
**LIFE CYCLE ASSESSMENT (LCA)
OF CARBOLINE INTUMESCENT FIRE-
RESISTIVE MATERIALS**

Status Public report

Client Carboline



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1 INTRODUCTION

1.1 Opportunity

Carboline is a professional coating company who develops and manufactures protective coatings, linings, and fireproofing products designed for industrial or architectural applications. Carboline commits to not only offering high performance products to solve real-world problems but also satisfying the regional and national architectural codes. Moving forward, Carboline has decided to extend its commitment to the sustainability of products it provides to the market.

The first step for this action is to transparently communicate the environmental impact and performance of its products. As a result, it is important to conduct life cycle assessments (LCAs) to evaluate the environmental impacts from raw materials acquisition through the end of life. The goal of conducting an LCA is to explore the environmental impacts that Carboline's products have and to identify ways to improve processes and reduce impacts.

To understand the true impact of production, Carboline commissioned Sustainable Minds to help develop LCAs for its intumescent fire-resistive materials (IFRMs) using a cradle-to-grave approach. The products are either water-based or epoxy-based intumescent fireproofing coatings. Carboline wants to learn from the results and is looking forward to having guidance for future product improvements that can be deduced from the results.

The products included in this study are listed below:

1. Firefilm III
2. Firefilm IV
3. Thermo-Sorb VOC
4. Thermo-Sorb 263
5. Thermo-Lag E100
6. Thermo-Lag E100-S
7. Thermo-Lag 3000
8. Thermo-Lag 3000-SP

Carboline is interested in having LCA data available for its IFRM products to be able to obtain a Sustainable Minds Transparency Report™ (TR), a Type III Environmental Declaration that can be used for communication with and amongst other companies, architects, and consumer communication, and that can also be utilized in whole building LCA tools in conjunction with the LCA background report and life cycle inventory (LCI). This study aims at being compliant with the requirements of ISO 14040/14044 [1], ISO 21930 standards [2], and the NSF PCR for Architectural Coatings [3].

1.2 Life cycle assessment

This LCA follows the ISO 14044 standard. This study includes the following phases:

- Goal and Scope
- Inventory Analysis
- Impact Assessment
- Interpretation

A critical review of the LCA and an independent verification of the TR are required for Type III Environmental Declarations. Both are included in this project.

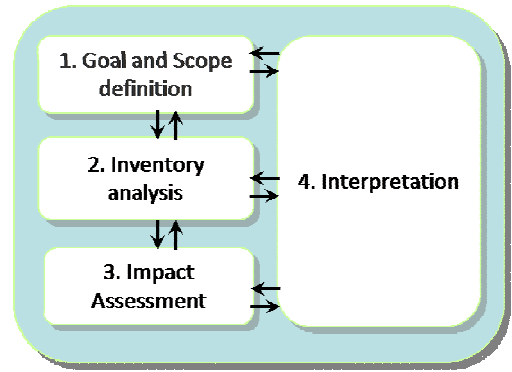


Figure 1. Life cycle assessment approach

1.3 Status

All information in this report reflects the best possible inventory by Carboline at the time it was collected, and best practices were conducted by Sustainable Minds and Carboline employees to transform this information into this LCA report.

The data covers annual manufacturing data for the 2021 calendar year from Carboline's manufacturing plant in Lake Charles, Louisiana and Dayton, Nevada. Where data was missing, assumptions were made from manufacturing data for the two facilities based upon expertise from Carboline employees.

This study includes primary data from the processes at these manufacturing facilities and background data to complete the inventory and fill gaps where necessary.

The LCA review and Sustainable Minds Transparency Reports / EPDs verification was performed by Jack Geibig, President, Ecoform to determine conformance to ISO 14040/14044 and the aforementioned PCR.

1.4 Team

This report is based on the work of the project team led by Stephanie Gelhot on behalf of Carboline. Sustainable Minds led the development of the LCA results, report, and TRs.

1.5 Structure

This report follows the following structure:

- Chapter 2: Goal and scope
- Chapter 3: Life cycle inventory analysis
- Chapter 4: Assessment and interpretation
- Chapter 5: References

This report includes LCA terminology. To assist the reader, special attention has been given to list definitions of important terms used at the end of this report.

2 GOAL AND SCOPE

This chapter explains the starting points for the LCA. The aim of the goal and scope is to define the products under study and the depth and width of the analysis.

2.1 Intended application and audience

This report intends to define the specific application of the LCA methodology to the life cycle of Carboline products. It is intended for both internal and external purposes. The intended audience includes the program operator (Sustainable Minds) and reviewers who will be assessing the LCA for conformance to the PCR, as well as Carboline internal stakeholders involved in marketing and communications, operations, and design. Results presented in this document are not intended to support comparative assertions within this study. However, the results will be disclosed to the public in Sustainable Minds Transparency Reports (Type III Environmental Declarations per ISO 14025) which are focused on products that are available in the US market. These Transparency Reports will undergo critical review for conformance to the PCR and to ISO 14025.

2.2 Product description

For more than 70 years, Carboline has combined innovative product development with technical knowledge and experience to provide superior protective coating solutions around the world. As a manufacturer of intumescent fireproofing coatings and fire-resistive materials, Carboline is interested in demonstrating its sustainability leadership and leveraging business value associated with transparent reporting of its products' cradle-to-grave environmental impacts. For more information on Carboline products, go to <https://www.carboline.com/>.

Carboline's IFRM products are thin-film, intumescent coating products for structural steel. They allow the designer to express the structure as an artform at interior or exterior locations in buildings where fire resistance ratings are required. In a fire, they soften and expand to form thick meringue-like layers, which insulate the structure and protect the steel from fire. The manufacturing location for these coating products are listed in Table 1a. The declaration name with product represented and type of declaration, and other product information are listed in Tables 1b and 1c, respectively.

Table 1a. Product name and manufacturing location

Product name	Manufacturing location
Firefilm III	Lake Charles, Louisiana, USA
Firefilm IV	
Thermo-Sorb VOC	
Thermo-Sorb 263	Dayton, Nevada, USA
Thermo-Lag E100	
Thermo-Lag E100-S	
Thermo-Lag 3000	
Thermo-Lag 3000-SP	

Table 1b. Declaration names with products represented and type of declaration

Product name	CSI MasterFormat®	Transparency Report	Type of declaration
Firefilm III	07 81 23	Firefilm Series	Product-specific declaration from a manufacturer's plant
Firefilm IV			
Thermo-Sorb VOC	07 81 23	Thermo-Sorb Series	
Thermo-Sorb 263			
Thermo-Lag E100	07 81 23	Thermo-Lag Series	
Thermo-Lag E100-S			
Thermo-Lag 3000			
Thermo-Lag 3000-SP			

Table 1c. Other product information

Product name	Application environment	Application
Firefilm III	Interior steel beams, columns, tubes, and pipes	Water-based thin film intumescent coating products that are sprayed on steel substrate for improving fire resistance.
Firefilm IV	Interior steel columns	
Thermo-Sorb VOC	Interior steel beams, columns, tubes, and pipes	Building codes require certain beam, column, floor, wall, and roof assemblies to have fire resistance ratings which are determined on the basis of standard fire tests.
Thermo-Sorb 263		
Thermo-Lag E100	Structural steel beams, I-section columns, tubular columns, and pipes in both exterior and interior environments	Thermo-Lag E100 and 3000 series are two-component epoxy-based intumescent fireproofing coatings designed for both exterior and interior use.
Thermo-Lag E100-S		
Thermo-Lag 3000	Provides asset integrity from the damaging effects of hydrocarbon fires in oil, gas, refineries, power, marine, petrochemical, and LNG facilities	These products offer superior fire protection and high-quality aesthetics for commercial and light industrial projects.
Thermo-Lag 3000-SP		

2.3 Functional unit

According to the PCR, the functional unit is:

1 m² of covered and protected substrate for a period of 60 years (the assumed average lifetime of a building).

Carboline's fireproofing coatings are protective coatings in the general exterior coatings and interior coatings category. Product life for architectural coatings is expressed both in terms of a typical market life (5 years) and a technical life (either 5, 10, or 20 years) per the PCR, depending on performance in certain durability tests/methodologies prescribed.

Since these fireproofing coatings fall under the primer designation and are applied to interior architecture, no design life was needed. They are applied to interior steel structures which typically do not have cosmetic requirements. However, in cases where color choices are desired, optional Carboline approved topcoats or topcoat systems can be used to meet project specifications for color, finish, service requirements, and UV protection. Colorants are not added to the fireproofing coatings themselves, neither at the point of sale nor at the point of application as defined in the application manuals and are therefore not included in the scope of this study. Only a market lifetime of 5 years was used in the LCA models. The results of the LCA in this report are expressed in terms of the functional unit.

There are different theoretical coverages for Carboline's IFRM products when following the application methods described in Carboline's product data sheets. Different fireproof coating products shall be applied to the specified Dry Film Thickness (DFT) in order to provide designed fire protection.

Since the functional unit mandates a 60-year product life, one initial coating application and eleven reapplications are necessary over the average lifetime of a building. The results in this report are presented per functional unit. The mass of the declared products that meet the market-based life of 1 m² of covered and protected substrate for a period of 5 years is listed in Table 2.

Table 2. The mass of the declared products that meets the market-based life

Product	Dry Film Thickness (DFT) / coat	Theoretical coverage at 1 mil thickness	Density (lb / gal)	Mass per 1 m ² coverage at DFT (lb)	Mass per 1 m ² coverage at DFT per market life (kg)	Reference flow per functional unit (kg)
Firefilm III	30 mils	111 m ² per gallon	█	█	█	8.94
Firefilm IV	28 mils	111 m ² per gallon	█	█	█	8.58
Thermo-Sorb VOC	35 mils	116 m ² per gallon	█	█	█	9.06
Thermo-Sorb 263	27 mils	113 m ² per gallon	█	█	█	7.80
Thermo-Lag E100	80 mils	149 m ² per gallon	█	█	█	17.7
Thermo-Lag E100-S	60 mils	141 m ² per gallon	█	█	█	13.6
Thermo-Lag 3000	80 mils	149 m ² per gallon	█	█	█	17.6
Thermo-Lag 3000-SP	60 mils	141 m ² per gallon	█	█	█	13.9

2.4 System boundaries

This section describes the system boundary for the analysis. The system boundary defines which life cycle stages are included and which are excluded.

Figure 2 illustrates all the life cycle phases included in this study. This LCA's system boundary is from cradle to grave. Therefore, the life cycle activities and related processes shall include from ISO 21930 stage 1 to ISO 21930 stage 4. This includes the product stage, design and construction stage, use and maintenance stage, and end-of-life stage.

Table 3 lists specific inclusions and exclusions for the system boundaries.

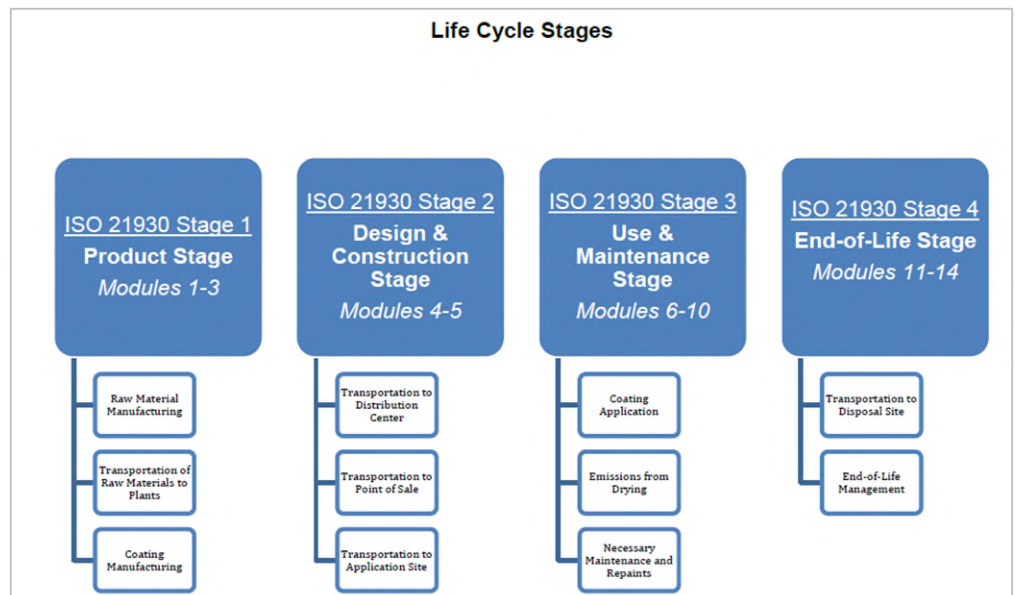


Figure 2. Applied system boundaries for the modeled IFRMs

Table 3. System boundaries

Included	Excluded
<ul style="list-style-type: none"> • Raw material acquisition and processing • Processing of materials • Energy production • Transport of raw materials • Outbound transportation of products • Overhead energy (heating, lighting, forming, finishing, etc.) of manufacturing facilities • Packaging of final products • Installation and maintenance, including material loss, energy use, and auxiliary material requirements • Emissions to air from drying • End of life, including transportation • Final disposition 	<ul style="list-style-type: none"> • Construction of major capital equipment • Maintenance and operation of support equipment • Human labor and employee transport • Manufacture and transport of packaging materials not associated with final product • Disposal of packaging materials not associated with final product • Building operational energy and water use

2.4.1. Product stage

Raw material manufacturing

The product stage includes, where relevant, the following processes:

- Extraction and processing of raw materials
- Average transport of raw materials from extraction/production to manufacturer
- Energy and water consumption for raw material manufacturing

Transportation of raw materials to plants

- Transport of raw materials to manufacturer
- Packaging for raw material transportation

Coating manufacturing

The manufacturing stage includes the following:

- Energy and water consumption for coating manufacturing
- Releases to environmental media (air, soil, ground, and surface water)
- Manufacturing waste, packaging waste, and scrap
- Waste transportation from manufacturing plant to disposal sites
- Waste disposal

2.4.2. Design and construction stage

The transportation stage includes the following:

- Transportation of IFRM products from manufacturer to distributor
- Transportation of the product from distributor to point of sale
- Transportation of the product from point of sale to application site

2.4.3. Use and maintenance stage

The installation and maintenance stage includes the following:

- Application on the building including any materials specifically required for application
- Releases to environmental media (air, soil, ground, and surface water)
- Unused coating product remains in the paint sprayer and pail
- Number of replacements of the IFRM product
- Maintenance of the IFRM coating that under normal conditions will be necessary to achieve the defined reference service life
- Releases to environmental media (air, soil, ground, and surface water) from drying processes
- Packaging waste after installation

2.4.4. End-of-life stage

The disposal/reuse/recycling stage includes the following:

- Dismantling/Demolition
- Transport from building site to final disposition
- Final disposition (e.g., recycling / reuse / landfill / waste incineration / conversion to energy)

2.5 Impact assessment characterization

The environmental indicators as required by the PCR are included as well as other indicators required to use the SM2013 Methodology [4] (see Table 4). The impact indicators are derived using the 100-year time horizon¹ factors, where relevant, as defined by TRACI 2.1 classification and characterization [5]. Long-term emissions (> 100 years) are not taken into consideration in the impact estimate. This follows the approach from the PCR.

Table 4. Selected impact categories and units

Impact category	Unit	Description
Acidification	kg SO ₂ eq (sulphur dioxide)	Acidification processes increase the acidity of water and soil systems and causes damage to lakes, streams, rivers and various plants and animals as well as building materials, paints, and other human-built structures.
Ecotoxicity	CTUe	Ecotoxicity causes negative impacts to ecological receptors and, indirectly, to human receptors through the impacts to the ecosystem.
Eutrophication	kg N eq (nitrogen)	Eutrophication is the enrichment of an aquatic ecosystem with nutrients (nitrates and phosphates) that accelerate biological productivity (growth of algae and weeds) and an undesirable accumulation of algal biomass.
Global warming	kg CO ₂ eq (carbon dioxide)	Global warming is an average increase in the temperature of the atmosphere near the Earth's surface and in the troposphere.
Ozone depletion	kg CFC-11 eq	Ozone depletion is the reduction of ozone in the stratosphere caused by the release of ozone depleting chemicals.
Carcinogenics	CTUh	Carcinogens have the potential to form cancers in humans.
Non-carcinogenics	CTUh	Non-Carcinogens have the potential to causes non-cancerous adverse impacts to human health.
Respiratory effects	kg PM _{2.5} eq (fine particulates)	Particulate matter concentrations have a strong influence on chronic and acute respiratory symptoms and mortality rates.
Smog	kg O ₃ eq (ozone)	Smog formation (photochemical oxidant formation) is the formation of ozone molecules in the troposphere by complex chemical reactions.
Fossil fuel depletion	MJ surplus	Fossil fuel depletion is the surplus energy to extract minerals and fossil fuels.

It shall be noted that the above impact categories represent impact potentials. They are approximations of environmental impacts that could occur if the emitted molecules would follow the underlying impact pathway and meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach).

¹ The 100-year period relates to the period in which the environmental impacts are modeled. This is different from the time period of the functional unit. The two periods are related as follows: all environmental impacts that are created in the period of the functional unit or market-based life are modeled through life cycle impact assessment using a 100-year time horizon to understand the impacts that take place.

