the GHG emissions/sequestration would be altered, or whether the carbon/nitrogen ratio would be affected.

more detailed methodology on emission factors, please see the sections below on individual materials management strategies.

Exhibit 3: Net Emissions for Wood Products 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
Dimensional Lumber	-2.02	-2.46	NA	-0.58	-0.98
MDF	-2.23	-2.47	NA	-0.58	-0.86

NA = Not applicable.

3. RAW MATERIALS ACQUISITION AND MANUFACTURING

GHG emissions associated with raw materials acquisition and manufacturing (RMAM) from the manufacturing of wood products are (1) GHG emissions from energy used during the RMAM processes, (2) GHG emissions from energy used to transport materials, and (3) non-energy GHG emissions resulting from manufacturing processes.

Dimensional lumber is mechanically shaped to standard dimensions in sawmills. Sawmill operations vary widely, but typically full logs are transported by truck to the mill, where they are graded for different uses. Electrically powered saws are used to cut the logs into different lengths, widths and thicknesses. The cut boards are then stacked and placed in drying kilns. Waste wood from the process is used to generate process heat and, in some cases, electricity.[2] Once dry, the boards are planed to specific dimensions and a smooth finish before being shipped (NFI, 2010b).

In addition to serving as a source of energy for the lumber manufacturing process, waste wood is also used in the manufacture of structural panels, including MDF. The first step in manufacturing MDF is breaking down waste woodchips into their cellulosic fibers and resin. The fibers and resin are combined with wax or other binders and then subjected to high temperatures and pressure, requiring energy inputs that result in GHG emissions, to form the MDF (English et al., 1994; NFI, 2010a). Drying and heating the MDF components results in non-energy carbon dioxide (CO_2) and methane emissions (CH_4).

The RMAM calculation in WARM also incorporates "retail transportation," which includes the average emissions from truck, rail, water and other modes of transportation required to transport wood products 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 4. Transportation emissions from the retail point to the consumer are not included in WARM. The miles travelled fuel-specific information is obtained from the 2012 *U.S. Census Commodity Flow Survey* (BTS, 2013) and *Greenhouse Gas Emissions from the Management of Selected Materials* (EPA, 1998).

Exhibit 4: Retail Transportation Energy Use and GHG Emissions

Material/Product	Average Miles per Shipment	Transportation Energy per Short Ton of Product (Million Btu)	Transportation Emission Factors ($MTCO_2E$/ Short Ton)
Dimensional Lumber	246	0.29	0.02
MDF	675	0.79	0.05

[2] CO_2 emissions produced from the combustion of waste wood for energy are considered biogenic, and are excluded from WARM's emission factors.

4. MATERIALS MANAGEMENT METHODOLOGIES

WARM models four materials management alternatives for wood products: source reduction, recycling, combustion, and landfilling. For source reduction, net emissions depend not only on the management practice but also on the recycled content of the wood products. While MDF can be made from a combination of virgin and post-consumer recycled materials, EPA has not located evidence that MDF is manufactured with recycled material in the United States. Dimensional lumber cannot be manufactured from recycled material. As a result, WARM assumes that wood products that are source reduced or recycled in the United States will offset 100% virgin inputs. Although all materials management options have negative emissions—driven primarily by carbon storage—as Exhibit 3 indicates, recycling wood products is the most beneficial.

4.1 SOURCE REDUCTION

Source reduction activities reduce the quantity of dimensional lumber and MDF manufactured, reducing the associated GHG emissions. Recovering and reusing dimensional lumber or MDF from construction sites is one form of source reduction for these building materials. For more information on source reduction in general see the Source Reduction chapter.

Exhibit 5 provides the breakdown of the GHG emissions factors for source reducing wood products. GHG benefits of source reduction are calculated as the avoided emissions from RMAM of each product. The GHG emission sources and sinks from source reduction include:

- *Process energy, transportation and non-energy process GHG emissions.* Producing dimensional lumber and MDF results in GHG emissions from energy consumption in manufacturing processes and transportation, as well as non-energy related CO_2 emissions in the production of MDF.
- *Carbon storage.* Reducing the quantity of dimensional lumber and MDF manufactured results in increased forest carbon stocks from marginal changes in harvest rates, but also reduces the carbon stored in in-use wood products. For more information, see the Forest Carbon Storage chapter.

