

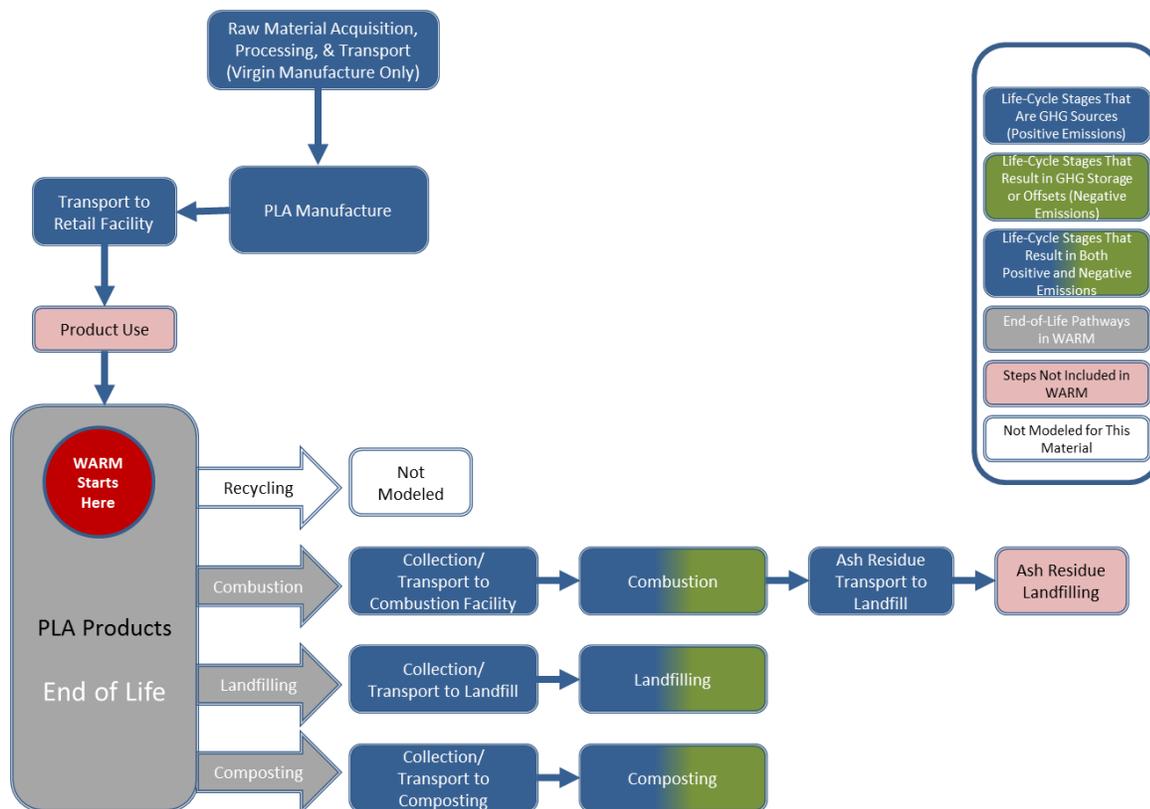
US EPA ARCHIVE DOCUMENT

POLYLACTIDE (PLA) BIOPOLYMER

1. INTRODUCTION TO WARM AND PLA

This chapter describes the methodology used in EPA’s Waste Reduction Model (WARM) to estimate streamlined life-cycle greenhouse gas (GHG) emission factors for Natureworks’ Ingeo polylactide (PLA) biopolymer resin, beginning at the waste generation reference point. Due to the large number of end applications for PLA (e.g., food containers, bottles and other consumer products) and the lack of data specific to the United States, EPA models all PLA in resin form only and does not include final processes that convert the resin into products. The WARM GHG emission factors are used to compare the net emissions associated with this biopolymer in the following four materials management options: source reduction, composting, landfilling, and combustion.¹ The rest of this module provides details on these materials management options as life-cycle pathways for PLA. Exhibit 1 shows the general outlines of materials management pathways for PLA 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 GHG emissions. 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 PLA in WARM



¹ As discussed in this chapter, life-cycle data for recycling PLA are not available and thus EPA cannot represent the recycling pathway in WARM.