The results from the impact assessment indicate potential environmental effects and do not predict actual impacts on category endpoints, the exceedance of thresholds, or safety margins or risks.

2.6 Normalization and weighting

To arrive to a single score indicator, normalization [6] and weighting [7] as shown in Table 5 conforming to the SM 2013 Methodology were applied.

Table 5. Normalization and weighting factors

Impact category	Normalization	Weighting (%)
Acidification	90.9	3.6
Ecotoxicity	11000	8.4
Eutrophication	21.6	7.2
Global warming	24200	34.9
Ozone depletion	0.161	2.4
Carcinogenics	5.07E-05	9.6
Non carcinogenics	1.05E-03	6.0
Respiratory effects	24.3	10.8
Smog	1390	4.8
Fossil fuel depletion	17300	12.1

2.7 Software and database

The LCA model was created using SimaPro Analyst 9.4. The ecoinvent database and other databases as listed in section 3.4 provide the life cycle inventory data of the raw materials and processes for modeling the products.

2.8 Cut-off criteria

The cut-off criteria on a unit process level can be summarized as follows:

- All inputs and outputs to a (unit) process shall be included in the calculation of the pre-set parameters results, for which data are available. Data gaps shall be filled by conservative assumptions with average, generic or proxy data. Any assumptions for such choices shall be documented.
- Mass – If a flow is less than 2% of the cumulative mass of the model it may be excluded, providing its environmental relevance is not a concern.
- Energy – If a flow is less than 1% of the cumulative energy of the model it may be excluded, providing its environmental relevance is not a concern.
- Environmental relevance – If a flow meets the above criteria for exclusion, yet it is thought to potentially have a significant environmental impact, it is included.
- Hazardous and toxic materials – The study shall include all hazardous and toxic materials in the inventory therefore the cutoff rules shall not apply to such substances.
- The sum of the neglected material flows does not exceed 5% of mass, energy or environmental relevance for flows indirectly related to the process (e.g., operating materials).

In this report, no known flows are deliberately excluded. Over 95% of total material mass and energy consumption in the products' lifetimes were included in the model. The completeness of the bill of materials defined in this report satisfies the above defined cut-off criteria.

2.9 Allocation

Whenever a system boundary is crossed, environmental inputs and outputs have to be assigned to the different products. Where multi-inputs or multi-outputs are considered, the same applies. The PCR prescribes to report where and how allocation occurs in the modeling of the LCA. In this LCA, the following rules have been applied.

The model used in this report ensures that the sum of the allocated inputs and outputs of a unit process shall be equal to the inputs and outputs of the unit process before allocation. This means that no double counting or omissions of inputs or outputs through allocation is occurring.

In this LCA, the only manufacturing input that needed allocation was electricity since there is only one single meter that includes the production of multiple Carboline IFRM products. The allocation of electricity was based on the percentage of production for individual products divided by total site production output. In addition, there is no co-product produced in the manufacturing process.

2.10 Critical review

This is a supporting LCA report for Carboline Transparency Reports™ / EPDs and will be evaluated for conformance to the PCR according to ISO 14025 [8] and the ISO 14040/14044 standards [1].

3 LIFE CYCLE INVENTORY ANALYSIS

This chapter includes an overview of the obtained data and data quality that has been used in this study. For the complete life cycle inventory, which catalogs the flows crossing the system boundary and provides the starting point for life cycle impact assessment, see Tables 7a-h below.

3.1 Data collection

Data used for this project represents a mix of primary data collected from Carboline on the production of the intumescent fire-resistive materials (gate-to-gate) and background data from SimaPro databases. Overall, the quality of the data used in this study is considered to be good and representative of the described systems. All appropriate means were employed to guarantee the data quality and representativeness as described below.

- **Gate-to-gate:** Data on processing materials and manufacturing the intumescent fireproofing coatings were collected in a consistent manner and level of detail to ensure high quality data. All submitted data were checked for quality multiple times on the plausibility of inputs and outputs. All questions regarding data were resolved with Carboline. Data were collected primarily at Carboline's Lake Charles and Dayton facilities. Data was collected by a product line analyst at Carboline by contacting Carboline's purchasing department and others with product knowledge. Resulting inventory calculations were developed by an analyst at Sustainable Minds and subsequently checked internally.
- **Background data:** The model was constructed in SimaPro with consistency in mind. Expert judgment was used in selecting appropriate datasets to model the materials and energy for this study and has been noted in the preceding sections. Databases adopted in the model include ecoinvent v3, US-EI 2.2, and ELCD databases.

All primary data were provided by Carboline. Upon receipt, data were cross-checked for completeness and plausibility using mass balance, stoichiometry, and benchmarking. If gaps, outliers, or other inconsistencies occurred, Sustainable Minds engaged with Carboline to resolve any open issues.

3.2 Primary data

Carboline's intumescent fireproofing coatings are produced in the Lake Charles and Dayton manufacturing facilities as mentioned above in Table 1a. The manufacturing process involves adding pre-weighted ingredients and then mixing them in proper order for the products. Carboline then packages and distributes the finished products to distribution centers. The flow charts in Figure 3a and Figure 3b illustrate the life cycle of Carboline's products produced in the Lake Charles and Dayton facilities.



Figure 3a. Life cycle flow chart of IFRM production in the Lake Charles facility



Figure 3b. Life cycle flow chart of IFRM production in the Dayton facility

3.2.1. Product stage

Raw materials extraction, manufacturing, and transportation represents the first stage of the intumescent fireproofing coating life cycle. The full Bills of Material (BOMs) were provided by Carboline with a detailed breakdown of the raw materials for its products.

Raw materials are extracted and manufactured by material suppliers. Suppliers then transport raw materials along with the associated packaging to Carboline's manufacturing plant in Lake Charles, Louisiana and Dayton, Nevada. Most of the ingredients are transported via truck and trailer within the U.S., but some of the ingredients are imported overseas.

After the batch materials are transported to Carboline's facilities, they are offloaded and stored before processing. Raw materials are mixed and added to the mixer and ribbon blender. Manual and air-operated diaphragm pumps (AODs) are used for adding ingredients to the mixer and ribbon blender. At the end of the line, the mixed product is complete.

Carboline's Lake Charles and Dayton facilities produce various products in any given year. To accurately allocate electricity to the individual products, the total annual electricity consumption of the plant (obtained from utility bills) was assessed proportionately based on the percentage of production for individual products versus total site outputs. Manufacturing inputs and outputs for the products are shown in Tables 7a-h.

In the case of the products manufactured at the Lake Charles facility, scrap, packaging waste, non-hazardous waste, and recyclables are shipped to the Lake Charles Hauling and Transfer Station, 5.6 miles away from Carboline's Lake Charles plant. Hazardous waste is assumed to be sent 19.8 miles to a management facility for disposal.

In the case of the products manufactured at the Dayton facility, scrap, packaging waste, non-hazardous waste, and recyclables are shipped to the Sutro Transfer Station, 7.6 miles away from Carboline's Dayton plant. Hazardous waste is assumed to be sent 55.5 miles to a management facility for disposal.

To be able to apply Carboline's Thermo-Lag E100 and Thermo-Lag 3000 series products, end users must mix Parts A and B at the application site. Therefore, this study uses the average packaging weight as input data for the Thermo-Lag E100 and Thermo-Lag 3000 series products. In compliance with the PCR, the study did not include the transportation for the steel pail packaging. Table 6a shows the information for the finished products and their packaging. Raw materials and the associated packaging inputs for Carboline's intumescent fireproofing coatings are listed in Table 6b.

Table 6a. Product and packaging information

Product	Product weight (kg)	Packaging weight (kg)	Average packaging weight for 1kg product (kg)
Firefilm III	27.60	1.36 steel pail	0.049
Firefilm IV	28.38	1.36 steel pail	0.048
Thermo-Sorb VOC	25.07	1.86 steel pail	0.074
Thermo-Sorb 263	27.31	1.86 steel pail	0.068
Thermo-Lag E100	24.21- Part A 25.19- Part B	1.86 steel pail	0.075
Thermo-Lag E100-S	12.03- Part A 12.42- Part B	1.86 steel pail	0.153
Thermo-Lag 3000	24.37- Part A 24.87- Part B	1.86 steel pail	0.076
Thermo-Lag 3000-SP	12.04- Part A 12.37- Part B	1.86 steel pail	0.153

Table 6b. Transportation for raw material and packaging

Product	Ocean - Total transported mass for 1kg product (tkm)	Road - Total transported mass for 1kg product (tkm)
Firefilm III	28.020	13.921
Firefilm IV	7.186	11.948
Thermo-Sorb VOC	17.859	14.809
Thermo-Sorb 263	13.393	13.587
Thermo-Lag E100	47.393	26.963
Thermo-Lag E100-S	44.963	26.560
Thermo-Lag 3000	42.306	30.349
Thermo-Lag 3000-SP	18.958	65.019

Table 7a. Firefilm III manufacturing inputs and outputs for 1 lb of Firefilm III

Manufacturing facility in Lake Charles, Louisiana			
Resource category	Flow	Amount	Unit
Electricity	Electricity	█	kWh
Fuels	Natural gas	█	MJ
Raw materials	Acid catalyst	20-30	%
	Resin	10-20	%
	Pigment	10-20	%
	Deionized water	10-20	%
	Carbon donor	10-20	%
	Additives	10-20	%
	Packaging	Steel pail for finished product	0.049
Waste generation	Landfill disposal – manufacturing scrap	0.019	lb
	Landfill Disposal – Non-hazardous waste	0.00382	lb
	Landfill Disposal – Plastic packaging waste	0.0011	lb
	Treatment of hazardous waste	0.0361	lb
	Recyclable – Paper packaging waste	0.0175	lb
	Recyclable – Steel packaging waste	0.0186	lb
Waste transport	Transportation for landfill / recycling– Scrap, non-hazardous waste, packaging, recyclables	0.336	lbmi
	Transportation for hazardous waste	0.715	lbmi

Table 7b. Firefilm IV manufacturing inputs and outputs for 1 lb of Firefilm IV

Manufacturing facility in Lake Charles, Louisiana			
Resource category	Flow	Amount	Unit
Electricity	Electricity	█	kWh
Fuels	Natural gas	█	MJ
Raw materials	Acid catalyst	30-40	%
	Resin	10-20	%
	Pigment	10-20	%
	Spumific	5-10	%
	Additives	10-20	%
Packaging	Steel pail for finished product	0.048	lb
Waste generation	Landfill disposal – manufacturing scrap	0.003	lb
	Landfill Disposal – Non-hazardous waste	0.00371	lb
	Landfill Disposal – Plastic packaging waste	0.0015	lb
	Treatment of hazardous waste	0.0351	
	Recyclable – Paper packaging waste	0.011	lb
	Recyclable – Steel packaging waste	0.0207	lb
Waste transport	Transportation for landfill / recycling – scrap, non-hazardous waste, packaging, recyclables	0.223	lbmi
	Transportation for hazardous waste	0.693	lbmi

Table 7c. Thermo-Sorb VOC manufacturing inputs and outputs for 1 lb of Thermo-Sorb VOC

Manufacturing facility in Lake Charles, Louisiana			
Resource category	Flow	Amount	Unit
Electricity	Electricity	█	kWh
Fuels	Natural gas	█	MJ
Raw materials	Acid catalyst	10-20	%
	Solvent	10-20	%
	Carbon donor	5-10	%
	Resin	5-10	%
	Spumific	5-10	%
	Additives	10-20	%
	Packaging	Steel pail for finished product	0.074
Waste generation	Landfill disposal – manufacturing scrap	0.019	lb
	Landfill Disposal – Non-hazardous waste	0.0032	lb
	Landfill Disposal – Plastic packaging waste	0.0048	lb
	Treatment of hazardous waste	0.0327	
	Recyclable – paper packaging waste	0.0162	lb
Recyclable – steel packaging waste	0.0183	lb	
Waste transport	Transportation for landfill / recycling– scrap, non-hazardous waste, packaging, recyclables	0.35	lbmi
	Transportation for hazardous waste	0.786	lbmi

Table 7d. Thermo-Sorb 263 manufacturing inputs and outputs for 1 lb of Thermo-Sorb 263

Manufacturing facility in Dayton, Nevada			
Resource category	Flow	Amount	Unit
Electricity	Electricity	█	kWh
Fuels	Natural gas	█	MJ
Raw materials	Acid catalyst	20-30	%
	Pigment	10-20	%
	Solvent	10-20	%
	Resin	10-20	%
	Spumific	5-10	%
	Carbon donor	5-10	%
	Additives	10-20	%
Packaging	Steel pail for finished product	0.068	lb
Waste generation	Landfill disposal – manufacturing scrap	0.019	lb
	landfill disposal – non-hazardous waste	0.00337	lb
	landfill disposal – plastic packaging waste	0.0019	lb
	Treatment of hazardous waste	0.035	
	Recyclable – paper packaging waste	0.0097	lb
	Recyclable – steel packaging waste	0.0151	lb
Waste transport	Transportation for landfill / recycling– scrap, non-hazardous waste, packaging, recyclables	0.373	lbmi
	Transportation for hazardous waste	1.94	lbmi

Table 7e. Thermo-Lag E100 manufacturing inputs and outputs for 1 lb of Thermo-Lag E100

Manufacturing facility in Dayton, Nevada			
Resource category	Flow	Amount	Unit
Electricity	Electricity	█	kWh
Fuels	Natural gas	█	MJ
Raw materials	Acid catalyst	20-30	%
	Curing agent	20-30	%
	Resin	10-20	%
	Spumific	5-10	%
	Carbon donor	5-10	%
	Spumific	5-10	%
	Additives	10-20	%
Packaging	Steel pail for finished product	0.075	lb
Waste generation	Landfill disposal – manufacturing scrap	0.019	lb
	Landfill Disposal – non-hazardous waste	0.00335	lb
	Landfill Disposal – plastic packaging waste	0.0005	lb
	Treatment of hazardous waste	0.0348	
	Recyclable – paper packaging waste	0.0163	lb
	Recyclable – steel packaging waste	0.0189	lb
Waste transport	Transportation for landfill / recycling– scrap, non-hazardous waste, packaging, recyclables	0.44	lbmi
	Transportation for hazardous waste	1.93	lbmi

Table 7f. Thermo-Lag E100-S manufacturing inputs and outputs for 1 lb of Thermo-Lag E100-S

Manufacturing facility in Dayton, Nevada			
Resource category	Flow	Amount	Unit
Electricity	Electricity	█	kWh
Fuels	Natural gas	█	MJ
Raw materials	Acid catalyst	20-30	%
	Curing agent	20-30	%
	Resin	10-20	%
	Spumific	10-20	%
	Carbon donor	5-10	%
	Pigment	0-5	%
	Additives	10-20	%
Packaging	Steel pail for finished product	0.152	lb
Waste generation	Landfill disposal – manufacturing scrap	0.019	lb
	Landfill Disposal – non-hazardous waste	0.00346	lb
	Landfill Disposal – plastic packaging waste	0.0003	lb
	Treatment of hazardous waste	0.0359	
	Recyclable – paper packaging waste	0.0003	lb
	Recyclable – steel packaging waste	0.0172	lb
Waste transport	Transportation for landfill / recycling– scrap, non-hazardous waste, packaging, recyclables	0.431	lbmi
	Transportation for hazardous waste	1.99	lbmi

Table 7g. Thermo-Lag 3000 manufacturing inputs and outputs for 1 lb of Thermo-Lag 3000

Manufacturing facility in Dayton, Nevada			
Resource category	Flow	Amount	Unit
Electricity	Electricity	█	kWh
Fuels	Natural gas	█	MJ
Raw materials	Curing agent	20-30	%
	Acid catalyst	20-30	%
	Resin	10-20	%
	Spumific	10-20	%
	Modified resin	5-10	%
	Carbon donor	5-10	%
	Additives	10-20	%
	Packaging	Steel pail for finished product	0.076
Waste generation	Landfill disposal – manufacturing scrap	0.013	lb
	Landfill Disposal – non-hazardous waste	0.00337	lb
	Landfill Disposal – plastic packaging waste	0.0004	lb
	Treatment of hazardous waste	0.0349	
	Recyclable – paper packaging waste	0.0156	lb
	Recyclable – steel packaging waste	0.0228	lb
Waste transport	Transportation for landfill / recycling– scrap, non-hazardous waste, packaging, recyclables	0.42	lbmi
	Transportation for hazardous waste	1.94	lbmi

Table 7h. Thermo-Lag 3000-SP manufacturing inputs and outputs for 1 lb of Thermo-Lag 3000-SP

Manufacturing facility in Dayton, Nevada			
Resource category	Flow	Amount	Unit
Electricity	Electricity	■	kWh
Fuels	Natural gas	■	MJ
Raw materials	Curing agent	20-30	%
	Acid catalyst	20-30	%
	Resin	10-20	%
	Spumific	10-20	%
	Carbon donor	5-10	%
	Pigment	0-5	%
	Additives	10-20	%
Packaging	Steel pail for finished product	0.153	lb
Waste generation	Landfill disposal – manufacturing scrap	0.019	lb
	Landfill Disposal – non-hazardous waste	0.0034	lb
	Landfill Disposal – plastic packaging waste	0.0004	lb
	Treatment of hazardous waste	0.0352	
	Recyclable – paper packaging waste	0.0157	lb
	Recyclable – steel packaging waste	0.0186	lb
Waste transport	Transportation for landfill / recycling– scrap, non-hazardous waste, packaging, recyclables	0.434	lbmi
	Transportation for hazardous waste	1.95	lbmi

3.2.2. Design and construction stage

Finished products are packaged in the manufacturing plants and shipped directly to dealer distribution centers. All the finished intumescent fireproofing products are contained in a steel pail for shipping.