Exhibit 5: Source Reduction Emission Factors for Wood Products ($MTCO_2E$/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 Storage for Current Mix of Inputs	Forest Carbon Storage for 100% Virgin Inputs	Net Emissions for Current Mix of Inputs	Net Emissions for 100% Virgin Inputs
Dimensional Lumber	-0.18	-0.18	-1.84	-1.84	-2.02	-2.02
MDF	-0.39	-0.39	-1.84	-1.84	-2.23	-2.23

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

4.1.1 Developing the Emission Factor for Source Reduction of Wood Products

To calculate the avoided GHG emissions for wood products, EPA first looks at three components of GHG emissions from RMAM activities: process energy, transportation energy and non-energy GHG emissions. Exhibit 6 shows the results for each component and the total GHG emission factors for source reduction. More information on each component making up the final emission factor is provided below.

Exhibit 6: Raw Material Acquisition and Manufacturing Emission Factor for Virgin Production of Wood Products ($MTCO_2E$/Short Ton)

(a) Material/Product	(b) Process Energy	(c) Transportation Energy	(d) Process Non-Energy	(e) Net Emissions (e = b + c + d)
Dimensional Lumber	0.10	0.08	0.00	0.18
MDF	0.26	0.12	0.00	0.39

– = Zero emissions.

Exhibit 7, Exhibit 8, and Exhibit 9 provide the calculations for each source of RMAM emissions: process energy, transportation energy and non-energy processes. Data on the energy requirements for processing and transportation, and data on non-energy emissions from processing, are provided by FAL (1998). WARM includes energy and GHG emissions associated with retail transportation of wood products from the manufacturing plant to the point of sale based on transportation modes and distances provided by the U.S. Census Bureau's *Commodity Flow Survey* (BTS, 2013), and transportation energy requirements provided by EPA (1998).

Exhibit 7: Process Energy GHG Emissions Calculations for Virgin Production of Wood Products

Material/Product	Process Energy per Short Ton Made from Virgin Inputs (Million Btu)	Process Energy GHG Emissions ($MTCO_2E$/Short Ton)
Dimensional Lumber	2.53	0.10
MDF	10.18	0.26

Exhibit 8: Transportation Energy Emissions Calculations for Virgin Production of Wood Products

Material/Product	Transportation Energy per Short Ton Made from Virgin Inputs (Million Btu)	Transportation Energy GHG Emissions ($MTCO_2E$/Short Ton)
Dimensional Lumber	0.88	0.07
MDF	1.01	0.07

Note: The transportation energy and emissions in this exhibit do not include retail transportation, which is presented separately in Exhibit 4.

Exhibit 9: Process Non-Energy Emissions Calculations for Virgin Production of Wood Products

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)
Dimensional Lumber	–	–	–	–	–	–
MDF	0.00	0.00	–	–	–	0.00

– = Zero emissions.

In addition to RMAM emissions, forest carbon sequestration is factored into each wood product's total GHG emission factor for source reduction. Reducing the quantity of dimensional lumber and MDF manufactured increases forest carbon stocks from marginal changes in harvest rates, resulting in increased forest carbon storage. Conversely, source reduction also reduces the quantity of carbon stored in in-use wood products. Exhibit 10 provides the components of the overall forest carbon sequestration factor for wood products. For more information, see the Forest Carbon Storage chapter.