In recent years, there has been a push towards manufacturing “greener alternatives” for consumer products and packaging; bio-based materials are being developed for constructing materials such as containers and packaging products. Polylactic acid or PLA is one such biopolymer that is constructed from renewable agricultural products (e.g., corn) and is being used for a wide range of products such as rigid packaging and folding boxes, disposable cups, cutlery, bottles, films, carpet, apparel, and personal hygiene products. Although there are a number of different types of biopolymers, for example Poly-3-hydroxybutyrate-co-3-hydroxyoctanoate (PHBO), EPA is currently only modeling the PLA biopolymer material type in WARM due to life-cycle data availability. Additionally, there are several different grades of PLA biopolymer used to manufacture a wide variety of products. The emission factors developed for WARM have been developed using life-cycle inventory data specifically for thermoplastic resin (i.e., 2002D and 2003D) that can be extruded for use in various applications, including fresh food packaging and service ware. EPA did not obtain life-cycle information about the additional PLA grades (e.g., 3001D, 4043D, 7001D or 7032D) to develop appropriate GHG emission factors for these biopolymer grades.² Note that the data provided by NatureWorks and used to create the GHG emission factors for WARM only represents Ingeo polylactide (PLA) resin production by NatureWorks LLC in Blair, Nebraska. However, considering that there are no direct competitors to NatureWorks that operate a fully industrial-scale PLA manufacturing plant in the United States, these data are considered representative of U.S. PLA production. In WARM, the definition of PLA is shown below:

PLA. PLA is a versatile thermoplastic biopolymer constructed entirely from annually renewable agricultural products, e.g., corn, and used in manufacturing fresh food packaging and food service ware such as rigid packaging, food containers, disposable plastic cups, cutlery, and plates (U.S. LCI, 2010a).

2. LIFE-CYCLE ASSESSMENT AND EMISSION FACTOR RESULTS

The streamlined life-cycle GHG analysis in WARM focuses on the waste generation point, or the moment a material is discarded, as the reference point and only considers upstream GHG emissions when the production of new materials is affected by materials management decisions.³ 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. The upstream manufacturing process for PLA is summarized in section 3. For further information on evaluating upstream emissions, see the chapters on Recycling and Source Reduction.

The overall life-cycle energy associated with manufacturing PLA from virgin inputs is given in Exhibit 2. Life-cycle data for recycling PLA are not available and this practice is not common in the US. Therefore, we cannot represent the recycling pathway in WARM.

Exhibit 2: Life-Cycle Energy Associated with Manufacture (with 100% Virgin and 100% Recycled Inputs)

Material/Product	Virgin Manufacture		Recycled Manufacture	
	Process Energy per Ton Made from Virgin Inputs (Million Btu)	Transportation Energy per Ton Made from Virgin Inputs (Million Btu)	Process Energy per Ton Made from Recycled Inputs (Million Btu)	Transportation Energy per Ton Made from Recycled Inputs (Million Btu)
PLA	29.19	0.15	NA	NA

NA = Not applicable.

² A list of the various PLA grades can be found here: <http://www.natureworkslc.com/Technical-Resources.aspx>

³ The analysis is streamlined in the sense that it examines GHG emissions only and is not a comprehensive environmental analysis of all emissions from materials management.

As Exhibit 3 illustrates, most of the GHG sources relevant to PLA in this analysis fall under the raw materials acquisition and manufacturing and end-of-life sections of the life cycle. The source reduction pathway has the largest emission factor for PLA since upstream manufacturing emissions are significant. PLA contains biogenic carbon but does not generate CH₄ emissions when landfilled because it stores carbon. Therefore, the emissions associated with landfilling PLA include only transportation- and landfill-equipment-related emissions.