Average transportation distances between the manufacturing plant and the distribution centers were provided by Carboline based on sales data. Based on Carboline’s records, all products are shipped by a combination of truck and trailer. Since packaging was transported along with finished fireproofing products, the model also includes the packaging weight in the design and construction stage.

After finished products arrive distribution center, dealers then ship the packaged products to the point of sale. The transportation from distribution centers to point of sale is assumed to be 500 miles via truck and trailer [3].

Finally, Carboline’s IFRM products are purchased by the end users at the point of sale in the US. The transportation from the point of sale to the application site is assumed to be 0 miles via truck and trailer [3].

3.2.3. Use and maintenance stage

3.2.3.1. Coating application

At the application site, the fireproof coating is unpackaged and installed. Spray application is recommended for the optimum coverage and finish. Based on the application equipment guidelines in Carboline’s product data sheets, Graco Mark V, an electric airless sprayer, was adopted in the models. The electricity use during the application process was assumed based on the application equipment guidance mentioned in Carboline’s product data sheets. Table 8 details application equipment guidance and the equipment information.

Table 8. Recommended equipment guidance and information

Product	Equipment	Power rating (kWh)	Flow rate (gpm)
Firefilm III	Graco Mark V Airless Sprayer	2.09	1
Firefilm IV			1
Thermo-Sorb VOC			1.35
Thermo-Sorb 263			1.35
Thermo-Lag E100			1.35
Thermo-Lag E100-S			1.35
Thermo-Lag 3000			1.35
Thermo-Lag 3000-SP			1.35

3.2.3.2. Emissions from drying

During the drying process, the coating will shrink due to the evaporation of water. Table 9 lists the VOCs emitted during the drying processes.

Table 9. VOC emissions from drying

Product	VOC values (lb/gal)
Firefilm III	0.17
Firefilm IV	0.03
Thermo-Sorb VOC	1.18
Thermo-Sorb 263	1.24
Thermo-Lag E100	0.11
Thermo-Lag E100-S	0.53
Thermo-Lag 3000	0.11
Thermo-Lag 3000-SP	0.53

3.2.3.3. Necessary maintenance and repaints

Carboline's fireproof coating products are assumed to be primer coatings and to be applied in an interior environment. Therefore, a 5-year market-based lifetime was adopted in the LCA models. One initial coating application and 11 recoats are required because the average life span of a building is assumed to be 60 years.

3.2.4. End-of-life stage

For this LCA, the steel pail was assumed to be recycled. The 10% unused coating remaining was assumed to be sent for disposal. 100% of the Firefilm and Thermo-Sorb product waste is assumed to be landfilled, and 100% of the Thermo-Lag E100 and 3000 series product waste is assumed to be incinerated [3].

According to the 2012 EPA Waste Reduction Model (WARM model), assumptions include [9]:

- 10% of the wet mass of the coating remains unused after coating application and is properly disposed
- Steel pail is assumed to travel 7 miles to be 100% recycled
- At the end of life, water-based waste coatings are 100% landfilled, and solvent-based waste coatings are 100% incinerated
- Waste coatings are shipped 7 miles the point of disposal

3.3 Data selection and quality

Data requirements provide guidelines for data quality in the LCA and are important to ensure data quality is consistently tracked. Data quality considerations include precision, completeness, and representativeness.

- Precision describes the variability of the inventory data. This study applies a combination of primary data, estimates, and assumptions for some inventory

inputs. Since the inputs and outputs were directly measured by Carboline, we consider inventory data to have good precision.

- Completeness is a measure of the flows (mass, energy, emissions) that are included in the study in relation to the total flows covered in the scope of the product life cycle. Separate data collection forms were developed for each product, and Sustainable Minds worked extensively with Carboline to obtain a comprehensive set of primary data associated with the manufacturing processes. The dataset is considered complete based on our understanding of the manufacturing site. Even though cut-off criteria were observed consistent with those prescribed in the PCR, no known flows are deliberately excluded from this analysis.
- Consistency refers to modeling choices and data sources. The goal is to ensure that differences in results occur due to actual differences between product systems, and not due to inconsistencies in modeling choices, data sources, emission factors, or others.
- Representativeness describes the ability of the data to reflect the system in question. Representativeness is measured using time, technology, and geographic coverage of the data.

An evaluation of the data quality with regard to these requirements is provided in the interpretation chapter of this report.

Time coverage. Primary data were collected on intumescent fireproofing coating production for the calendar year 2021. This period of time was chosen in order to capture a representative picture of businesses activities at Carboline. Background data for upstream and downstream processes (i.e., raw materials, energy resources, transportation, and ancillary materials) were obtained from the ecoinvent v3, ecoinvent 2.2, and ELCD databases.

Technology coverage. Data were collected for intumescent fireproofing coating production at Carboline's manufacturing plants in Lake Charles, Louisiana and Dayton, Nevada.

Geographical coverage. The geographical coverage for this study is based on United States system boundaries for all processes and products. Whenever US background data were not readily available, rest of world (non-Europe) data or global data were used as proxies. Input and output data for modeling come from the manufacturing facilities which are responsible for production.

3.4 Background data

This section details background datasets used in modeling intumescent fireproofing coating environmental performance. Each table lists dataset purpose, name, source, reference year, and location.

3.4.1 Fuels and energy

National and regional averages for fuel inputs and electricity grid mixes were obtained from SimaPro. Table 10 shows the most relevant LCI datasets used in modeling the product systems. The background data which are more than 5 years old were chosen based on being the most technologically representative for raw materials. For the manufacturing stage, the Emissions & Generation Resource Integrated Database (eGRID) dataset was adopted to represent the environmental characteristics of the geographic region where Carboline's manufacturing facility is located.

For the application stage, a mixed generic at-grid electricity dataset for the US was used since Carboline’s products can be applied in various regions in the U.S. The eGRID mixes and the US electricity grid mix were sourced from the U.S. Environmental Protection Agency (US EPA).

Table 10. Key energy datasets used in inventory analysis

Stage	Energy	Dataset name	Primary source	Reference year	Geography
Manufacturing	Electricity	eGRID– SERC	US EPA	2019	US SERC
	Electricity	eGRID– WECC	US EPA	2019	US WECC
	Technical heat	Heat, natural gas, at boiler modulating >100kW/US-US-EI U	US EI 2.2	2018	US
Application	Electricity	Electricity grid mix – US region	US EPA	2019	US

3.4.2. Raw materials production

Data for up- and down-stream raw materials were obtained from the ecoinvent v3, US-EI 2.2, and ELCD databases. Table 11 lists the most relevant LCI datasets used in modeling the raw materials.

Table 11. Key material datasets used in inventory analysis

Raw material	Dataset name	Content (W/W)	Source	Reference year	Geography
■	■	■	ecoinvent v3	2011	Global
	■	■	US-EI 2.2	2008	US
■	■	■	ecoinvent v3	2021	Rest of World (non-Europe)
■	■	■	ecoinvent v3	2021	Global
	■	■	US-EI 2.2	2005	US
■	■	■	ecoinvent v3	2020	Rest of World (non-Europe)
■	■	■	ecoinvent v3	2011	Global
	■	■	ecoinvent v3	2011	Global
■	■	■	ecoinvent v3	2014	Global
■	■	■	ecoinvent v3	2010	Rest of World (non-Europe)
■	■	■	ecoinvent v3	2015	Rest of World (non-Europe)
■	■	■	ecoinvent v3	2021	Rest of World (non-Europe)
■	■	■	US-EI 2.2	2003	US
	■	■	ecoinvent v3	2011	Global
■	■	■	ecoinvent v3	2020	Rest of World (non-Europe)
	■	■	US-EI 2.2	2019	US
■	■	■	ecoinvent v3	2010	Rest of World (non-Europe)
■	■	■	ecoinvent v3	2011	Rest of World (non-Europe)
	■	■	US-EI 2.2	2005	US
■	■	■	US-EI 2.2	2008	US
■	■	■	ELCD	2018	North America
■	■	■	ecoinvent v3	2021	Rest of World (non-Europe)
■	■	■	ecoinvent v3	2021	Global
■	■	■	ecoinvent v3	2018	North America
■	■	■	ecoinvent v3	2021	Rest of World (non-Europe)
■	■	■	ecoinvent v3	2010	Rest of World (non-Europe)

█	█	█	ecoinvent v3	2021	Rest of World (non-Europe)
█	█	█	ecoinvent v3	2010	Rest of World (non-Europe)
█	█				
█	█				
█	█				
█	█	█	ecoinvent v3	2012	Global
█	█	█	ecoinvent v3	2012	Global
█	█	█	US-EI 2.2	2011	US
█	█	█	ecoinvent v3	2021	Rest of World (non-Europe)
█	█				
█	█				
█	█	█	ecoinvent v3	2011	Global
█	█	█	ecoinvent v3	2011	Global
█	█	█	ecoinvent v3	2011	Global
█	█	█	ecoinvent v3	2018	Rest of World (non-Europe)
█	█	█	ecoinvent v3	2015	Global
█	█	█	ecoinvent v3	2010	Rest of World (non-Europe)
█	█	█	ecoinvent v3	2021	Rest of World (non-Europe)
█	█				
█	█	█	ecoinvent v3	2018	North America
█	█	█	ecoinvent v3	2021	Global
█	█	█	US-EI 2.2	2008	US
█	█	█	US-EI 2.2	2011	US
█	█	█	ecoinvent v3	2021	Global
█	█	█	ecoinvent v3	2018	North America
█	█	█	ecoinvent v3	2010	Rest of World (non-Europe)
█	█	█	ecoinvent v3	2012	Global
█	█	█	ecoinvent v3	2019	Rest of World (non-Europe)
█	█	█	ecoinvent v3	2012	US
█	█	█	ecoinvent v3	2011	Rest of World (non-Europe)
█	█				
█	█	█	US-EI 2.2	2005	US
█	█	█	ecoinvent v3	2010	Rest of World (non-Europe)
█	█	█	ecoinvent v3	2010	Rest of World (non-Europe)
█	█	█	ecoinvent v3	2010	Rest of World (non-Europe)
█	█	█	ecoinvent v3	2011	Global
█	█	█	ecoinvent v3	2012	Global
█	█	█	ecoinvent v3	2018	Global
█	█	█	ecoinvent v3	2021	Rest of World (non-Europe)
█	█	█	ecoinvent v3	2015	Global
█	█	█	ecoinvent v3	2021	Rest of World (non-Europe)
█	█				
█	█				
█	█	█	ecoinvent v3	2012	Global
█	█	█	ecoinvent v3	2021	Global
█	█	█	ecoinvent v3	2011	Global
█	█	█	ecoinvent v3	2011	Global
█	█	█	ecoinvent v3	2011	Global
█	█	█	US-EI 2.2	2005	US
█	█	█	ecoinvent v3	2011	Rest of World (non-Europe)
█	█				
█	█	█	ecoinvent v3	2011	Rest of World (non-Europe)
█	█	█	ecoinvent v3	2021	Rest of World (non-Europe)
█	█	█	ecoinvent v3	2012	Global
█	█	█	ecoinvent v3	2021	Global
█	█	█	ecoinvent v3	2021	Global
█	█	█	ecoinvent v3	2012	Global
█	█	█	US-EI 2.2	2008	US
█	█	█	ecoinvent v3	2021	Rest of World (non-Europe)

3.4.3. Transportation

Average transportation distances and modes of transport are included for the transportation of raw materials to the production facility. Typical vehicles used include trucks and ships. Table 12 shows the most relevant LCI datasets used in modeling the transportation.

Table 12. Transportation datasets used in inventory analysis

Transportation	Dataset name	Source	Reference year	Geography
Transport of raw material and packaging to manufacturing facility (U.S. region)	Transport, freight, lorry, 16-32 metric ton, EURO6	ecoinvent v3	2019	Rest of World (non-Europe)
Transport of raw material and packaging to manufacturing facility (Overseas)	Transport, freight, sea, bulk carrier for dry goods	ecoinvent v3	2019	Global
Transport of wastes to disposal point (U.S. region)	Transport, freight, lorry, 16-32 metric ton, EURO6	ecoinvent v3	2019	Rest of World (non-Europe)
Transport of recyclables to recycling center (U.S. region)	Transport, freight, lorry, 16-32 metric ton, EURO6	ecoinvent v3	2019	Rest of World (non-Europe)

3.4.4. Disposal

Disposal processes were obtained from ecoinvent v3 and US-EI 2.2 databases. These processes were chosen to correspond to the materials being disposed, which are packaging materials, scrap, hazardous waste, and unused product. Table 13 reviews the relevant disposal datasets used in the model.

Table 13. Key disposal datasets used in inventory analysis

Material	Dataset name	Source	Reference year	Geography
Scrap	Municipal solid waste {GLO} treatment of municipal solid waste, unsanitary landfill, dry infiltration class (100mm)	ecoinvent v3	2021	Global
Non-Hazardous waste				
Unused product - landfill				
Hazardous waste	Hazardous waste, for underground deposit {RoW} treatment of hazardous waste, underground deposit	ecoinvent v3	2021	Rest of World (non-Europe)
Plastic	Disposal, plastic plaster, 0% water, to inert material landfill	US-EI 2.2	2018	US
Paper	Recycling paper	US-EI 2.2	--	US
Steel	Recycling steel and iron	US-EI 2.2	--	US

3.4.5. Emissions to air, water, and soil

VOC emissions during drying processes reported by Carboline for the use and maintenance stage were taken into account in the study. The dataset for VOC emissions is displayed in Table 14.

Table 14. VOC emission dataset used in the inventory analysis

Emission	Dataset name	Primary source	Reference year
VOC	VOC, volatile organic compounds, unspecified origin	SimaPro	--

3.5 Limitations

A life cycle assessment of a product system is broad and complex, and inherently requires assumptions and simplifications. The following limitations of the study should be recognized:

- Primary data were modeled based on the information provided by Carboline and supplemented by data contained in the technical and safety data sheets provided. Proxy materials were used when matching secondary data sets were not identified.
- Material input and transportation distances are averages and do not reflect changes in material efficiency and supplier locations.
- Generic data sets used for material inputs, transport, and waste processing are considered good quality, but actual impacts from material suppliers, transport carriers, and local waste processing may vary.
- The impact assessment methodology categories do not represent all possible environmental impact categories.
- Characterization factors used within the impact assessment methodology may contain varying levels of uncertainty.
- LCA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins, or risks.

4 ASSESSMENT AND INTERPRETATION

This chapter includes the results from the LCA for the products studied. The model was first calculated for 1 lb of intumescent fireproofing coating, which was later scaled to meet the functional unit. Product life for architectural coatings is expressed both in terms of a typical market life (5 years) and a technical life (either 5, 10, or 20 years) per the PCR, depending on performance in certain durability tests/methodologies prescribed. Since these fireproofing coatings fall under the primer designation and are applied to interior architecture, no design life was needed. Only a market lifetime of 5 years was used in the LCA models, and the results are presented per functional unit for a period of 60 years.

4.1 Resource use and waste flows

Resource use indicators, output flows and waste category indicators, and carbon emissions and removals are presented in this section as required by ISO 21930:2017.

Resource use indicators represent the amount of materials consumed to produce not only the product itself but also the raw materials, electricity, natural gas, etc. that go into the product's life cycle.

Primary energy is an energy form found in nature that has not been subjected to any conversion or transformation process and is expressed in energy demand from renewable and non-renewable resources. Efficiencies in energy conversion are considered when calculating primary energy demand from process energy consumption. Water use represents total water used over the entire life cycle. No renewable energy was used in production beyond that accounted for in the eGRID datasets, and no energy was recovered.

Non-hazardous and hazardous wastes are calculated based on the amount of waste generated during the manufacturing based on Carboline's record. All waste treatments in models were considered based on the local waste management code and the assumptions described in this report. Unrecyclable wastes end up landfilled.

Tables 15a-h show resource use and waste flows for all products per functional unit. Information is presented per life cycle stage according to the PCR. The modules are titled accordingly:

- 1-1 Raw material manufacturing phase;
- 1-2 Transportation of raw materials to plants phase;
- 1-3 Coating manufacturing phase;
- 2-1 Transportation to distribution center phase;
- 2-2 Transportation to point of sale phase;
- 2-3 Transportation to application site phase;
- 3-1 Coating application phase;
- 3-2 Emissions from drying phase;
- 3-3 Necessary maintenance and repaints phase;
- 4-1 Transportation to disposal site phase; and
- 4-2 End-of-life management phase.