Exhibit 10: Net Change in Carbon Storage per Unit of Reduced Wood Product Production

(a) Material/ Product	(b) Reduction in Timber Harvest per Unit of Reduced Wood Product Production (Short Tons Timber/ Short Ton of Wood Recycled)	(c) Change in Forest C Storage per Unit of Reduced Timber Harvest (Metric Tons Forest C/ Metric Ton Timber)	(d) Change in C Storage in In-use Products per Unit of Increased Wood Product Recycling ($MTCO_2E$/Short Ton)	(e) Net Change in C Storage per Unit of Reduced Wood Product Production ($MTCO_2E$/Short Ton) (e = b × c × 0.907 + d)
Wood Products	1.10	0.99	-1.77	1.84

Note: Positive values denote an *increase* in carbon storage; negative values denote a *decrease* in carbon storage.
One metric ton = 0.907 short tons.

4.2 RECYCLING

In theory, dimensional lumber and MDF can be recycled in a closed-loop process (i.e., back into dimensional lumber and MDF). While EPA does not believe this is commonly practiced in the United States, WARM nevertheless models emission factors for closed-loop recycling for both dimensional lumber and MDF. The upstream GHG emissions from manufacturing the wood products are included as a "recycled input credit" by assuming that the recycled material avoids—or offsets—the GHG emissions associated with producing the wood products from virgin inputs. Consequently, GHG emissions associated with management (i.e., collection, transportation and processing) of waste wood products are included in the recycling credit calculation. In addition, there are forest carbon benefits associated with recycling. Each component of the recycling emission factor as provided in Exhibit 11 is discussed further in Section 4.2.1. For more information on recycling in general, see the Recycling chapter.

Exhibit 11: Recycling Emission Factor for Wood Products ($MTCO_2E$/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 Storage	Net Emissions (Post-Consumer)
Dimensional Lumber	–	–	0.07	0.01	–	-2.53	-2.46
MDF	–	–	0.05	0.02	–	-2.53	-2.47

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

4.2.1 Developing the Emission Factor for Recycling of Wood Products

EPA calculates the GHG benefits of recycling wood products by taking the difference between producing wood products from virgin inputs and producing wood products from recycled inputs, after accounting for losses that occur during the recycling process. This difference is called the "recycled input credit" and represents the net change in GHG emissions from process and transportation energy sources in recycling wood products relative to virgin production of wood products. The data sources consulted indicated no process non-energy emissions from recycling of wood products.

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 wood products.* The GHG emissions from virgin production of wood products are provided in Exhibit 7, Exhibit 8, and Exhibit 9.

Step 2. *Calculate GHG emissions for recycled production of wood products.* Exhibit 12 and Exhibit 13 provide the process and transportation energy emissions associated with producing recycled wood products. Data on these energy requirements and the associated emissions are from FAL (1998).

Exhibit 12: Process Energy GHG Emissions Calculations for Recycled Production of Wood Products

Material/Product	Process Energy per Short Ton Made from Recycled Inputs (Million Btu)	Energy Emissions ($MTCO_2E$/Short Ton)
Dimensional Lumber	3.17	0.18
MDF	10.99	0.32

Exhibit 13: Transportation Energy GHG Emissions Calculations for Recycled Production of Wood Products

Material/Product	Transportation Energy per Ton Made from Recycled Inputs (Million Btu)	Transportation Emissions ($MTCO_2E$/Short Ton)
Dimensional Lumber	0.97	0.07
MDF	1.27	0.09

Note: The transportation energy and emissions in this exhibit do not include retail transportation, which is presented separately in Exhibit 4.

Step 3. *Calculate the difference in emissions between virgin and recycled production.* To calculate the GHG emissions implications of recycling one short ton of wood products, 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 14. For both dimensional lumber and MDF, the energy and GHG emissions from recycling are less than those associated with virgin production of these materials.