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

Materials Management Strategies for PLA	GHG Sources and Sinks Relevant to PLA		
	Raw Materials Acquisition and Manufacturing	Changes in Forest or Soil Carbon Storage	End of Life
Source Reduction	Offsets <ul style="list-style-type: none"> • Transport of raw materials and products • Virgin manufacture process energy • Virgin manufacture process non-energy • Transport of PLA to point of sale 	NA	NA
Recycling	Not applicable since data for recycling of PLA (in the United States) does not exist		
Composting	NA	Offsets <ul style="list-style-type: none"> • Increase in soil carbon storage 	Emissions <ul style="list-style-type: none"> • Transport to compost facility • Compost machinery
Combustion	NA	NA	Emissions <ul style="list-style-type: none"> • Transport to WTE facility
Landfilling	NA	NA	Emissions <ul style="list-style-type: none"> • Transport to landfill • Landfilling machinery Offsets <ul style="list-style-type: none"> • Landfill carbon storage

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 PLA generated for each materials management alternative as shown in Exhibit 4. For additional discussion on the detailed methodology used to develop these emission factors, see sections 3 and 4.

Exhibit 4: Net Emissions for PLA under Each Materials Management Option (MTCO₂E/Short Ton)

Material/Product	Net Source Reduction (Reuse) Emissions For Current Mix of Inputs*	Net Recycling Emissions	Net Composting Emissions	Net Combustion Emissions	Net Landfilling Emissions
PLA	-2.08	NA	-0.13	-0.62	-1.62

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

NA = Not applicable.

*Due to unavailable data, it is assumed that the current mix of PLA is 100% virgin inputs

3. RAW MATERIALS ACQUISITION AND MANUFACTURING

GHG emissions associated with raw materials acquisition and manufacturing (RMAM) are (1) GHG emissions from energy used during the acquisition and manufacturing processes, (2) GHG emissions from energy used to transport materials, and (3) non-energy GHG emissions resulting from manufacturing processes. Process non-energy GHG emissions occur during the manufacture of certain materials and are not associated with energy consumption. For example, in PLA manufacture, CO₂

emissions occur during production of calcium hydroxide from conversion of calcium carbonate into calcium oxide.

The RMAM calculation in WARM also incorporates “retail transportation,” which includes the average truck, rail, water and other-modes transportation emissions required to transport these PLA products from the manufacturing facility to the retail/distribution point. The energy and GHG emissions from retail transportation are presented in Exhibit 5. Transportation emissions from the retail point to the consumer are not included. The number of miles traveled and mode-specific fuel use 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, 1998c), respectively. The “plastics and rubber” commodity type in the Commodity Flow Survey is used as a proxy for PLA.

Exhibit 5: Retail Transportation Energy Use and GHG Emissions

Material/Product	Average Miles per Shipment	Retail Transportation Energy (Million Btu per Short Ton of Product)	Retail Transportation Emission Factors (MTCO ₂ E per Short Ton of Product)
PLA	497	0.490	0.036

The total RMAM emissions for PLA manufacture are shown in the section on source reduction. The net emission factor for source reduction of PLA includes RMAM “upstream” emissions.

PLA manufacture involves production of the following materials in a step-by-step process – corn, dextrose, lactic acid, lactide and polymer production. Corn production involves harvesting and drying of corn and its transportation to a corn wet mill (CWM). At the CWM, the starch is separated from the corn kernel and hydrolyzed using enzymes to obtain dextrose. This unrefined dextrose solution is sent to an adjacent fermentation facility via a pipeline for fermentation into lactic acid. The fermentation process produces crude lactic acid by combining dextrose with other materials including microbes. The addition of some calcium hydroxide, to maintain pH balance, and sulfuric acid in the end, to acidify the lactic acid, results in precipitation of gypsum. The purified lactic acid is polymerized to form polylactide polymer through removal of water in a continuous condensation process and catalytic conversion of the lactic acid into lactide (a cyclic dimer). Finally, this lactide is distilled and polymerized. Polymer pellets are the final product of this manufacturing process. (U.S. LCI, 2010a)

The GHG emissions associated with embedded carbon (either biogenic or non-biogenic) are not considered part of the RMAM emissions. Since WARM uses a materials management perspective, the GHG emissions associated with embedded carbon are incorporated within the various waste management scenarios (i.e., source reduction, recycling, landfilling, composting, or combustion) according to the relative amount of biogenic carbon that is ultimately stored and non-biogenic carbon that is eventually released at end-of-life.