Table 15a. Resource use and waste flows for Firefilm III coating per functional unit

Parameter	Unit	Stage 1 - Product Stage			Stage 2 - Design & Construction Stage			Stage 3 - Use & Maintenance Stage			Stage 4 - End-of-Life Stage		Total
		1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	
Renewable primary energy used as energy carrier (fuel)	MJ, LHV	3.31E+01	1.07E-01	1.60E+00	1.04E-01	3.11E-02	0	5.68E-03	0	6.25E-02	4.36E-04	1.38E-03	3.50E+01
Renewable primary resources with energy content used as material	MJ, LHV	1.54E+01	3.90E-02	2.29E+00	3.79E-02	1.14E-02	0	1.75E-03	0	1.93E-02	1.59E-04	4.72E-04	1.78E+01
Total use of renewable primary resources with energy content	MJ, LHV	4.84E+01	1.46E-01	3.89E+00	1.42E-01	4.25E-02	0	7.43E-03	0	8.18E-02	5.95E-04	1.86E-03	5.27E+01
Non-renewable primary resources with energy content used as an energy carrier (fuel)	MJ, LHV	9.33E+02	1.12E+02	9.64E+01	1.09E+02	3.26E+01	0	9.58E-02	0	1.05E+00	4.57E-01	1.15E+00	1.29E+03
Non-renewable primary resources with energy content used as material	MJ, LHV	2.92E-01	3.41E-04	4.38E-03	3.25E-04	9.75E-05	0	8.16E-10	0	8.98E-09	1.37E-06	6.54E-06	2.97E-01
Total use of non-renewable primary resources with energy content	MJ, LHV	9.33E+02	1.12E+02	9.64E+01	1.09E+02	3.26E+01	0	9.58E-02	0	1.05E+00	4.57E-01	1.15E+00	1.29E+03
Secondary materials	kg	0	0	0	0	0	0	0	0	0	0	0	0
Renewable secondary fuels	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Non-renewable secondary fuels	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Recovered energy	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Use of net fresh water resources	m ³	1.18E+02	1.81E+00	2.98E+00	1.76E+00	5.27E-01	0	1.78E-04	0	1.95E-03	7.38E-03	2.31E-02	1.25E+02
Output flows and waste category indicators													
Hazardous waste disposed	kg	0	0	1.58E+00	0	0	0	0	0	0	0	0	1.58E+00
Non-hazardous waste disposed	kg	0	0	1.68E-01	0	0	0	0	0	0	0	0	1.68E-01
High-level radioactive waste, conditioned, to final repository	kg	8.67E-03	3.90E-05	4.98E-04	3.75E-05	1.12E-05	0	3.71E-07	0	4.08E-06	1.57E-07	5.92E-07	9.26E-03
Intermediate- and low-level radioactive waste, conditioned, to final repository	kg	3.23E-05	1.66E-05	4.06E-06	1.61E-05	4.83E-06	0	4.09E-09	0	4.50E-08	6.76E-08	1.72E-07	7.42E-05
Components for re-use	kg	0	0	0	0	0	0	0	0	0	0	0	0
Materials for recycling	kg	0	0	0	0	0	0	0	0	0	0	0	0
Materials for energy recovery	kg	0	0	0	0	0	0	0	0	0	0	0	0
Exported energy	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Carbon emissions and removals													
Biogenic Carbon Removal from Product	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Product	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Removal from Packaging	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Packaging	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Calcination Carbon Emissions	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Carbonation Carbon Removals	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Emissions from Combustion of Waste from Non-Renewable Sources used in Production Processes	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0

Table 15b. Resource use and waste flows for Firefilm IV coating per functional unit

Parameter	Unit	Stage 1 - Product Stage			Stage 2 - Design & Construction Stage			Stage 3 - Use & Maintenance Stage			Stage 4 - End-of-Life Stage		Total
		1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	
Renewable primary energy used as energy carrier (fuel)	MJ, LHV	9.06E+01	8.14E-02	1.47E+00	8.57E-02	2.99E-02	0	5.32E-03	0	5.86E-02	4.18E-04	1.33E-03	9.23E+01
Renewable primary resources with energy content used as material	MJ, LHV	3.31E+01	2.96E-02	2.11E+00	3.13E-02	1.09E-02	0	1.64E-03	0	1.81E-02	1.52E-04	4.53E-04	3.53E+01
Total use of renewable primary resources with energy content	MJ, LHV	1.24E+02	1.11E-01	3.58E+00	1.17E-01	4.07E-02	0	6.96E-03	0	7.66E-02	5.70E-04	1.78E-03	1.28E+02
Non-renewable primary resources used as an energy carrier (fuel)	MJ, LHV	2.22E+03	8.53E+01	8.86E+01	8.98E+01	3.13E+01	0	8.98E-02	0	9.87E-01	4.38E-01	1.10E+00	2.52E+03
Non-renewable primary resources with energy content used as material	MJ, LHV	1.07E+00	2.56E-04	4.10E-03	2.69E-04	9.36E-05	0	7.65E-10	0	8.41E-09	1.31E-06	6.28E-06	1.07E+00
Total use of non-renewable primary resources with energy content	MJ, LHV	2.22E+03	8.53E+01	8.86E+01	8.98E+01	3.13E+01	0	8.98E-02	0	9.87E-01	4.38E-01	1.10E+00	2.52E+03
Secondary materials	kg	0	0	0	0	0	0	0	0	0	0	0	0
Renewable secondary fuels	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Non-renewable secondary fuels	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Recovered energy	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Use of net fresh water resources	m ³	2.37E+02	1.12E+00	1.39E+00	1.18E+00	4.11E-01	0	1.66E-04	0	1.83E-03	5.75E-03	2.12E-02	2.41E+02
Output flows and waste category indicators													
Hazardous waste disposed	kg	0	0	1.48E+00	0	0	0	0	0	0	0	0	1.48E+00
Non-hazardous waste disposed	kg	0	0	1.56E-01	0	0	0	0	0	0	0	0	1.56E-01
High-level radioactive waste, conditioned, to final repository	kg	3.75E-02	2.94E-05	4.60E-04	3.09E-05	1.08E-05	0	3.48E-07	0	3.82E-06	1.51E-07	5.69E-07	3.81E-02
Intermediate- and low-level radioactive waste, conditioned, to final repository	kg	6.41E-05	1.26E-05	3.73E-06	1.33E-05	4.63E-06	0	3.83E-09	0	4.22E-08	6.49E-08	1.66E-07	9.87E-05
Components for re-use	kg	0	0	0	0	0	0	0	0	0	0	0	0
Materials for recycling	kg	0	0	0	0	0	0	0	0	0	0	0	0
Materials for energy recovery	kg	0	0	0	0	0	0	0	0	0	0	0	0
Exported energy	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Carbon emissions and removals													
Biogenic Carbon Removal from Product	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Product	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Removal from Packaging	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Packaging	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Calcination Carbon Emissions	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Carbonation Carbon Removals	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Emissions from Combustion of Waste from Non-Renewable Sources used in Production Processes	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0

Table 15c. Resource use and waste flows for Thermo-Sorb VOC coating functional unit

Parameter	Unit	Stage 1 - Product Stage			Stage 2 - Design & Construction Stage			Stage 3 - Use & Maintenance Stage			Stage 4 - End-of-Life Stage		Total
		1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	
Renewable primary energy used as energy carrier (fuel)	MJ, LHV	3.15E+01	1.34E-01	1.90E+00	7.15E-02	3.23E-02	0	4.71E-03	0	5.18E-02	4.53E-04	1.41E-03	3.37E+01
Renewable primary resources with energy content used as material	MJ, LHV	1.67E+02	4.85E-02	2.54E+00	2.61E-02	1.18E-02	0	1.45E-03	0	1.60E-02	1.65E-04	4.79E-04	1.70E+02
Total use of renewable primary resources with energy content	MJ, LHV	1.99E+02	1.82E-01	4.44E+00	9.76E-02	4.41E-02	0	6.17E-03	0	6.78E-02	6.18E-04	1.88E-03	2.03E+02
Non-renewable primary energy carrier (fuel)	MJ, LHV	1.25E+03	1.39E+02	1.13E+02	7.50E+01	3.39E+01	0	7.95E-02	0	8.74E-01	4.75E-01	1.17E+00	1.62E+03
Non-renewable primary resources with energy content used as material	MJ, LHV	5.87E+00	4.40E-04	5.93E-03	2.24E-04	1.01E-04	0	6.77E-10	0	7.45E-09	1.42E-06	6.63E-06	5.88E+00
Total use of non-renewable primary resources with energy content	MJ, LHV	1.26E+03	1.39E+02	1.13E+02	7.50E+01	3.39E+01	0	7.95E-02	0	8.74E-01	4.75E-01	1.17E+00	1.62E+03
Secondary materials	kg	0	0	0	0	0	0	0	0	0	0	0	0
Renewable secondary fuels	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Non-renewable secondary fuels	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Recovered energy	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Use of net fresh water resources	m ³	1.29E+02	2.16E+00	3.81E+00	1.15E+00	5.22E-01	0	1.47E-04	0	1.62E-03	7.30E-03	2.23E-02	1.37E+02
Output flows and waste category indicators													
Hazardous waste disposed	kg	0	0	1.77E+00	0	0	0	0	0	0	0	0	1.77E+00
Non-hazardous waste disposed	kg	0	0	1.87E-01	0	0	0	0	0	0	0	0	1.87E-01
High-level radioactive waste, conditioned, to final repository	kg	1.07E-02	4.87E-05	6.14E-04	2.58E-05	1.17E-05	0	3.08E-07	0	3.38E-06	1.63E-07	6.01E-07	1.14E-02
Intermediate- and low-level radioactive waste, conditioned, to final repository	kg	2.92E-05	2.07E-05	4.63E-06	1.11E-05	5.02E-06	0	3.39E-09	0	3.73E-08	7.03E-08	1.75E-07	7.10E-05
Components for re-use	kg	0	0	0	0	0	0	0	0	0	0	0	0
Materials for recycling	kg	0	0	0	0	0	0	0	0	0	0	0	0
Materials for energy recovery	kg	0	0	0	0	0	0	0	0	0	0	0	0
Exported energy	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Carbon emissions and removals													
Biogenic Carbon Removal from Product	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Product	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Removal from Packaging	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Packaging	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Calcination Carbon Emissions	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Carbonation Carbon Removals	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Emissions from Combustion of Waste from Non-Renewable Sources used in Production Processes	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0

Table 15d. Resource use and waste flows for Thermo-Sorb 263 coating per functional unit

Parameter	Unit	Stage 1 - Product Stage			Stage 2 - Design & Construction Stage			Stage 3 - Use & Maintenance Stage			Stage 4 - End-of-Life Stage		Total
		1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	
Renewable primary energy used as energy carrier (fuel)	MJ, LHV	3.03E+01	9.51E-02	1.46E+00	1.09E-01	2.77E-02	0	3.76E-03	0	4.14E-02	3.88E-04	1.21E-03	3.20E+01
Renewable primary resources with energy content used as material	MJ, LHV	1.14E+01	3.45E-02	1.91E+00	3.97E-02	1.01E-02	0	1.16E-03	0	1.28E-02	1.42E-04	4.13E-04	1.34E+01
Total use of renewable primary resources with energy content	MJ, LHV	4.17E+01	1.30E-01	3.37E+00	1.48E-01	3.78E-02	0	4.92E-03	0	5.41E-02	5.30E-04	1.63E-03	4.54E+01
Non-renewable primary energy used as an energy carrier (fuel)	MJ, LHV	1.09E+03	9.92E+01	1.12E+02	1.14E+02	2.91E+01	0	6.34E-02	0	6.97E-01	4.07E-01	1.00E+00	1.45E+03
Non-renewable primary resources with energy content used as material	MJ, LHV	1.33E-01	3.10E-04	4.63E-03	3.41E-04	8.69E-05	0	5.40E-10	0	5.94E-09	1.22E-06	5.72E-06	1.39E-01
Total use of non-renewable primary resources with energy content	MJ, LHV	1.09E+03	9.92E+01	1.12E+02	1.14E+02	2.91E+01	0	6.34E-02	0	6.97E-01	4.07E-01	1.00E+00	1.45E+03
Secondary materials	kg	0	0	0	0	0	0	0	0	0	0	0	0
Renewable secondary fuels	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Non-renewable secondary fuels	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Recovered energy	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Use of net fresh water resources	m ³	1.14E+02	1.64E+00	3.63E+00	1.87E+00	4.77E-01	0	1.80E-04	0	1.98E-03	6.67E-03	2.04E-02	1.22E+02
Output flows and waste category indicators													
Hazardous waste disposed	kg	0	0	1.34E+00	0	0	0	0	0	0	0	0	1.34E+00
Non-hazardous waste disposed	kg	0	0	1.29E-01	0	0	0	0	0	0	0	0	1.29E-01
High-level radioactive waste, conditioned, to final repository	kg	3.75E-02	2.94E-05	4.60E-04	3.09E-05	1.08E-05	0	3.48E-07	0	3.82E-06	1.51E-07	5.69E-07	3.81E-02
Intermediate- and low-level radioactive waste, conditioned, to final repository	kg	6.41E-05	1.26E-05	3.73E-06	1.33E-05	4.63E-06	0	3.83E-09	0	4.22E-08	6.49E-08	1.66E-07	9.87E-05
Components for re-use	kg	0	0	0	0	0	0	0	0	0	0	0	0
Materials for recycling	kg	0	0	0	0	0	0	0	0	0	0	0	0
Materials for energy recovery	kg	0	0	0	0	0	0	0	0	0	0	0	0
Exported energy	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Carbon emissions and removals													
Biogenic Carbon Removal from Product	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Product	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Removal from Packaging	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Packaging	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Calcination Carbon Emissions	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Carbonation Carbon Removals	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Emissions from Combustion of Waste from Non-Renewable Sources used in Production Processes	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0

Table 15e. Resource use and waste flows for Thermo-Lag E100 coating per functional unit

Parameter	Unit	Stage 1 - Product Stage			Stage 2 - Design & Construction Stage			Stage 3 - Use & Maintenance Stage			Stage 4 - End-of-Life Stage		Total
		1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	
Renewable primary energy used as energy carrier (fuel)	MJ, LHV	7.24E+01	2.28E-01	1.82E+01	2.24E-01	6.30E-02	0	8.35E-03	0	9.18E-02	8.82E-04	2.74E-03	9.11E+01
Renewable primary resources with energy content used as material	MJ, LHV	5.55E+01	8.26E-02	3.01E+00	8.18E-02	2.30E-02	0	2.57E-03	0	2.83E-02	3.22E-04	9.32E-04	5.88E+01
Total use of renewable primary resources with energy content	MJ, LHV	1.28E+02	3.11E-01	2.12E+01	3.06E-01	8.60E-02	0	1.09E-02	0	1.20E-01	1.20E-03	3.67E-03	1.50E+02
Non-renewable primary energy used as an energy carrier (fuel)	MJ, LHV	2.35E+03	2.38E+02	2.03E+02	2.35E+02	6.60E+01	0	1.41E-01	0	1.55E+00	9.25E-01	2.27E+00	3.10E+03
Non-renewable primary resources with energy content used as material	MJ, LHV	1.17E+00	7.65E-04	1.11E-02	7.03E-04	1.97E-04	0	1.20E-09	0	1.32E-08	2.76E-06	1.29E-05	1.19E+00
Total use of non-renewable primary resources with energy content	MJ, LHV	2.36E+03	2.38E+02	2.03E+02	2.35E+02	6.60E+01	0	1.41E-01	0	1.55E+00	9.25E-01	2.27E+00	3.10E+03
Secondary materials	kg	0	0	0	0	0	0	0	0	0	0	0	0
Renewable secondary fuels	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Non-renewable secondary fuels	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Recovered energy	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Use of net fresh water resources	m ³	1.92E+02	2.25E+00	4.99E+00	2.19E+00	6.16E-01	0	2.53E-04	0	2.78E-03	8.62E-03	2.81E-02	2.02E+02
Output flows and waste category indicators													
Hazardous waste disposed	kg	0	0	3.02E+00	0	0	0	0	0	0	0	0	3.02E+00
Non-hazardous waste disposed	kg	0	0	2.90E-01	0	0	0	0	0	0	0	0	2.90E-01
High-level radioactive waste, conditioned, to final repository	kg	2.65E-02	8.34E-05	7.01E-04	8.09E-05	2.27E-05	0	5.45E-07	0	6.00E-06	3.18E-07	1.17E-06	2.74E-02
Intermediate- and low-level radioactive waste, conditioned, to final repository	kg	6.41E-05	3.53E-05	3.55E-06	3.48E-05	9.78E-06	0	6.01E-09	0	6.61E-08	1.37E-07	3.41E-07	1.48E-04
Components for re-use	kg	0	0	0	0	0	0	0	0	0	0	0	0
Materials for recycling	kg	0	0	0	0	0	0	0	0	0	0	0	0
Materials for energy recovery	kg	0	0	0	0	0	0	0	0	0	0	0	0
Exported energy	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Carbon emissions and removals													
Biogenic Carbon Removal from Product	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Product	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Removal from Packaging	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Packaging	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Calcination Carbon Emissions	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Carbonation Carbon Removals	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Emissions from Combustion of Waste from Non-Renewable Sources used in Production Processes	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0

Table 15f. Resource use and waste flows for Thermo-Lag E100-S coating per functional unit