Exhibit 14: Differences in Emissions between Recycled and Virgin Wood Product Manufacture ($MTCO_2E$/Short Ton)

Material/Product	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
Dimensional Lumber	0.10	0.08	–	0.18	0.09	–	0.08	0.01	–
MDF	0.26	0.12	0.00	0.32	0.14	0.00	0.06	0.02	–

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

Step 4. *Adjust the emissions differences to account for recycling losses.* The recycled input credits calculated above are then adjusted to account for any loss of product during the recycling process. The difference between virgin and recycled manufacture is multiplied by the product's net retention rate (FAL, 1998), which is calculated as follows:

Net Retention Rate for Wood Products = Recovery Stage Retention Rate × Manufacturing Stage Retention Rate

= 88.0% × 90.9% = 80.8%

Step 5. *Calculate the net change in carbon storage associated with recycling wood products.* These adjusted credits are then combined with the estimated forest carbon sequestration from recycling wood products to calculate the final GHG emission factor for recycling dimensional lumber and MDF. EPA estimates forest carbon storage in wood products, involving three parameters, as mentioned in the section on source reduction:

1. The change in timber harvests resulting from increased recycling of wood products;
2. The change in forest carbon storage as a result of a reduction in timber harvests; and
3. The change in carbon stored in in-use wood products from increased recycling.

Exhibit 15 provides data on these components of the overall forest carbon sequestration factor for both wood products. Compared to source reduction of wood products, recycling results in a larger increase in net carbon storage (i.e., an additional 0.7 $MTCO_2e$ of carbon storage from recycling compared to source reduction, or the difference between 2.5 and 1.8 $MTCO_2e$). This result is driven by the change in carbon storage in in-use products. When wood products are recycled, the recycled wood remains in in-use products; when virgin wood products are avoided through source reduction, however, they do not enter the in-use pool of wood products. Consequently, the reduction in carbon storage in in-use wood products is less for recycling than it is for source reduction. For more information on forest carbon storage and each component of the overall factor, see the Forest Carbon Storage chapter.

Exhibit 15: Net Change in Carbon Storage per Unit of Increased Wood Product Recycling

(a) Material/Product	(b) Reduction in Timber Harvest per Unit of Increased Wood Product Recycling (Short Tons Timber/ Short Ton of Wood Recycled)	(c) Change in Forest C Storage per Unit of Reduced Timber Harvest (Metric Tons Forest C/ Metric Ton Timber)	(d) Change in C Storage in In-use Products per Unit of Increased Wood Product Recycling ($MTCO_2E$/Short Ton)	(e) Net Change in C Storage per Unit of Increased Wood Product Recycling ($MTCO_2E$/Short Ton) ($e = b \times c \times 0.907 + d$)
Wood products	0.88	0.99	-0.35	2.53

Note: Positive values denote an increase in carbon storage; negative values denote a decrease in carbon storage.
One metric ton = 0.907 short tons.

Step 6. *Calculate the net GHG emission factor for recycling wood products.* The recycling credit calculated in Step 4 is added to the estimated forest carbon sequestration from recycling wood products to calculate the final GHG emission factor for recycling dimensional lumber and MDF, as shown in Exhibit 11.

4.3 COMPOSTING

While composting wood products is technically feasible, there is not much information available on composting wood products or the associated GHG emissions. As such, WARM does not consider GHG emissions or storage associated with composting wood products. However, this is a potential area for future research for EPA.

4.4 COMBUSTION

Because carbon in wood products is considered to be biogenic, CO_2 emissions from combustion of wood products are not considered in WARM.[3] Combusting wood products results in emissions of nitrous oxide (N_2O), however, and these emissions are included in WARM's GHG emission factors for wood products. Transporting wood products to combustion facilities also results in GHG emissions from the combustion of fossil fuels in vehicles. Finally, electricity produced from waste combustion energy recovery is used to offset the need for electricity production at power plants, consequently reducing the power sector's consumption of fossil fuels. WARM takes this into account by calculating an avoided

[3] WARM assumes that biogenic CO_2emissions are balanced by CO_2 captured by regrowth of the plant sources of the material. Consequently, these emissions are excluded from net GHG emission factors in WARM.

utility emission offset.[4] Exhibit 16 provides the breakdown of each wood product's emission factor into these components.