4. MATERIALS MANAGEMENT

WARM analyzes all of the GHG sources and sinks outlined in Exhibit 3 and calculates net GHG emissions per short ton of PLA input. Landfilling, composting, source reduction and combustion are the four materials management options used to manage PLA. Source reduction and landfilling have the lowest net emission factors among the various materials management options for PLA.

4.1 SOURCE REDUCTION

When a material is source reduced (i.e., less of the material is made), GHG emissions associated with making the material and managing the post-consumer waste are avoided. As discussed above, under the measurement convention used in this analysis, source reduction results in negative raw

material and manufacturing GHG emissions (i.e., it avoids emissions attributable to production) and zero end-of-life management GHG emissions. For more information, please refer to the [Source Reduction](#) chapter.

The biogenic carbon emissions associated with the growth of the plant sources in the production of PLA are assumed to be net zero during source reduction of PLA. WARM assumes that carbon in biogenic sources was originally removed from the atmosphere by photosynthesis, and under natural conditions, would cycle back to the atmosphere due to degradation processes. Unlike other bio-based materials such as paper and wood materials where WARM assumes that source reduction of these products increases the amount of carbon stored in forests by reducing the amount of wood harvested in forests, the implications for growing annual crops used to produce PLA is unclear and highly uncertain. Most likely, source reducing the manufacture of PLA would result in the underlying input corn crop being harvested for other purposes. Since the corn crops are annual crops, unharvested crops would eventually decay and release the biogenic carbon back to the atmosphere. Therefore, it is unlikely that any additional biogenic carbon would be stored. Thus, the biogenic carbon emissions associated with source reducing PLA are considered net zero.

Exhibit 6 presents the inputs to the source reduction emission factor for both current mix of inputs and 100 percent virgin inputs manufacture of PLA. Due to unavailable data, it is assumed that the current mix of PLA is 100% virgin inputs. Please see the [Source Reduction](#) chapter for more information.

Exhibit 6: Source Reduction Emission Factors for PLA (MTCO₂E/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
PLA	-2.08	-2.08	NA	NA	-2.08	-2.08

NA = Not applicable.

Note: Negative values denote net GHG emission reductions or carbon storage from a materials management practice. Information on the share of recycled inputs used in production is unavailable or is not a common practice; EPA assumes that the current mix is comprised of 100% virgin inputs. Consequently, the source reduction benefits of both the “current mix of inputs” and “100% virgin inputs” are the same

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

4.1.1 Developing the Emission Factor for Source Reduction of PLA

To calculate the avoided GHG emissions for PLA, EPA first looks at three components of GHG emissions from RMAM activities: process energy, transportation energy and non-energy GHG emissions. Exhibit 7 shows the results for each component and the total GHG emission factors for source reduction of PLA.

Exhibit 7: Raw Material Acquisition and Manufacturing Emission Factor for Source Reduction of Virgin Production of PLA (MTCO₂E/Short Ton)

(a) Material/Product	(b) Process Energy	(c) Transportation Energy	(d) Process Non-Energy	(e) Net Emissions (e = b + c + d)
PLA	1.81	0.05	0.22	2.08

Process Energy: To calculate this factor, EPA obtained an estimate of the amount of energy required to acquire and produce one short ton of PLA, in Btu. Next, we determined the fuel mix that comprises this Btu estimate (U.S. LCI, 2010b), mainly electricity from the grid and natural gas combusted in industrial equipment and boilers, and then multiplied the fuel consumption (in Btu) by the fuel-specific carbon contents. The appropriate emissions profile for electricity consumption is calculated by using the electricity factor representative of the West-North Central grid mix from eGRID because PLA is developed at one main production facility in Nebraska, which draws electricity from the West-North Central grid.