Parameter	Unit	Stage 1 - Product Stage			Stage 2 - Design & Construction Stage			Stage 3 - Use & Maintenance Stage			Stage 4 - End-of-Life Stage		Total
		1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	
Renewable primary energy used as energy carrier (fuel)	MJ, LHV	5.51E+01	1.77E-01	1.52E+01	1.67E-01	5.19E-02	0	6.63E-03	0	7.30E-02	7.27E-04	2.10E-03	7.07E+01
Renewable primary resources with energy content used as material	MJ, LHV	2.89E+01	6.41E-02	2.50E+00	6.09E-02	1.89E-02	0	2.05E-03	0	2.25E-02	2.65E-04	7.17E-04	3.16E+01
Total use of renewable primary resources with energy content	MJ, LHV	8.40E+01	2.41E-01	1.77E+01	2.28E-01	7.09E-02	0	8.68E-03	0	9.55E-02	9.92E-04	2.82E-03	1.02E+02
Non-renewable primary energy used as an energy carrier (fuel)	MJ, LHV	1.91E+03	1.85E+02	1.98E+02	1.75E+02	5.44E+01	0	1.12E-01	0	1.23E+00	7.62E-01	1.74E+00	2.52E+03
Non-renewable primary resources with energy content used as material	MJ, LHV	4.48E-01	5.93E-04	1.46E-02	5.23E-04	1.63E-04	0	9.53E-10	0	1.05E-08	2.28E-06	9.93E-06	4.63E-01
Total use of non-renewable primary resources with energy content	MJ, LHV	1.91E+03	1.85E+02	1.98E+02	1.75E+02	5.44E+01	0	1.12E-01	0	1.23E+00	7.62E-01	1.74E+00	2.52E+03
Secondary materials	kg	0	0	0	0	0	0	0	0	0	0	0	0
Renewable secondary fuels	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Non-renewable secondary fuels	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Recovered energy	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Use of net fresh water resources	m ³	1.70E+02	2.31E+00	8.34E+00	2.17E+00	6.75E-01	0	2.01E-04	0	2.21E-03	9.44E-03	2.72E-02	1.83E+02
Output flows and waste category indicators													
Hazardous waste disposed	kg	0	0	2.39E+00	0	0	0	0	0	0	0	0	2.39E+00
Non-hazardous waste disposed	kg	0	0	2.30E-01	0	0	0	0	0	0	0	0	2.30E-01
High-level radioactive waste, conditioned, to final repository	kg	2.11E-02	6.48E-05	9.17E-04	6.02E-05	1.87E-05	0	4.33E-07	0	4.76E-06	2.62E-07	9.00E-07	2.22E-02
Intermediate- and low-level radioactive waste, conditioned, to final repository	kg	4.78E-05	2.74E-05	3.77E-06	2.59E-05	8.06E-06	0	4.78E-09	0	5.25E-08	1.13E-07	2.62E-07	1.13E-04
Components for re-use	kg	0	0	0	0	0	0	0	0	0	0	0	0
Materials for recycling	kg	0	0	0	0	0	0	0	0	0	0	0	0
Materials for energy recovery	kg	0	0	0	0	0	0	0	0	0	0	0	0
Exported energy	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Carbon emissions and removals													
Biogenic Carbon Removal from Product	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Product	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Removal from Packaging	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Packaging	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Calcination Carbon Emissions	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Carbonation Carbon Removals	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Emissions from Combustion of Waste from Non-Renewable Sources used in Production Processes	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0

Table 15g. Resource use and waste flows for Thermo-Lag 3000 coating per functional unit

Parameter	Unit	Stage 1 - Product Stage			Stage 2 - Design & Construction Stage			Stage 3 - Use & Maintenance Stage			Stage 4 - End-of-Life Stage		Total
		1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	
Renewable primary energy used as energy carrier (fuel)	MJ, LHV	7.52E+01	2.27E-01	1.82E+01	2.28E-01	6.29E-02	0	8.32E-03	0	9.16E-02	8.80E-04	2.73E-03	9.41E+01
Renewable primary resources with energy content used as material	MJ, LHV	4.57E+01	8.25E-02	3.02E+00	8.32E-02	2.29E-02	0	2.57E-03	0	2.82E-02	3.21E-04	9.29E-04	4.90E+01
Total use of renewable primary resources with energy content	MJ, LHV	1.21E+02	3.10E-01	2.12E+01	3.11E-01	8.58E-02	0	1.09E-02	0	1.20E-01	1.20E-03	3.66E-03	1.43E+02
Non-renewable primary resources used as an energy carrier (fuel)	MJ, LHV	2.44E+03	2.38E+02	2.04E+02	2.39E+02	6.59E+01	0	1.40E-01	0	1.54E+00	9.23E-01	2.26E+00	3.19E+03
Non-renewable primary resources with energy content used as material	MJ, LHV	8.31E-01	7.19E-04	1.12E-02	7.14E-04	1.97E-04	0	1.20E-09	0	1.32E-08	2.76E-06	1.29E-05	8.43E-01
Total use of non-renewable primary resources with energy content	MJ, LHV	2.44E+03	2.38E+02	2.04E+02	2.39E+02	6.59E+01	0	1.40E-01	0	1.54E+00	9.23E-01	2.26E+00	3.19E+03
Secondary materials	kg	0	0	0	0	0	0	0	0	0	0	0	0
Renewable secondary fuels	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Non-renewable secondary fuels	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Recovered energy	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Use of net fresh water resources	m ³	1.87E+02	2.17E+00	4.58E+00	2.19E+00	6.03E-01	0	2.52E-04	0	2.77E-03	8.44E-03	2.74E-02	1.97E+02
Output flows and waste category indicators													
Hazardous waste disposed	kg	0	0	3.01E+00	0	0	0	0	0	0	0	0	3.01E+00
Non-hazardous waste disposed	kg	0	0	2.91E-01	0	0	0	0	0	0	0	0	2.91E-01
High-level radioactive waste, conditioned, to final repository	kg	2.86E-02	8.23E-05	7.06E-04	8.22E-05	2.27E-05	0	5.43E-07	0	5.98E-06	3.18E-07	1.17E-06	2.95E-02
Intermediate- and low-level radioactive waste, conditioned, to final repository	kg	6.54E-05	3.52E-05	3.56E-06	3.54E-05	9.76E-06	0	5.99E-09	0	6.59E-08	1.37E-07	3.40E-07	1.50E-04
Components for re-use	kg	0	0	0	0	0	0	0	0	0	0	0	0
Materials for recycling	kg	0	0	0	0	0	0	0	0	0	0	0	0
Materials for energy recovery	kg	0	0	0	0	0	0	0	0	0	0	0	0
Exported energy	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Carbon emissions and removals													
Biogenic Carbon Removal from Product	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Product	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Removal from Packaging	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Packaging	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Calcination Carbon Emissions	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Carbonation Carbon Removals	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Emissions from Combustion of Waste from Non-Renewable Sources used in Production Processes	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0

Table 15h. Resource use and waste flows for Thermo-Lag 3000SP coating per functional unit

Parameter	Unit	Stage 1 - Product Stage			Stage 2 - Design & Construction Stage			Stage 3 - Use & Maintenance Stage			Stage 4 - End-of-Life Stage		Total
		1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	
Renewable primary energy used as energy carrier (fuel)	MJ, LHV	5.74E+01	2.03E-01	1.52E+01	1.89E-01	5.29E-02	0	6.65E-03	0	7.31E-02	7.41E-04	2.14E-03	7.32E+01
Renewable primary resources with energy content used as material	MJ, LHV	2.92E+01	7.37E-02	2.51E+00	6.89E-02	1.93E-02	0	2.05E-03	0	2.25E-02	2.70E-04	7.30E-04	3.19E+01
Total use of renewable primary resources with energy content	MJ, LHV	8.67E+01	2.76E-01	1.77E+01	2.58E-01	7.22E-02	0	8.69E-03	0	9.56E-02	1.01E-03	2.87E-03	1.05E+02
Non-renewable primary energy used as an energy carrier (fuel)	MJ, LHV	1.91E+03	2.12E+02	2.00E+02	1.98E+02	5.55E+01	0	1.12E-01	0	1.23E+00	7.77E-01	1.78E+00	2.58E+03
Non-renewable primary resources with energy content used as material	MJ, LHV	4.46E-01	6.50E-04	1.49E-02	5.92E-04	1.66E-04	0	9.55E-10	0	1.05E-08	2.32E-06	1.01E-05	4.62E-01
Total use of non-renewable primary resources with energy content	MJ, LHV	1.91E+03	2.12E+02	2.00E+02	1.98E+02	5.55E+01	0	1.12E-01	0	1.23E+00	7.77E-01	1.78E+00	2.58E+03
Secondary materials	kg	0	0	0	0	0	0	0	0	0	0	0	0
Renewable secondary fuels	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Non-renewable secondary fuels	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Recovered energy	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Use of net fresh water resources	m ³	1.75E+02	2.16E+00	8.37E+00	2.01E+00	5.63E-01	0	2.01E-04	0	2.21E-03	7.89E-03	2.36E-02	1.88E+02
Output flows and waste category indicators													
Hazardous waste disposed	kg	0	0	2.39E+00	0	0	0	0	0	0	0	0	2.39E+00
Non-hazardous waste disposed	kg	0	0	2.31E-01	0	0	0	0	0	0	0	0	2.31E-01
High-level radioactive waste, conditioned, to final repository	kg	2.17E-02	7.34E-05	9.35E-04	6.81E-05	1.91E-05	0	4.34E-07	0	4.77E-06	2.67E-07	9.16E-07	2.28E-02
Intermediate- and low-level radioactive waste, conditioned, to final repository	kg	4.93E-05	3.14E-05	3.82E-06	2.93E-05	8.21E-06	0	4.78E-09	0	5.26E-08	1.15E-07	2.67E-07	1.22E-04
Components for re-use	kg	0	0	0	0	0	0	0	0	0	0	0	0
Materials for recycling	kg	0	0	0	0	0	0	0	0	0	0	0	0
Materials for energy recovery	kg	0	0	0	0	0	0	0	0	0	0	0	0
Exported energy	MJ, LHV	0	0	0	0	0	0	0	0	0	0	0	0
Carbon emissions and removals													
Biogenic Carbon Removal from Product	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Product	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Removal from Packaging	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Packaging	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Calcination Carbon Emissions	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Carbonation Carbon Removals	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Emissions from Combustion of Waste from Non-Renewable Sources used in Production Processes	kg CO ₂	0	0	0	0	0	0	0	0	0	0	0	0

4.2 Life cycle impact assessment (LCIA)

It shall be reiterated at this point that the reported impact categories represent impact potentials; they are approximations of environmental impacts that could occur if the emitted molecules would follow the underlying impact pathway and meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach). LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

Life cycle impact assessment (LCIA) results are shown for Carboline's intumescent fireproofing coatings. Unlike life cycle inventories, which only report sums for individual inventory flows, the LCIA includes a classification of individual emissions with regard to the impacts they are associated with and subsequently a characterization of the emissions by a factor expressing their respective contribution to the impact category indicator. The end result is a single metric for quantifying each potential impact, such as "Global Warming Potential".

The impact assessment results are calculated using characterization factors published by the United States Environmental Protection Agency. The TRACI 2.1 (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts 2.1) methodology is the most widely applied impact assessment method for U.S. LCA studies. The SM 2013 Methodology is also applied to come up with single score results for the sole purpose of representing total impacts per life cycle phase to explain where in the product life cycle greatest impacts are occurring and what is contributing to the impacts [4].

TRACI impact categories are globally deemed mature enough to be included in Type III environmental declarations. Other categories are being developed and defined and LCA should continue making advances in their development; however, the EPD users shall not use additional measures for comparative purposes. All impact categories from TRACI are used to calculate single score millipoints using the SM2013 Methodology, but it should be noted that there are known limitations related to these impact categories due to their high degree of uncertainty.

4.2.1. Impact assessment results

4.2.1.1. Firefilm III

Table 16a shows the impact assessment results, and Table 16b and Figure 4 show the percent contribution of each stage to the overall impacts of Firefilm III.

Broadly speaking, the upstream production stage (Stage 1) dominates the results for all the impact categories. The design & construction stage (Stage 2) is the next highest contributor for all impact categories except for global warming, smog, eutrophication, and carcinogenics.

To go a step further, the raw material manufacturing phase (1-1) contributes the most to the total impacts for most of the impact categories. For ozone depletion and acidification, the transportation of raw materials phase (1-2) is the next highest contributor. For the global warming and eutrophication impact categories, the second highest impact comes from the end-of-life management phase (4-2).

It's worth noting that VOC emissions released during the drying process make the emissions from drying phase (3-2) the second largest contributor for smog formation.

The coating application (3-1), necessary maintenance and repaints (3-3), and transportation to disposal point (4-1) phases are small contributors to all product life cycle impacts. The transportation to application site (2-3) phase shall account for zero impacts for all impact categories because there were assumed to be no material and energy inputs in the stage.

The SM 2013 Methodology single figure millipoint (mPts) score by life cycle phase for this product is presented below (Table 16c). The scores are consistent with the results using the impact assessment results before normalization and weighting. The raw material manufacturing phase (1-1) dominates the results (72.88%).

The coating manufacturing phase (1-3) accounts for the second highest score result (8.93%), followed by the transportation of raw materials to plants (1-2), transportation to distribution center (2-1), and end-of-life management (4-2) phases. These three phases come up with similar score results.

Table 16a. Firefilm III coating impact potential results per functional unit

Impact category	Unit	Stage 1 - Product Stage			Stage 2 - Design & Construction Stage			Stage 3 - Use & Maintenance Stage			Stage 4 - End-of-Life Stage		Total
		1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	
Ozone depletion	kg CFC-11 eq	5.12E-06	1.89E-06	2.67E-07	1.83E-06	5.49E-07	0	2.18E-10	0	2.40E-09	7.69E-09	1.96E-08	9.70E-06
Global warming	kg CO ₂ eq	5.13E+01	7.99E+00	6.33E+00	7.69E+00	2.31E+00	0	5.32E-03	0	5.86E-02	3.23E-02	1.83E+01	9.40E+01
Smog	kg O ₃ eq	2.50E+00	4.53E-01	2.19E-01	1.72E-01	5.14E-02	0	1.78E-04	8.99E-01	1.96E-03	7.20E-04	2.60E-02	4.33E+00
Acidification	kg SO ₂ eq	2.82E-01	2.97E-02	2.02E-02	1.34E-02	4.01E-03	0	2.08E-05	0	2.28E-04	5.61E-05	1.88E-03	3.51E-01
Eutrophication	kg N eq	4.95E-02	3.37E-03	2.37E-03	2.79E-03	8.35E-04	0	1.73E-06	0	1.91E-05	1.17E-05	1.38E-02	7.28E-02
Carcinogenics	CTUh	2.12E-06	7.14E-09	3.14E-07	7.06E-09	2.12E-09	0	1.02E-11	0	1.12E-10	2.96E-11	7.17E-08	2.52E-06
Non carcinogenics	CTUh	7.14E-06	1.04E-06	2.19E-07	1.08E-06	3.24E-07	0	1.71E-10	0	1.88E-09	4.53E-09	1.23E-07	9.94E-06
Respiratory effects	kg PM _{2.5} eq	3.34E-02	3.59E-03	3.65E-03	2.70E-03	8.08E-04	0	1.22E-06	0	1.34E-05	1.13E-05	1.42E-04	4.43E-02
Ecotoxicity	CTUe	5.60E+01	2.09E+01	6.12E+00	2.18E+01	6.55E+00	0	4.01E-04	0	4.41E-03	9.16E-02	4.20E+00	1.16E+02
Fossil fuel depletion	MJ surplus	9.75E+01	1.68E+01	6.77E+00	1.63E+01	4.89E+00	0	7.02E-03	0	7.73E-02	6.84E-02	1.75E-01	1.43E+02

Table 16b. Percent contributions of each stage to each impact category for Firefilm III

Impact category	Unit	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	Total
Ozone depletion	kg CFC-11 eq	52.84%	19.51%	2.76%	18.91%	5.67%	0%	0.00%	0%	0.02%	0.08%	0.20%	100.00%
Global warming	kg CO ₂ eq	54.57%	8.50%	6.74%	8.19%	2.45%	0%	0.01%	0%	0.06%	0.03%	19.44%	100.00%
Smog	kg O ₃ eq	57.86%	10.47%	5.06%	3.97%	1.19%	0%	0.00%	20.78%	0.05%	0.02%	0.60%	100.00%
Acidification	kg SO ₂ eq	80.21%	8.46%	5.75%	3.81%	1.14%	0%	0.01%	0%	0.06%	0.02%	0.53%	100.00%
Eutrophication	kg N eq	68.06%	4.63%	3.25%	3.83%	1.15%	0%	0.00%	0%	0.03%	0.02%	19.03%	100.00%
Carcinogenics	CTUh	84.08%	0.28%	12.43%	0.28%	0.08%	0%	0.00%	0%	0.00%	0.00%	2.84%	100.00%
Non carcinogenics	CTUh	71.86%	10.50%	2.21%	10.87%	3.26%	0%	0.00%	0%	0.02%	0.05%	1.24%	100.00%
Respiratory effects	kg PM _{2.5} eq	75.34%	8.11%	8.25%	6.09%	1.82%	0%	0.00%	0%	0.03%	0.03%	0.32%	100.00%
Ecotoxicity	CTUe	48.40%	18.08%	5.28%	18.87%	5.65%	0%	0.00%	0%	0.00%	0.08%	3.63%	100.00%
Fossil fuel depletion	MJ surplus	68.35%	11.81%	4.75%	11.44%	3.43%	0%	0.00%	0%	0.05%	0.05%	0.12%	100.00%