Exhibit 17 provides the calculation for the avoided utility emissions. EPA used three data elements to estimate the avoided electric utility CO_2 emissions associated with combustion of waste in a waste-to-energy (WTE) plant: (1) the energy content of each waste material,[5] (2) the combustion system efficiency in converting energy in municipal solid waste (MSW) to delivered electricity,[6] and (3) the electric utility CO_2 emissions avoided per kilowatt-hour (kWh) of electricity delivered by WTE plants. For more information on combustion in general, see the Combustion chapter.

Exhibit 16: Components of the Combustion Net Emission Factor for Wood Products ($MTCO_2E$/Short Ton)

Material/ Product	Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Transportation to Combustion	CO_2 from Combustion[a]	N_2O from Combustion	Avoided Utility Emissions	Steel Recovery	Net Emissions (Post-Consumer)
Dimensional Lumber	–	0.03	–	0.04	-0.65	–	-0.58
MDF	–	0.03	–	0.04	-0.65	–	-0.58

– = Zero emissions.
[a] CO_2 emissions from combustion of wood products are assumed to be biogenic and are excluded from net emissions.

Exhibit 17: Utility GHG Emissions Offset from Combustion of Wood Products

(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) ($e = b \times c \times d$)
Wood products	16.6	17.8%	0.22	0.65

4.5 LANDFILLING

Wood products are often sent to landfills at the end of life. When wood products are landfilled, anaerobic bacteria degrade the materials, producing CH_4 and CO_2. Only CH_4 emissions are counted in WARM, because the CO_2 emissions are considered to be biogenic. In addition, because wood products are not completely decomposed by anaerobic bacteria, some of the carbon in these materials remains stored in the landfill. This stored carbon constitutes a sink (i.e., negative emissions) in the net emission factor calculation. In addition, WARM factors in transportation of wood products to landfill, which results in anthropogenic CO_2 emissions, due to the combustion of fossil fuels in vehicles and landfilling equipment. Exhibit 18 provides the emission factors for dimensional lumber and MDF broken down into these components. More information on the development of the emission factor is provided in section 4.5.1. For more information on landfilling in general, see the Landfilling chapter.

[4] The utility offset credit is calculated based on the non-baseload GHG emissions intensity of U.S. electricity generation, since it is non-baseload power plants that will adjust to changes in the supply of electricity from energy recovery at landfills.
[5] Based on the higher end of the heat content range of basswood from the USDA Forest Service (Fons et al., 1962). Basswood is relatively soft wood, so its high-end energy content value is likely most representative of dimensional lumber and MDF wood products.
[6] EPA used a net value of 550 kWh generated by mass burn plants per ton of mixed MSW combusted (Zannes, 1997) and accounted for transmission and distribution losses.

Exhibit 18: Landfilling Emission Factors for Wood Products ($MTCO_2E$/Short Ton)

Material/ Product	Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Transportation to Landfill	Landfill CH_4	Avoided CO_2 Emissions from Energy Recovery	Landfill Carbon Storage	Net Emissions (Post-Consumer)
Dimensional Lumber	–	0.04	0.07	-0.00	-1.09	-0.98
MDF	–	0.04	0.02	-0.00	-0.92	-0.86

– = Zero emissions.

Negative values denote GHG emission reductions or carbon storage.

Note: The emission factors for landfill CH_4 presented in this table are based on national-average rates of landfill gas capture and energy recovery. Avoided CO_2 emissions from energy recovery are calculated based on the non-baseload GHG emissions intensity of U.S. electricity generation, since it is non-baseload power plants that will adjust to changes in the supply of electricity from energy recovery at landfills.

4.5.1 Developing the Emission Factor for Landfilling of Wood Products

WARM calculates CH_4 emission factors for landfilled materials based on the CH_4 collection system type installed at a given landfill. As detailed in the Landfilling chapter, there are three categories of landfills modeled in WARM: (1) landfills that do not recover landfill gas (LFG), (2) landfills that collect the LFG and flare it without recovering the flare energy, and (3) landfills that collect LFG and combust it for energy recovery by generating electricity. Direct use of landfill gas for process heat is not modeled. WARM calculates emission factors for each of these three landfill types and uses the national average mix of collection systems installed at landfills in the United States to calculate a national average emission factor that accounts for the extent to which CH_4 (1) is not captured, (2) is flared without energy recovery, or (3) is combusted on-site for energy recovery.[7, 8] The Landfill CH_4 column of Exhibit 18 presents emission factors based on the national average of LFG collection usage.