The sums of the resulting GHG emissions by fuel type comprise the total process energy GHG emissions, including both CO₂ and CH₄, from all fuel types used in PLA production. The process energy used to produce PLA and the resulting emissions are shown in Exhibit 8.

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

Material/Product	Process Energy per Short Ton Made from Virgin Inputs (Million Btu)	Process Energy GHG Emissions (MTCO ₂ E/Short Ton)
PLA	29.19	1.81

Transportation Energy: Transportation energy emissions occur when fossil fuels are used to transport raw materials and intermediate products for PLA production. The methodology for estimating these emissions is the same as that used for process energy emissions. All transport is reported as taking place via diesel-powered combination truck. Hence, EPA calculates the total emissions by applying the carbon coefficient for diesel to the transportation fuel use (U.S. LCI, 2010b). The calculations for estimating the transportation energy emission factor are shown in Exhibit 9.

Exhibit 9: Transportation Energy Emissions Calculations Virgin Production of PLA

Material/Product	Transportation Energy per Short Ton Made from Virgin Inputs (Million Btu)	Transportation Energy GHG Emissions (MTCO ₂ E/Short Ton)
PLA	0.15	0.01

Note: The transportation energy and emissions in this exhibit do not include retail transportation, which is presented separately in Exhibit 5.

Non-energy Process: Non-energy GHG emissions occur during manufacturing but are not related to the consumption of fuel for energy. For example, there are N₂O emissions associated with offgassing from fertilizer production and application in corn production. Also, non-energy CO₂ emissions are emitted in calcium hydroxide production in the conversion of calcium carbonate into calcium oxide during upstream production. According to NatureWorks (EPA, 2010b), all of the nitrous oxide (N₂O) and 30 percent of the total CO₂ emitted are non-energy emissions, and the CH₄ emissions are mainly energy related.⁴ Hence, the appropriate proportion of total CO₂ and all of the N₂O output per short ton of PLA produced as provided in U.S. LCI database (U.S. LCI, 2010b) is assigned to non-energy process emissions. Exhibit 10 shows the components for estimating process non-energy GHG emissions for PLA.

⁴ According to responses received from NatureWorks (EPA 2010b) all of the N₂O is released during crop production and is hence considered non-energy process emissions.

Exhibit 10: Process Non-Energy Emissions Calculations for Source Reduction of Virgin Production of PLA

Material/Product	CO ₂ Emissions (MT/Short Ton)	CH ₄ Emissions (MT/Short Ton)	CF ₄ Emissions (MT/Short Ton)	C ₂ F ₆ Emissions (MT/Short Ton)	N ₂ O Emissions (MT/Short Ton)	Non-Energy Carbon Emissions (MTCO ₂ E/Short Ton)
PLA	0.11	NA*	–	–	0.00	0.22

* CH₄ emissions are not accounted for here since these are associated with energy use which is captured in the energy emissions for process energy use.

– = Zero emissions.

4.2 RECYCLING

Although the NatureWorks' PLA website⁵ indicates that PLA can be recycled indefinitely with virtually no use of virgin polymer for remanufacture, no life-cycle emission factor for recycling was developed as recycling data are currently unavailable. Also, the infrastructure for recycling PLA in the United States is still developing (due to economic and technological issues) and therefore is not a common waste management practice.

4.3 COMPOSTING

The net composting emission factor is calculated as the sum of emissions from transportation to compost facility, processing of compost, and the carbon storage resulting from compost application. Transportation of PLA to the central composting site results in nonbiogenic CO₂ emissions.⁶ In addition, during the composting process the compost is mechanically turned, and the operation of this equipment results in non biogenic CO₂ emissions. Additionally, microbial activity during composting decomposes waste into a variety of compounds, which generates small amounts of CH₄ and N₂O gas, a net contributor to the GHG emissions associated with the composting pathway (for more information on fugitive emissions, please refer to the Composting chapter). Exhibit 11 details these components for PLA.

PLA is biogenic and according to the NatureWorks' PLA website⁷, fully biodegrades within 45 days. Hence, it is assumed to have the same composting life-cycle emission factor as other biogenic materials in WARM. For additional information on composting in WARM, see the Composting chapter. Exhibit 11 shows the two emission sources and one emission sink resulting from the composting of organics.