Table 16c. SM millipoint scores for Firefilm III by life cycle stage per functional unit

Impact category	Unit	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	Total
SM single figure score	mPts	6.79E+00	5.21E-01	8.32E-01	5.00E-01	1.50E-01	0	1.84E-04	3.11E-02	2.02E-03	2.10E-03	4.88E-01	9.31E+00
	%	72.88%	5.59%	8.93%	5.37%	1.61%	0%	0.00%	0.33%	0.02%	0.02%	5.24%	100.00%

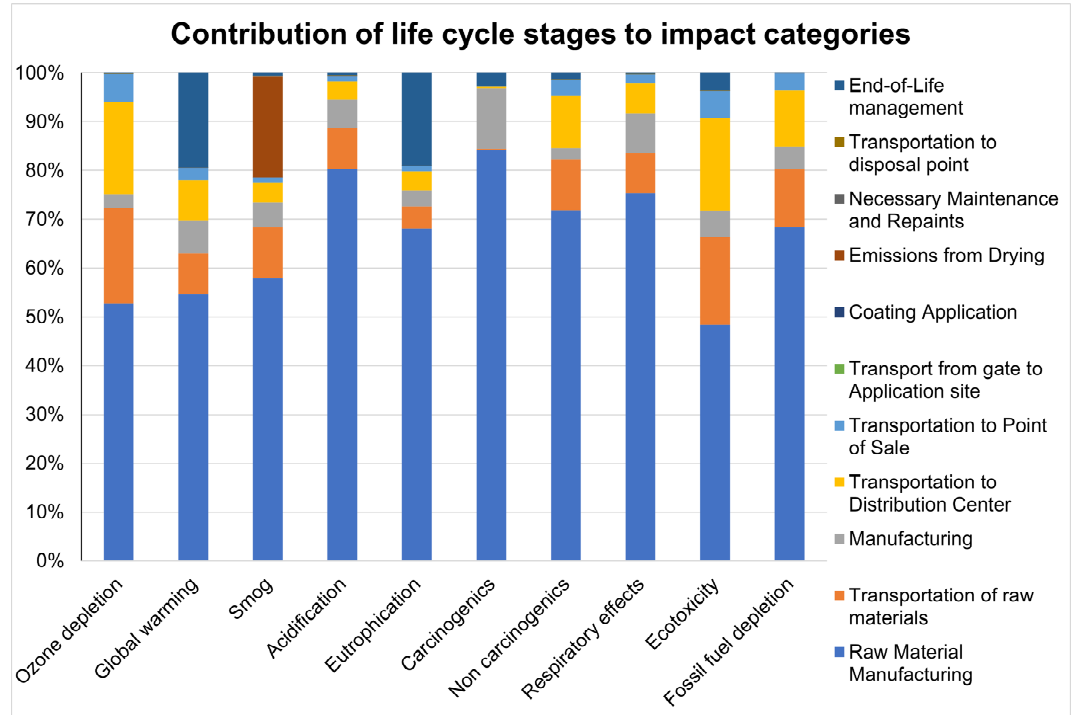


Figure 4. Contribution analysis of each impact category for Firefilm III

4.2.1.2. Firefilm IV

Table 17a shows the impact assessment results, and Table 17b and Figure 5 show the percent contribution of each stage to the overall impacts of Firefilm IV.

Broadly speaking, the upstream production stage (Stage 1) dominates the results for all the impact categories. The design & construction stage (Stage 2) is the next highest contributor for all impact categories except for global warming, eutrophication, and carcinogenics.

To go a step further, the raw material manufacturing phase (1-1) contributes the most (>70%) of the total impacts to most of the impact categories. For ozone depletion, the next highest impacts come from the transportation of raw materials phase (1-2) and the transportation to distribution center phase (2-1), which have a similar contribution. The contributions to transportation are caused by the use of trucks and trailer transport.

For the global warming and eutrophication impact categories, the next highest impact comes from the end-of-life management phase (4-2). The coating manufacturing phase (1-3) is the second highest contributor for the acidification impact.

Different from the LCA results of Firefilm III, the transportation of raw materials to plants phase (1-2) of Firefilm IV is the second largest contributor for smog formation. The

reason for that could be that Firefilm IV emits less (<20%) VOC than Firefilm III during the drying process.

The coating application (3-1), necessary maintenance and repaints (3-3), and transportation to disposal point (4-1) phases are small contributors to all product life cycle impacts. The transportation to application site (2-3) phase shall account for zero impacts for all impact categories because there were assumed to be no material and energy inputs in the stage.

The SM 2013 Methodology single figure millipoint (mPts) score by life cycle phase for this product is presented below (Table 17c). A higher score result of Firefilm IV reflects that Firefilm IV contributed to a higher life cycle impact compared with Firefilm III. The raw material manufacturing phase (1-1) dominates the results (89.84%).

The coating manufacturing phase (1-3) accounts for the second highest score result (3.56%), followed by the end-of-life management phase (4-2). The rest of the product phases have an insignificant contribution to the overall life cycle impacts.

Table 17a. Firefilm IV coating impact potential results per functional unit

Impact category	Unit	Stage 1 - Product Stage			Stage 2 - Design & Construction Stage			Stage 3 - Use & Maintenance Stage			Stage 4 - End-of-Life Stage		Total
		1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	
Ozone depletion	kg CFC-11 eq	1.37E-05	1.44E-06	2.47E-07	1.51E-06	5.27E-07	0	2.04E-10	0	2.25E-09	7.38E-09	1.88E-08	1.75E-05
Global warming	kg CO ₂ eq	1.48E+02	6.04E+00	5.55E+00	6.35E+00	2.21E+00	0	4.99E-03	0	5.49E-02	3.10E-02	1.75E+01	1.86E+02
Smog	kg O ₃ eq	1.12E+01	2.01E-01	2.02E-01	1.42E-01	4.94E-02	0	1.67E-04	1.48E-01	1.84E-03	6.91E-04	2.50E-02	1.19E+01
Acidification	kg SO ₂ eq	9.17E-01	1.43E-02	1.86E-02	1.10E-02	3.85E-03	0	1.94E-05	0	2.14E-04	5.38E-05	1.80E-03	9.67E-01
Eutrophication	kg N eq	9.30E-02	2.30E-03	1.99E-03	2.30E-03	8.01E-04	0	1.62E-06	0	1.79E-05	1.12E-05	1.33E-02	1.14E-01
Carcinogenics	CTUh	4.99E-06	5.50E-09	2.94E-07	5.83E-09	2.03E-09	0	9.52E-12	0	1.05E-10	2.84E-11	6.89E-08	5.37E-06
Non carcinogenics	CTUh	4.39E-05	8.29E-07	2.01E-07	8.92E-07	3.11E-07	0	1.61E-10	0	1.77E-09	4.35E-09	1.18E-07	4.63E-05
Respiratory effects	kg PM _{2.5} eq	1.39E-01	2.31E-03	3.41E-03	2.22E-03	7.75E-04	0	1.14E-06	0	1.25E-05	1.09E-05	1.37E-04	1.48E-01
Ecotoxicity	CTUe	2.65E+02	1.67E+01	5.68E+00	1.80E+01	6.28E+00	0	3.76E-04	0	4.14E-03	8.79E-02	4.04E+00	3.16E+02
Fossil fuel depletion	MJ surplus	2.34E+02	1.28E+01	6.22E+00	1.35E+01	4.69E+00	0	6.58E-03	0	7.24E-02	6.57E-02	1.68E-01	2.71E+02

Table 17b Percent contributions of each stage to each impact category for Firefilm IV

Impact category	Unit	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	Total
Ozone depletion	kg CFC-11 eq	78.54%	8.22%	1.41%	8.66%	3.02%	0%	0.00%	0%	0.01%	0.04%	0.11%	100.00%
Global warming	kg CO ₂ eq	79.71%	3.24%	2.98%	3.41%	1.19%	0%	0.00%	0%	0.03%	0.02%	9.42%	100.00%
Smog	kg O ₃ eq	93.54%	1.68%	1.70%	1.19%	0.41%	0%	0.00%	1.24%	0.02%	0.01%	0.21%	100.00%
Acidification	kg SO ₂ eq	94.84%	1.48%	1.93%	1.14%	0.40%	0%	0.00%	0%	0.02%	0.01%	0.19%	100.00%
Eutrophication	kg N eq	81.77%	2.02%	1.75%	2.02%	0.70%	0%	0.00%	0%	0.02%	0.01%	11.70%	100.00%
Carcinogenics	CTUh	92.99%	0.10%	5.48%	0.11%	0.04%	0%	0.00%	0%	0.00%	0.00%	1.28%	100.00%
Non carcinogenics	CTUh	94.91%	1.79%	0.43%	1.93%	0.67%	0%	0.00%	0%	0.00%	0.01%	0.25%	100.00%
Respiratory effects	kg PM _{2.5} eq	94.00%	1.56%	2.30%	1.50%	0.52%	0%	0.00%	0%	0.01%	0.01%	0.09%	100.00%
Ecotoxicity	CTUe	83.91%	5.29%	1.80%	5.70%	1.99%	0%	0.00%	0%	0.00%	0.03%	1.28%	100.00%
Fossil fuel depletion	MJ surplus	86.18%	4.71%	2.29%	4.96%	1.73%	0%	0.00%	0%	0.03%	0.02%	0.06%	100.00%

Table 17c. SM millipoint scores for Firefilm IV by life cycle stage per functional unit

Impact category	Unit	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	Total
SM single figure score	mPts	1.94E+01	3.93E-01	7.71E-01	4.12E-01	1.44E-01	0	1.72E-04	5.12E-03	1.89E-03	2.01E-03	4.69E-01	2.16E+01
	%	89.84%	1.82%	3.56%	1.91%	0.66%	0%	0.00%	0.02%	0.01%	0.01%	2.17%	100.00%

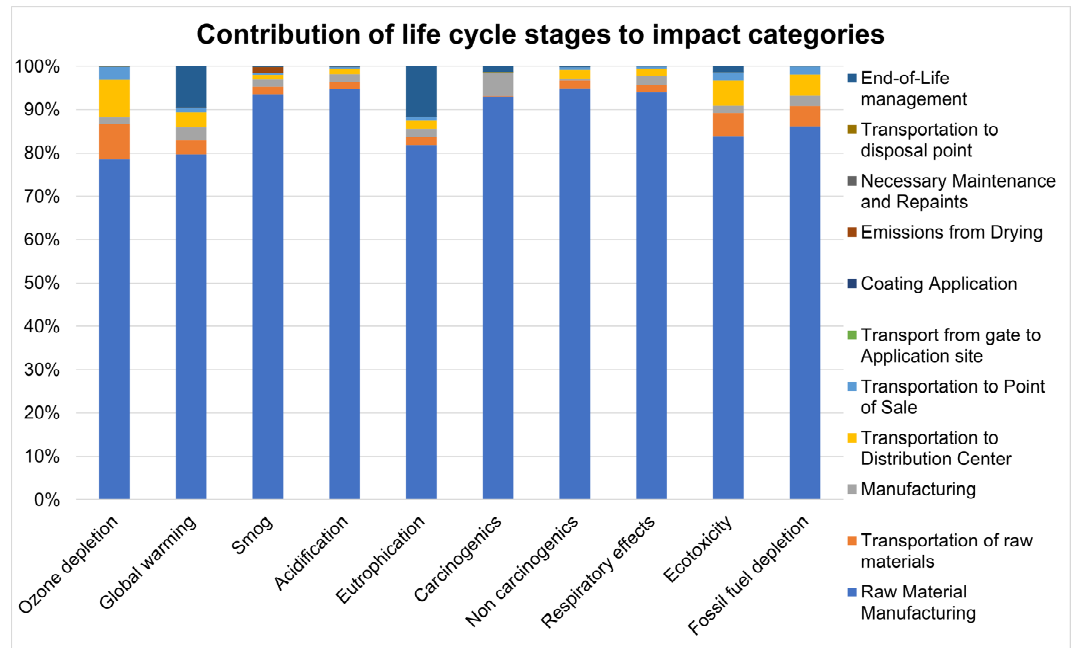


Figure 5. Contribution analysis of each impact category for Firefilm IV

4.2.1.3. Thermo-Sorb VOC

Table 18a shows the impact assessment results, and Table 18b and Figure 6 show the percent contribution of each stage to the overall impacts of Thermo-Sorb VOC.

Broadly speaking, the upstream production stage (Stage 1) dominates the results for all the impact categories except for smog. The design & construction stage (Stage 2) is the next highest contributor for all impact categories except for global warming, smog formation, eutrophication, and carcinogenics impact categories.

To be more specific, the raw material manufacturing phase (1-1) is the major contributor to most impact categories except for smog. The emissions from the drying phase (3-2) contributes the most to smog formation, which accounts for 60.83%. The VOC emissions released during the drying process is the reason for the smog formation impact.

For ozone depletion and acidification, the transportation of raw materials phase (1-2) is the second highest contributor. For the global warming and eutrophication impact categories, the next highest impact comes from the end-of-life management phase (4-2).

The coating application (3-1), necessary maintenance and repaints (3-3), and transportation to disposal point (4-1) phases are small contributors to all product life cycle impacts. The transportation to application site (2-3) phase shall account for zero impacts for all impact categories because there were assumed to be no material and energy inputs in the stage.

The SM 2013 Methodology single figure millipoint (mPts) score by life cycle phase for this product is presented below (Table 18c). The scores are consistent with the result using the impact assessment results before normalization and weighting. The raw material manufacturing (1-1) dominates the results (69.53%).

The coating manufacturing (1-3) phase accounts for the second highest score result (11.75%), followed by the transportation of raw materials to plants phase (1-2), which contributes to 6.44% of the total score. The rest of the phases have an insignificant contribution to the overall life cycle impacts.

Table 18a. Thermo-Sorb VOC coating impact potential results per functional unit

Impact category	Unit	Stage 1 - Product Stage			Stage 2 - Design & Construction Stage			Stage 3 - Use & Maintenance Stage			Stage 4 - End-of-Life Stage		Total
		1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	
Ozone depletion	kg CFC-11 eq	2.86E-05	2.36E-06	3.31E-07	1.26E-06	5.71E-07	0	1.81E-10	0	1.99E-09	7.99E-09	1.99E-08	3.32E-05
Global warming	kg CO ₂ eq	6.50E+01	9.94E+00	7.58E+00	5.30E+00	2.40E+00	0	4.42E-03	0	4.86E-02	3.35E-02	1.85E+01	1.09E+02
Smog	kg O ₃ eq	3.23E+00	7.80E-01	2.76E-01	1.18E-01	5.35E-02	0	1.48E-04	6.97E+00	1.63E-03	7.49E-04	2.64E-02	1.15E+01
Acidification	kg SO ₂ eq	3.05E-01	4.20E-02	2.45E-02	9.21E-03	4.17E-03	0	1.72E-05	0	1.89E-04	5.83E-05	1.91E-03	3.87E-01
Eutrophication	kg N eq	4.37E-01	4.57E-03	2.91E-03	1.92E-03	8.68E-04	0	1.44E-06	0	1.58E-05	1.22E-05	1.41E-02	4.62E-01
Carcinogenics	CTUh	1.30E-06	8.56E-09	4.68E-07	4.86E-09	2.20E-09	0	8.43E-12	0	9.27E-11	3.08E-11	7.28E-08	1.85E-06
Non carcinogenics	CTUh	5.74E-06	1.25E-06	2.77E-07	7.44E-07	3.37E-07	0	1.42E-10	0	1.56E-09	4.71E-09	1.25E-07	8.47E-06
Respiratory effects	kg PM _{2.5} eq	4.15E-02	5.39E-03	5.13E-03	1.86E-03	8.40E-04	0	1.01E-06	0	1.11E-05	1.18E-05	1.45E-04	5.49E-02
Ecotoxicity	CTUe	5.14E+01	2.49E+01	9.04E+00	1.50E+01	6.80E+00	0	3.33E-04	0	3.66E-03	9.52E-02	4.27E+00	1.12E+02
Fossil fuel depletion	MJ surplus	1.47E+02	2.09E+01	7.70E+00	1.12E+01	5.08E+00	0	5.83E-03	0	6.41E-02	7.11E-02	1.77E-01	1.93E+02

Table 18b. Percent contributions of each stage to each impact category for Thermo-Sorb VOC