Exhibit 19 depicts the specific emission factors for each landfill gas collection type. Overall, landfills that do not collect LFG produce the most CH_4 emissions.

Exhibit 19: Components of the Landfill Emission Factor for the Three Different Methane Collection Systems Typically Used In Landfills ($MTCO_2E$/Short Ton)

(a)	(b) Net GHG Emissions from CH_4 Generation			(c)	(d)	(e) Net GHG Emissions from Landfilling (e = b + c + d)		
Material/ Product	Landfills without LFG Recovery	Landfills with LFG Recovery and Flaring	Landfills with LFG Recovery and Electricity Generation	Net Landfill Carbon Storage	GHG Emissions from Transport-ation	Landfills without LFG Recovery	Landfills with LFG Recovery and Flaring	Landfills with LFG Recovery and Electricity Generation
Dimensional Lumber	0.15	0.06	0.05	-1.09	0.04	-0.90	-0.99	-1.00
MDF	0.05	0.02	0.01	-0.92	0.04	-0.83	-0.86	-0.87

Note: Negative values denote GHG emission reductions or carbon storage.

[7] Although gas from some landfills is piped to an offsite power plant and combusted there, for the purposes of this report, the assumption was that all gas for energy recovery was combusted onsite.

[8] For the year 2012, an estimated 38 percent of landfill CH_4 was generated at landfills with landfill gas recovery systems and flaring, while 44 percent was generated at landfills with gas collection and energy recovery systems (EPA, 2014a).

WARM calculates landfill carbon storage from wood products based on laboratory test data on the ratio of carbon storage per wet short ton of wood landfilled documented in Barlaz (1998), Wang et al. (2013), and Wang et al. (2011). Exhibit 20 provides the landfill carbon storage calculation used in WARM.

Exhibit 20: Calculation of the Carbon Storage Factor for Landfilled Wood Products

(a) Material	(b) Ratio of Carbon Storage to Dry Weight (g C Stored/Dry g)	(c) Ratio of Dry Weight to Wet Weight	(d) Ratio of C Storage to Wet Weight (g C/Wet g) (d = b × c)	(e) Amount of C Stored ($MTCO_2E$ per Wet Short Ton)
Dimensional Lumber	0.44	0.75	0.33	1.09
MDF	0.37	0.75	0.28	0.92

5. LIMITATIONS

In addition to the limitations associated with the forest carbon storage estimates as described in the Forest Carbon Storage chapter, the following limitations are associated with the wood products emission factors:

- The emission factors associated with producing and recycling dimensional lumber and MDF are representative of manufacturing processes in the mid-1990's and may have changed since the original life-cycle information was collected; depending upon changes in manufacturing process, such as efficiency improvements and fuel inputs, energy use and GHG emissions from virgin and recycled production of these products may have increased or decreased.
- Composting is not included as a material management pathway because of a lack of information on the GHG implications of composting wood products. The composting factor in WARM, described in the Composting chapter, assumes a generic compost mix, rather than looking at materials in isolation. It is not currently known what effect adding large amounts of wood would have at a composting site, whether the GHG emissions/sequestration would be altered, or whether the carbon/nitrogen ratio would be affected. As a result, EPA has not estimated emission factors for composting. However, EPA is planning to conduct further research in this area that could enable better assessments of composting emission factors for wood products.
- The energy content (by weight) for dimensional lumber and MDF is assumed to be the same, while in fact they may be different since MDF contains resins that bind the wood fibers together. EPA does not expect that this difference would have a large influence of the combustion emission factors.

6. REFERENCES

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