Exhibit 11: Components of the Composting Net Emission Factor for Organics

Composting of Post-Consumer Material (GHG Emissions in MTCO ₂ E/Short Ton)						
Material Type	Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Transportation to Composting	Compost CO ₂	Compost CH ₄ and N ₂ O	Soil Carbon Storage	Net Emissions (Post-Consumer)
PLA	NA	0.04	–	0.07	-0.24	-0.13

⁵ <http://www.natureworkslc.com/The-Ingeo-Journey/End-of-Life-Options/Recycling.aspx>

⁶ Transportation emissions from delivery of finished compost from the composting facility to its final destination were not counted.

⁷ <http://www.natureworkslc.com/The-Ingeo-Journey/End-of-Life-Options/Composting.aspx>

4.3.1 Emissions from Collection and Transport

Transportation energy emissions occur when fossil fuels are used to collect and transport yard trimmings and food scraps to a composting facility, and then to operate the composting equipment that turns the compost. To calculate these emissions, WARM relies on assumptions from FAL (1994), which are detailed in Exhibit 12.

Exhibit 12: Emissions Associated with Transporting and Turning Compost

	Diesel Fuel Required to Collect and Transport One Ton (million Btu) ^a	Diesel Fuel Required to Turn the Compost Piles (million Btu) ^a	Total Energy Required for Composting (million Btu)	Total CO ₂ Emissions from Composting (MTCO ₂ E)
PLA	0.36	0.22	0.58	0.04

^a Based on estimates found on Table I-17 on page I-32 of FAL (1994).

4.3.2 Carbon Storage Associated with Composting

WARM currently assumes that carbon from compost remains stored in the soil through two main mechanisms: direct storage of carbon in depleted soils (the “soil carbon restoration” effect)⁸ and carbon stored in non-reactive humus compounds (the “increased humus formation” effect).⁹ The carbon values from the soil carbon restoration effect are scaled according to the percentage of compost that is passive, or non-reactive, which is assumed to be 52 percent (Cole, 2000). The weighted soil restoration value is then added to the increased humus formation effect in order to estimate the total sequestration value associated with composting. The inputs to the calculation are shown in Exhibit 13.

Exhibit 13: Soil Carbon Effects as Modeled in Century Scenarios (MTCO₂E/Short Ton of Organics)

Scenario	Soil Carbon Restoration			Increased Humus Formation	Net Carbon Flux ^a
	Unweighted	Proportion of C that is Not Passive	Weighted estimate		
Annual application of 32 tons of compost per acre	-0.04	48%	-0.07	-0.17	-0.24

^a The net carbon flux sums each of the carbon effects together and represents the net effect of composting a short ton of yard trimmings in MTCO₂E.

4.3.3 Net Composting Emission Factor

The nonbiogenic CO₂ emissions from transportation, collection and compost turning are added to the compost carbon sink in order to calculate the net composting GHG emission factors for each organics type. WARM estimates that the net composting GHG factor for all compostable organic materials is the same for all sources of compost.

4.4 COMBUSTION

This study’s general approach was to estimate (1) gross emissions of CO₂ and N₂O from MSW combustion (including emissions from transportation of waste to the combustor and ash from the combustor to a landfill), (2) CO₂ emissions avoided due to displaced electric utility generation, and (3) CO₂ emissions avoided due to recovery and recycling of ferrous metals at the combustor. To obtain an

⁸ EPA evaluated the soil carbon restoration effect using Century, a plant-soil ecosystems model that simulates long-term dynamics of carbon, nitrogen, phosphorous and sulfur in soils. For more information, see the [Composting](#) chapter.

⁹ EPA evaluated the increased humus formation effect based on experimental data compiled by Dr. Michael Cole of the University of Illinois. These estimates accounted for both the fraction of carbon in the compost that is considered passive and the rate at which passive carbon is degraded into CO₂. For more information, see the [Composting](#) chapter.

estimate of the net GHG emissions from MSW combustion, the value for GHG emissions avoided is subtracted from the direct GHG emissions. Exhibit 14 provides the emission factors related to combusting of PLA.