Impact category	Unit	Stage 1 - Product Stage			Stage 2 - Design & Construction Stage			Stage 3 - Use & Maintenance Stage			Stage 4 - End-of-Life Stage		Total
		1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	
Ozone depletion	kg CFC-11 eq	86.26%	7.12%	1.00%	3.81%	1.72%	0%	0.00%	0%	0.01%	0.02%	0.06%	100.00%
Global warming	kg CO ₂ eq	59.71%	9.13%	6.97%	4.87%	2.20%	0%	0.00%	0%	0.04%	0.03%	17.04%	100.00%
Smog	kg O ₃ eq	28.21%	6.80%	2.41%	1.03%	0.47%	0%	0.00%	60.83%	0.01%	0.01%	0.23%	100.00%
Acidification	kg SO ₂ eq	78.84%	10.83%	6.31%	2.38%	1.08%	0%	0.00%	0%	0.05%	0.02%	0.49%	100.00%
Eutrophication	kg N eq	94.72%	0.99%	0.63%	0.42%	0.19%	0%	0.00%	0%	0.00%	0.00%	3.04%	100.00%
Carcinogenics	CTUh	69.97%	0.46%	25.25%	0.26%	0.12%	0%	0.00%	0%	0.01%	0.00%	3.93%	100.00%
Non carcinogenics	CTUh	67.71%	14.72%	3.27%	8.79%	3.97%	0%	0.00%	0%	0.02%	0.06%	1.47%	100.00%
Respiratory effects	kg PM _{2.5} eq	75.61%	9.82%	9.35%	3.38%	1.53%	0%	0.00%	0%	0.02%	0.02%	0.26%	100.00%
Ecotoxicity	CTUe	46.04%	22.36%	8.10%	13.49%	6.10%	0%	0.00%	0%	0.00%	0.09%	3.83%	100.00%
Fossil fuel depletion	MJ surplus	76.49%	10.88%	4.00%	5.84%	2.64%	0%	0.00%	0%	0.03%	0.04%	0.09%	100.00%

Table 18c. SM millipoint scores for Thermo-Sorb VOC by life cycle stage per functional unit

Impact category	Unit	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	Total
		SM single figure score	mPts	7.02E+00	6.51E-01	1.19E+00	3.44E-01	1.56E-01	0	1.52E-04	2.41E-01	1.68E-03	
	%	69.53%	6.44%	11.75%	3.41%	1.54%	0%	0.00%	2.38%	0.02%	0.02%	4.91%	100.00%

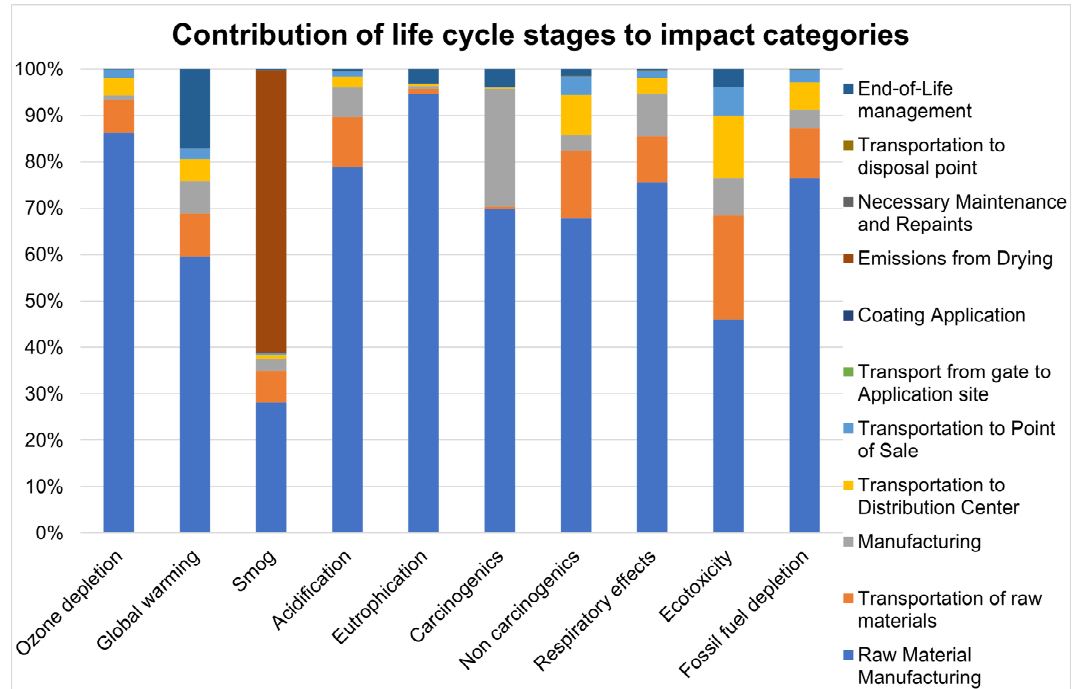


Figure 6. Contribution analysis of each impact category for Thermo-Sorb VOC

4.2.1.4. Thermo-Sorb 263

Table 19a shows the impact assessment results, and Table 19b and Figure 7 show the percent contribution of each stage to the overall impacts of Thermo-Sorb 263.

Broadly speaking, the upstream production stage (Stage 1) dominates the results for all the impact categories except for smog. For smog formation, the major contributor is the emissions from drying phase (3-2) in the use & maintenance stage (Stage 3). The design & construction stage (Stage 2) is the next highest contributor for all impact categories except for global warming, smog formation, eutrophication, and carcinogenics impact categories.

To be more specific, the raw material manufacturing phase (1-1) is the major contributor to most impact categories except for smog. The emissions from drying phase (3-2) contributes the most to smog formation, which accounts for 62.12%. The VOC emissions released during the drying process is the reason for the smog formation impact.

For ozone depletion, the next highest impacts come from the transportation of raw materials phase (1-2) and the transportation to distribution center phase (2-1), which have a similar contribution. The contributions to transportation are caused by the use of trucks and trailer transportation. For the global warming and eutrophication impact categories, the next highest impact comes from end-of-life management phase (4-2). The transportation of raw materials phase (1-2) is the second highest contributor to acidification.

The coating application (3-1), necessary maintenance and repaints (3-3), and transportation to disposal point (4-1) phases are small contributors to all product life cycle impacts. The transportation to application site (2-3) phase shall account for zero impacts

for all impact categories because there were assumed to be no material and energy inputs in the stage.

The SM 2013 Methodology single figure millipoint (mPts) score by life cycle phase for this product is presented below (Table 19c). The scores are consistent with the result using the impact assessment results before normalization and weighting. The raw material manufacturing (1-1) dominates the results (64.76%).

The coating manufacturing (1-3) phase accounts for the second highest score result (12.78%), followed by the transportation to distribution center (2-1), the transportation of raw materials to plants (1-2), and the end-of-life management (4-2) phases. These three phases come up with similar score results.

Table 19a. Thermo-Sorb 263 coating impact potential results per functional unit

Impact category	Unit	Stage 1 - Product Stage			Stage 2 - Design & Construction Stage			Stage 3 - Use & Maintenance Stage			Stage 4 - End-of-Life Stage		Total
		1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	
Ozone depletion	kg CFC-11 eq	9.22E-06	1.68E-06	2.99E-07	1.92E-06	4.90E-07	0	1.44E-10	0	1.59E-09	6.86E-09	1.71E-08	1.36E-05
Global warming	kg CO ₂ eq	5.22E+01	7.06E+00	7.75E+00	8.05E+00	2.05E+00	0	3.52E-03	0	3.88E-02	2.88E-02	1.60E+01	9.32E+01
Smog	kg O ₃ eq	2.57E+00	4.89E-01	2.31E-01	1.80E-01	4.59E-02	0	1.18E-04	5.80E+00	1.30E-03	6.42E-04	2.28E-02	9.34E+00
Acidification	kg SO ₂ eq	2.61E-01	2.69E-02	2.06E-02	1.40E-02	3.57E-03	0	1.37E-05	0	1.51E-04	5.00E-05	1.64E-03	3.28E-01
Eutrophication	kg N eq	4.84E-02	3.13E-03	2.38E-03	2.92E-03	7.44E-04	0	1.15E-06	0	1.26E-05	1.04E-05	1.21E-02	6.97E-02
Carcinogenics	CTUh	1.20E-06	6.15E-09	3.71E-07	7.39E-09	1.89E-09	0	6.73E-12	0	7.40E-11	2.64E-11	6.28E-08	1.65E-06
Non carcinogenics	CTUh	6.34E-06	9.04E-07	2.20E-07	1.13E-06	2.89E-07	0	1.13E-10	0	1.25E-09	4.04E-09	1.08E-07	9.00E-06
Respiratory effects	kg PM _{2.5} eq	3.09E-02	3.61E-03	4.12E-03	2.82E-03	7.20E-04	0	8.05E-07	0	8.85E-06	1.01E-05	1.25E-04	4.23E-02
Ecotoxicity	CTUe	3.82E+01	1.81E+01	7.15E+00	2.29E+01	5.83E+00	0	2.66E-04	0	2.92E-03	8.17E-02	3.68E+00	9.59E+01
Fossil fuel depletion	MJ surplus	1.26E+02	1.49E+01	1.03E+01	1.71E+01	4.36E+00	0	4.65E-03	0	5.11E-02	6.10E-02	1.53E-01	1.73E+02

Table 19b. Percent contributions of each stage to each impact category for Thermo-Sorb 263

Impact category	Unit	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	Total
Ozone depletion	kg CFC-11 eq	67.63%	12.31%	2.20%	14.08%	3.59%	0%	0.00%	0%	0.01%	0.05%	0.13%	100.00%
Global warming	kg CO ₂ eq	56.01%	7.58%	8.32%	8.64%	2.20%	0%	0.00%	0%	0.04%	0.03%	17.16%	100.00%
Smog	kg O ₃ eq	27.49%	5.23%	2.48%	1.92%	0.49%	0%	0.00%	62.12%	0.01%	0.01%	0.24%	100.00%
Acidification	kg SO ₂ eq	79.57%	8.22%	6.29%	4.27%	1.09%	0%	0.00%	0%	0.05%	0.02%	0.50%	100.00%
Eutrophication	kg N eq	69.40%	4.50%	3.41%	4.19%	1.07%	0%	0.00%	0%	0.02%	0.01%	17.40%	100.00%
Carcinogenics	CTUh	72.72%	0.37%	22.52%	0.45%	0.11%	0%	0.00%	0%	0.00%	0.00%	3.81%	100.00%
Non carcinogenics	CTUh	70.48%	10.04%	2.44%	12.57%	3.21%	0%	0.00%	0%	0.01%	0.04%	1.20%	100.00%
Respiratory effects	kg PM _{2.5} eq	73.00%	8.53%	9.75%	6.68%	1.70%	0%	0.00%	0%	0.02%	0.02%	0.29%	100.00%
Ecotoxicity	CTUe	39.81%	18.88%	7.46%	23.85%	6.08%	0%	0.00%	0%	0.00%	0.09%	3.84%	100.00%
Fossil fuel depletion	MJ surplus	72.85%	8.63%	5.95%	9.89%	2.52%	0%	0.00%	0%	0.03%	0.04%	0.09%	100.00%

Table 19c. SM millipoint scores for Thermo-Sorb 263 by life cycle stage per functional unit

Impact category	Unit	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	Total
SM single figure score	mPts	5.04E+00	4.62E-01	9.95E-01	5.23E-01	1.33E-01	0	1.22E-04	2.00E-01	1.34E-03	1.87E-03	4.27E-01	7.79E+00
	%	64.76%	5.93%	12.78%	6.72%	1.71%	0%	0.00%	2.57%	0.02%	0.02%	5.49%	100.00%

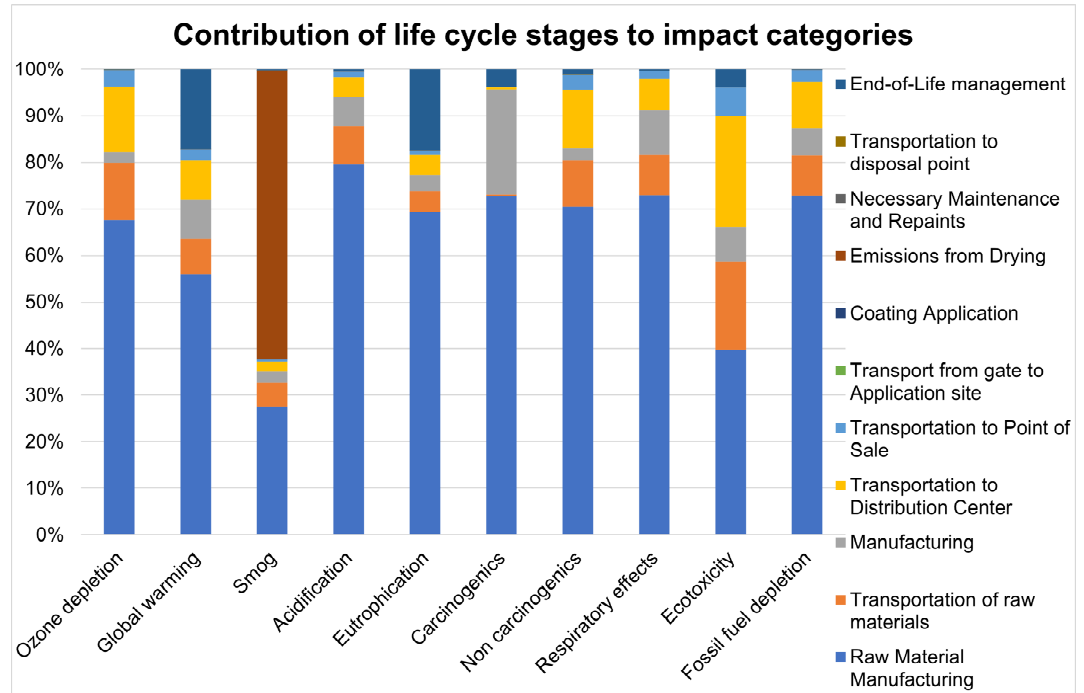


Figure 7. Contribution analysis of each impact category for Thermo-Sorb 263

4.2.1.5. Thermo-Lag E 100

Table 20a shows the impact assessment results, and Table 20b and Figure 8 show the percent contribution of each stage to the overall impacts of Thermo-Lag E 100.

Broadly speaking, the upstream production stage (Stage 1) dominates the results for all the impact categories. the design & construction stage (Stage 2) is the next highest contributor for all impact categories except for global warming, smog formation, eutrophication, and carcinogenics impact categories. To go a step further, the raw material manufacturing phase (1-1) contributes the most (>60%) of the total impacts to most of the impact categories.

For ozone depletion, the next highest impacts come from the transportation of raw materials phase (1-2) and the transportation to distribution center phase (2-1), which have a similar contribution. The contributions to transportation are caused by the use of trucks and trailer transportation. For the global warming and eutrophication impact categories, the next highest impact comes from the end-of-life management phase (4-2). The transportation of raw materials phase (1-2) is the second highest contributor to acidification and smog. Different with the results of the first four products, the emissions from drying phase (3-2) for Thermo-Lag E 100 is not the second highest contributor but the third highest contributor.

The coating application (3-1), necessary maintenance and repaints (3-3), and transportation to disposal point (4-1) phases are small contributors to all product life cycle impacts. The transportation to application site (2-3) phase shall account for zero impacts for all impact categories because there were assumed to be no material and energy inputs in the stage.

The SM 2013 Methodology single figure millipoint (mPts) score by life cycle phase for this product is presented below (Table 20c). The scores are consistent with the result using the impact assessment results before normalization and weighting. The raw material manufacturing (1-1) dominates the results (78.21%).

The coating manufacturing (1-3) phase accounts for the second highest score result (8.77%), followed by the transportation of raw materials to plants (1-2), the transportation to distribution center (2-1), and the end-of-life management (4-2) phases. These three phases come up with similar score results.