Exhibit 14: Components of the Combustion Net Emission Factor for PLA (MTCO₂E/Short Ton)

Material/Product	Raw Material Acquisition and Manufacturing (Current Mix of Inputs)	Transportation to Combustion	CO ₂ from Combustion	N ₂ O from Combustion	Avoided Utility Emissions	Steel Recovery	Net Emissions (Post-Consumer)
PLA	-	0.03	-	-	-0.65	-	-0.62

Note: Negative emissions indicate GHG benefits.

-- = Zero emissions.

Because this study considers a material from end of life, RMAM emissions are considered to be zero for this materials management pathway. Since there is no nitrogen content in PLA, we assume no N₂O emissions from combustion. There are also no emissions avoided due to steel recovery.

Emissions from Transportation of Waste. For the CO₂ emissions from transporting waste to the combustion facility, and ash from the combustion facility to a landfill, EPA used an estimate of 60 lbs CO₂ per ton of MSW for transportation of mixed MSW developed by FAL (1994). EPA then converted the Franklin Associates estimate from pounds of CO₂ per ton of mixed MSW to MTCO₂E per ton of mixed MSW and applied it to estimate CO₂ emissions from transporting one short ton of mixed MSW and the resulting ash. WARM assumes that transportation of PLA uses the same amount of energy as transportation of mixed MSW.

Avoided Utility Emissions. Most WTE plants in the United States produce electricity and only a few cogenerate electricity and steam (EPA, 2006). In this analysis, EPA assumes that the energy recovered with PLA combustion would be in the form of electricity, as shown in Exhibit 15. The exhibit shows emission factors for mass burn facilities (the most common type of WTE plant). EPA used three data elements to estimate the avoided electric utility CO₂ emissions associated with combustion of waste in a WTE plant: (1) the energy content of each waste material, (2) the combustion system efficiency in converting energy in MSW to delivered electricity, and (3) the electric utility CO₂ emissions avoided per kilowatt-hour (kWh) of electricity delivered by WTE plants.

For PLA, we can calculate the amount of GHG avoided using the national average non-baseload factor for utility generated electricity based on the energy content of PLA. According to the [NatureWorks' PLA website](http://www.natureworkslc.com/The-Ingeo-Journey/End-of-Life-Options/Incineration.aspx)¹⁰, the Ingeo PLA contains 8,368 Btu/pound. At a combustion efficiency of roughly 18 percent at mass burn combustion facilities, this translates into avoided CO₂ emissions of 0.68 MTCO₂E/short ton of PLA combusted as shown below.

¹⁰ <http://www.natureworkslc.com/The-Ingeo-Journey/End-of-Life-Options/Incineration.aspx>

Exhibit 15: Utility GHG Emissions Offset from Combustion of PLA

(a) Material/Product	(b) Energy Content (Million Btu per Short Ton)	(c) Combustion System Efficiency (%)	(d) Emission Factor for Utility-Generated Electricity (MTCO ₂ E/ Million Btu of Electricity Delivered)	(e) Avoided Utility GHG per Short Ton Combusted (MTCO ₂ E/Short Ton) (e = b × c × d)
PLA	16.74	17.8%	0.22	0.65

Source: NatureWorks, LLC (2010a).

To estimate the gross GHG emissions per ton of PLA combusted, EPA adds transportation CO₂ emissions to the avoided utility emissions in order to calculate the net GHG emission factor. As shown in Exhibit 15 WARM estimates that combustion of PLA results in a net emissions reduction.

4.5 LANDFILLING

The landfilling emissions factor is calculated as the sum of emissions from transportation of waste to the landfill and operation of landfill equipment, methane emissions from degradation of biogenic carbon in the landfill, avoided GHG emissions from landfill methane capture and subsequent energy recovery, and the carbon storage resulting from undecomposed carbon remaining in landfills. According to NatureWorks (2011a), PLA does not biodegrade in landfill conditions. However, other biopolymers such as poly(3-hydroxybutyrate-co-3-hydroxyoctanoate) (PHBO) (C₁₃H₂₁O₄) have been shown to degrade in landfills so it is important not to use PLA as a proxy for other biopolymers (Levis and Barlaz 2011). For Ingeo PLA, the percentage of sequestered biogenic carbon remains steady at close to 100 percent for the 2002D PLA product even after four months in simulated landfill conditions.¹¹ This is similar to petroleum-based polyethylene (PE) plastic resin. Therefore, landfill CH₄ emissions in the landfilling pathway are determined to be zero for PLA.¹² Accordingly, there are no avoided CO₂ emissions from landfill gas recovery for energy.

However, we can calculate the amount of biogenic carbon stored in the landfill based on the CO₂ sequestered via photosynthesis in corn production. The “inputs from nature” in the US LCI Database PLA spreadsheet accounts for “CO₂ taken from air during corn production and stored in polymer”. We have translated this information into the assumed “biogenic carbon content” of the PLA (Exhibit 16).

Exhibit 16: Biogenic Carbon Content of PLA¹³

(a) CO ₂ , biogenic, uptake by corn used to manufacture PLA (kg CO ₂ /kg PLA)	(b=a*0.907) CO ₂ , biogenic, uptake by corn used to manufacture PLA (short ton CO ₂ /short ton PLA)	(c = b *(12/44)) Carbon stored within PLA (short ton Carbon/short ton PLA)	(d) Biogenic Carbon Content (percent per short ton PLA)
1.83	1.66	0.50	50%

The only emissions associated with landfilling for PLA relate to transporting PLA waste to the landfills and moving waste around in the landfills. Transportation of waste and the use of landfilling equipment results in anthropogenic CO₂ emissions, due to the combustion of fossil fuels in the vehicles

¹¹ <http://www.natureworkslc.com/The-Ingeo-Journey/End-of-Life-Options/Landfill.aspx>

¹² It was determined that assuming zero degradation in landfill conditions for the PLA Ingeo 2002d is valid and supported by experimental results.

¹³ In response to the *Preliminary Review of NatureWorks polylactide biopolymer (PLA) LCI Data* memo (EPA, 2010) prepared by ICF, NatureWorks responded that the “net CO₂ uptake is 1.833 kg CO₂/kg PLA” which implies that Carbon content of PLA is 50% (EPA 2010b).

used. For further information please refer to the chapter on Landfilling. Exhibit 17 provides the net emission factor for landfilling of PLA.

Exhibit 17: Landfilling Emission Factors for PLA (MTCO₂E/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)
PLA	-	0.04	-	-	-1.66	-1.62

5. LIMITATIONS

In developing and reviewing the life-cycle emission factors for all the materials management pathways, it is clear that source reduction and landfilling result in net GHG benefits for PLA. This can also be seen in Exhibit 3. Landfilling appears to be a particularly attractive option because of the assumption that 100 percent of the biogenic carbon is stored in landfills. Source reduction is the only materials management strategy that results in more GHG benefits than landfilling (due to avoided PLA production).

A few key limitations and uncertainties of this analysis include the following:

High landfill carbon storage: For this analysis EPA assumes 100 percent landfill carbon storage for PLA. Limited lab testing by NatureWorks indicated that the biogenic carbon of only one of the PLA products (Ingeo 2002d - thermoforming) is fully stored in a landfill, while the other two (Ingeo 4032 D and 4060D – film) show a decrease in carbon storage under accelerated landfill conditions. Since the WARM analysis mainly considers thermoforming products in the waste stream, discussion with NatureWorks determined that assuming zero degradation in landfills for the PLA Ingeo 2002d is valid and supported by experimental results. However, this assumption may be conservative since PLA may break down over time, especially under accelerated conditions. Thus, the GHG benefits of landfilling PLA may be lower than currently calculated.

Currently unavailable recycling data: Data relevant to the recycling materials management pathway for PLA are lacking. EPA will consider incorporating the recycling pathway for PLA in the future should the necessary data become available.

6. REFERENCES

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