Table 20a. Thermo-Lag E100 coating impact potential results per functional unit

Impact category	Unit	Stage 1 - Product Stage			Stage 2 - Design & Construction Stage			Stage 3 - Use & Maintenance Stage			Stage 4 - End-of-Life Stage		Total
		1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	
Ozone depletion	kg CFC-11 eq	1.48E-05	4.03E-06	5.43E-07	3.96E-06	1.11E-06	0	3.20E-10	0	3.52E-09	1.56E-08	3.87E-08	2.45E-05
Global warming	kg CO ₂ eq	1.37E+02	1.70E+01	1.63E+01	1.66E+01	4.67E+00	0	7.82E-03	0	8.61E-02	6.53E-02	3.61E+01	2.28E+02
Smog	kg O ₃ eq	6.70E+00	1.70E+00	5.09E-01	3.71E-01	1.04E-01	0	2.62E-04	1.16E+00	2.89E-03	1.46E-03	5.14E-02	1.06E+01
Acidification	kg SO ₂ eq	6.84E-01	8.77E-02	4.48E-02	2.89E-02	8.11E-03	0	3.05E-05	0	3.35E-04	1.14E-04	3.71E-03	8.58E-01
Eutrophication	kg N eq	1.98E-01	8.44E-03	5.31E-03	6.02E-03	1.69E-03	0	2.55E-06	0	2.80E-05	2.37E-05	2.74E-02	2.47E-01
Carcinogenics	CTUh	7.19E-06	1.43E-08	9.15E-07	1.53E-08	4.28E-09	0	1.49E-11	0	1.64E-10	6.00E-11	1.42E-07	8.28E-06
Non carcinogenics	CTUh	1.51E-05	2.04E-06	4.81E-07	2.33E-06	6.56E-07	0	2.52E-10	0	2.77E-09	9.18E-09	2.43E-07	2.08E-05
Respiratory effects	kg PM _{2.5} eq	9.61E-02	1.05E-02	9.80E-03	5.82E-03	1.64E-03	0	1.79E-06	0	1.97E-05	2.29E-05	2.81E-04	1.24E-01
Ecotoxicity	CTUe	1.72E+02	4.05E+01	1.75E+01	4.72E+01	1.33E+01	0	5.90E-04	0	6.49E-03	1.86E-01	8.31E+00	2.99E+02
Fossil fuel depletion	MJ surplus	2.48E+02	3.57E+01	2.00E+01	3.52E+01	9.90E+00	0	1.03E-02	0	1.14E-01	1.39E-01	3.45E-01	3.50E+02

Table 20b. Percent contributions of each stage to each impact category for Thermo-Lag E100

Impact category	Unit	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	Total
Ozone depletion	kg CFC-11 eq	60.39%	16.45%	2.22%	16.16%	4.54%	0%	0.00%	0%	0.01%	0.06%	0.16%	100.00%
Global warming	kg CO ₂ eq	60.16%	7.45%	7.16%	7.29%	2.05%	0%	0.00%	0%	0.04%	0.03%	15.83%	100.00%
Smog	kg O ₃ eq	63.27%	16.00%	4.80%	3.50%	0.98%	0%	0.00%	10.91%	0.03%	0.01%	0.49%	100.00%
Acidification	kg SO ₂ eq	79.74%	10.23%	5.22%	3.37%	0.95%	0%	0.00%	0%	0.04%	0.01%	0.43%	100.00%
Eutrophication	kg N eq	80.20%	3.42%	2.15%	2.44%	0.68%	0%	0.00%	0%	0.01%	0.01%	11.08%	100.00%
Carcinogenics	CTUh	86.83%	0.17%	11.05%	0.18%	0.05%	0%	0.00%	0%	0.00%	0.00%	1.71%	100.00%
Non carcinogenics	CTUh	72.34%	9.77%	2.31%	11.20%	3.15%	0%	0.00%	0%	0.01%	0.04%	1.17%	100.00%
Respiratory effects	kg PM _{2.5} eq	77.42%	8.42%	7.90%	4.69%	1.32%	0%	0.00%	0%	0.02%	0.02%	0.23%	100.00%
Ecotoxicity	CTUe	57.54%	13.54%	5.86%	15.78%	4.43%	0%	0.00%	0%	0.00%	0.06%	2.78%	100.00%
Fossil fuel depletion	MJ surplus	70.97%	10.21%	5.73%	10.08%	2.83%	0%	0.00%	0%	0.03%	0.04%	0.10%	100.00%

Table 20c. SM millipoint scores for Thermo-Lag E100 by life cycle stage per functional unit

Impact category	Unit	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	Total
SM single figure score	mPts	2.11E+01	1.12E+00	2.37E+00	1.08E+00	3.03E-01	0	2.70E-04	3.99E-02	2.97E-03	4.24E-03	9.64E-01	2.70E+01
	%	78.21%	4.14%	8.77%	4.00%	1.12%	0%	0.00%	0.15%	0.01%	0.02%	3.58%	100.00%

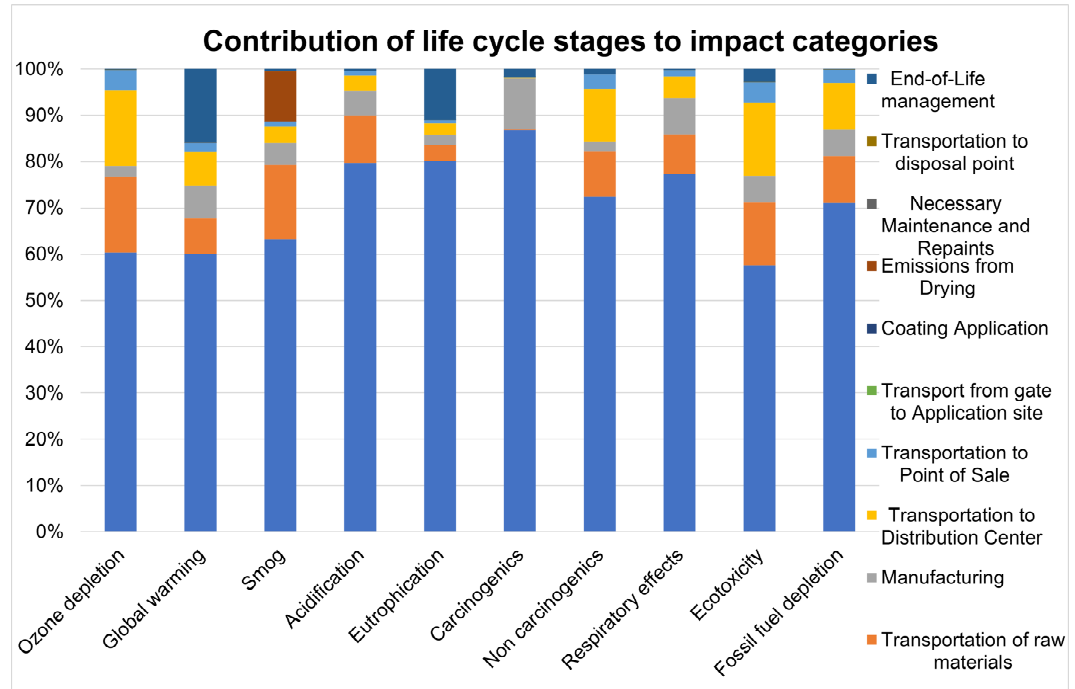


Figure 8. Contribution analysis of each impact category for Thermo-Lag E 100

4.2.1.6. Thermo-Lag E 100-S

Table 21a shows the impact assessment results, and Table 21b and Figure 9 show the percent contribution of each stage to the overall impacts of Thermo-Lag E 100-S.

Broadly speaking, the upstream production stage (Stage 1) dominates the results for all the impact categories. The design & construction stage (Stage 2) is the next highest contributor for all impact categories except for global warming, smog formation, eutrophication, and carcinogenics impact categories. To go a step further, the raw material manufacturing phase (1-1) contributes the most of the total impacts in most of the impact categories.

For ozone depletion, the next highest impacts come from the transportation of raw materials phase (1-2) and the transportation to distribution center phase (2-1), which have a similar contribution. The contributions to transportation are caused by the use of trucks and trailer transportation. For the global warming and eutrophication impact categories, the next highest impact comes from the end-of-life management phase (4-2). The transportation of raw materials phase (1-2) is the second highest contributor to acidification.

For smog formation, the second major contributor is the emissions from drying phase (3-2), which accounts for 37.12% of the total smog impact. The VOC emissions released during the drying process is the reason for the smog formation impact.

The coating application (3-1), necessary maintenance and repaints (3-3), and transportation to disposal point (4-1) phases are small contributors to all product life cycle impacts. The transportation to application site (2-3) phase shall account for zero impacts for all impact categories because there were assumed to be no material and energy inputs in the stage.

The SM 2013 Methodology single figure millipoint (mPts) score by life cycle phase for this product is presented below (Table 21c). The scores are consistent with the result using the impact assessment results before normalization and weighting. The raw material manufacturing (1-1) dominates the results (71.47%).

The coating manufacturing (1-3) phase accounts for the second highest score result (15.46%), followed by the transportation of raw materials to plants (1-2), the transportation to distribution center (2-1), and the end-of-life management (4-2) phases. These three phases come up with similar score results.

Table 21a Thermo-Lag E100-S coating impact potential results per functional unit

Impact category	Unit	Stage 1 - Product Stage			Stage 2 - Design & Construction Stage			Stage 3 - Use & Maintenance Stage			Stage 4 - End-of-Life Stage		Total
		1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	
Ozone depletion	kg CFC-11 eq	1.10E-05	3.13E-06	6.30E-07	2.95E-06	9.17E-07	0	2.54E-10	0	2.80E-09	1.28E-08	2.97E-08	1.87E-05
Global warming	kg CO ₂ eq	1.06E+02	1.32E+01	1.67E+01	1.24E+01	3.85E+00	0	6.22E-03	0	6.84E-02	5.39E-02	2.78E+01	1.80E+02
Smog	kg O ₃ eq	5.20E+00	1.28E+00	5.95E-01	2.76E-01	8.59E-02	0	2.08E-04	4.42E+00	2.29E-03	1.20E-03	3.95E-02	1.19E+01
Acidification	kg SO ₂ eq	5.23E-01	6.67E-02	4.77E-02	2.15E-02	6.69E-03	0	2.42E-05	0	2.67E-04	9.36E-05	2.85E-03	6.69E-01
Eutrophication	kg N eq	1.17E-01	6.50E-03	5.99E-03	4.48E-03	1.39E-03	0	2.02E-06	0	2.23E-05	1.95E-05	2.10E-02	1.56E-01
Carcinogenics	CTUh	5.13E-06	1.11E-08	1.38E-06	1.13E-08	3.53E-09	0	1.19E-11	0	1.31E-10	4.94E-11	1.09E-07	6.65E-06
Non carcinogenics	CTUh	1.13E-05	1.59E-06	5.74E-07	1.74E-06	5.40E-07	0	2.00E-10	0	2.20E-09	7.57E-09	1.87E-07	1.60E-05
Respiratory effects	kg PM _{2.5} eq	7.25E-02	8.01E-03	1.38E-02	4.33E-03	1.35E-03	0	1.42E-06	0	1.56E-05	1.89E-05	2.16E-04	1.00E-01
Ecotoxicity	CTUe	1.28E+02	3.16E+01	2.62E+01	3.51E+01	1.09E+01	0	4.69E-04	0	5.15E-03	1.53E-01	6.39E+00	2.39E+02
Fossil fuel depletion	MJ surplus	2.07E+02	2.77E+01	1.73E+01	2.62E+01	8.16E+00	0	8.20E-03	0	9.02E-02	1.14E-01	2.65E-01	2.87E+02

Table 21b Percent contributions of each stage to each impact category for Thermo-Lag E100-S

Impact category	Unit	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	Total
Ozone depletion	kg CFC-11 eq	59.02%	16.73%	3.37%	15.74%	4.90%	0%	0.00%	0%	0.01%	0.07%	0.16%	100.00%
Global warming	kg CO ₂ eq	59.00%	7.31%	9.23%	6.85%	2.13%	0%	0.00%	0%	0.04%	0.03%	15.39%	100.00%
Smog	kg O ₃ eq	43.68%	10.80%	5.00%	2.32%	0.72%	0%	0.00%	37.12%	0.02%	0.01%	0.33%	100.00%
Acidification	kg SO ₂ eq	78.20%	9.98%	7.13%	3.21%	1.00%	0%	0.00%	0%	0.04%	0.01%	0.43%	100.00%
Eutrophication	kg N eq	74.77%	4.15%	3.83%	2.86%	0.89%	0%	0.00%	0%	0.01%	0.01%	13.46%	100.00%
Carcinogenics	CTUh	77.16%	0.17%	20.81%	0.17%	0.05%	0%	0.00%	0%	0.00%	0.00%	1.64%	100.00%
Non carcinogenics	CTUh	70.94%	9.96%	3.60%	10.88%	3.39%	0%	0.00%	0%	0.01%	0.05%	1.17%	100.00%
Respiratory effects	kg PM _{2.5} eq	72.37%	7.99%	13.72%	4.32%	1.35%	0%	0.00%	0%	0.02%	0.02%	0.22%	100.00%
Ecotoxicity	CTUe	53.73%	13.26%	10.99%	14.70%	4.58%	0%	0.00%	0%	0.00%	0.06%	2.68%	100.00%
Fossil fuel depletion	MJ surplus	72.13%	9.67%	6.05%	9.14%	2.85%	0%	0.00%	0%	0.03%	0.04%	0.09%	100.00%

Table 21c SM millipoint scores for Thermo-Lag E100-S by life cycle stage per functional unit

Impact category	Unit	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	Total
SM single figure score	mPts	1.54E+01	8.66E-01	3.33E+00	8.03E-01	2.50E-01	0	2.14E-04	1.53E-01	2.36E-03	3.50E-03	7.42E-01	2.16E+01
	%	71.47%	4.02%	15.46%	3.72%	1.16%	0%	0.00%	0.71%	0.01%	0.02%	3.44%	100.00%

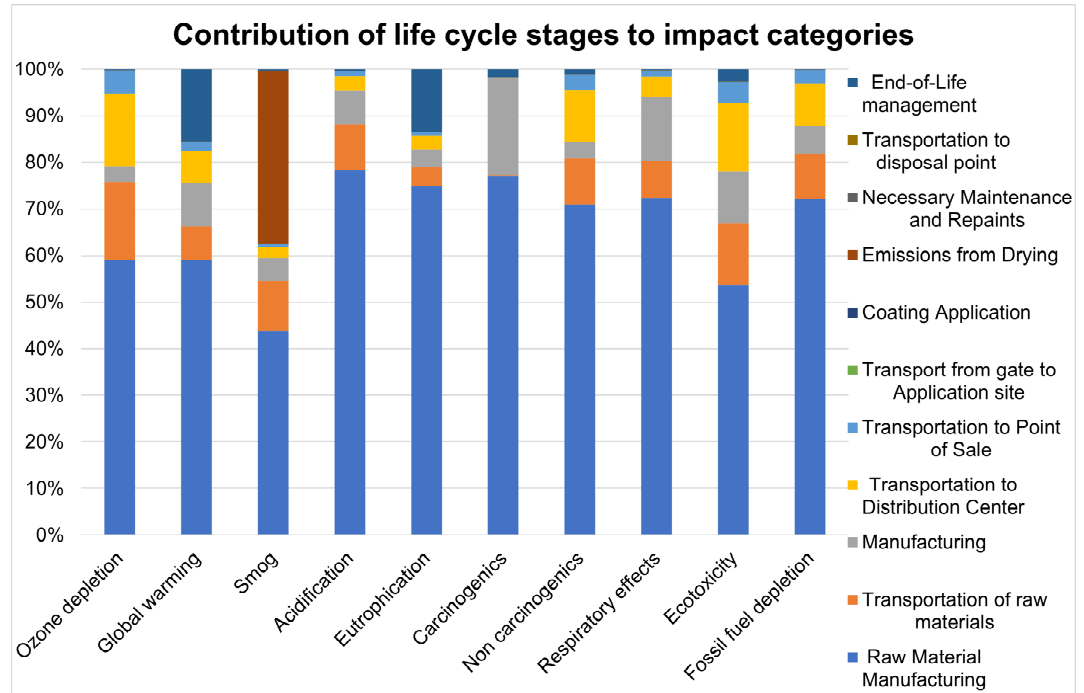


Figure 9. Contribution analysis of each impact category for Thermo-Lag E 100-S

4.2.1.7. Thermo-Lag 3000

Table 22a shows the impact assessment results, and Table 22b and Figure 10 show the percent contribution of each stage to the overall impacts of Thermo-Lag E 3000.

Broadly speaking, the upstream production stage (Stage 1) dominates the results for all the impact categories. the design & construction stage (Stage 2) is the next highest contributor for all impact categories except for global warming, smog formation, eutrophication, and carcinogenics impact categories. To go a step further, the raw material manufacturing phase (1-1) contributes the most (>60%) of the total impacts in most of the impact categories.

For ozone depletion, the next highest impacts come from the transportation of raw materials phase (1-2) and the transportation to distribution center phase (2-1), which have a similar contribution. The contributions to transportation are caused by the use of trucks and trailer transportation. For the global warming and eutrophication impact categories, the next highest impact comes from the end-of-life management phase (4-2). The transportation of raw materials (1-2) and the coating manufacturing (1-3) phases have a similar contribution to acidification.

The VOC emissions released during the drying process make the emissions from drying phase (3-2) the second highest contributor, which accounts for 11.75% of the total smog impact.

The coating application (3-1), necessary maintenance and repaints (3-3), and transportation to disposal point (4-1) phases are small contributors to all product life cycle impacts. The transportation to application site (2-3) phases shall account for zero impacts for all impact categories because there were assumed to be no material and energy inputs in the stage.

The SM 2013 Methodology single figure millipoint (mPts) score by life cycle phase for this product is presented below (Table 22c). The scores are consistent with the result using the impact assessment results before normalization and weighting. The raw material manufacturing (1-1) dominates the results (78.34%).

The coating manufacturing (1-3) phase accounts for the second highest score result (8.75%), followed by the transportation of raw materials to plants (1-2), the transportation to distribution center (2-1), and the end-of-life management (4-2) phases. These three phases come up with similar score results.

Table 22a. Thermo-Lag 3000 coating impact potential results per functional unit

Impact category	Unit	Stage 1 - Product Stage			Stage 2 - Design & Construction Stage			Stage 3 - Use & Maintenance Stage			Stage 4 - End-of-Life Stage		Total
		1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	
Ozone depletion	kg CFC-11 eq	1.54E-05	4.00E-06	5.46E-07	4.02E-06	1.11E-06	0	3.19E-10	0	3.51E-09	1.55E-08	3.85E-08	2.52E-05
Global warming	kg CO ₂ eq	1.40E+02	1.69E+01	1.62E+01	1.69E+01	4.66E+00	0	7.80E-03	0	8.58E-02	6.52E-02	3.60E+01	2.31E+02
Smog	kg O ₃ eq	6.85E+00	7.89E-01	5.11E-01	3.77E-01	1.04E-01	0	2.62E-04	1.16E+00	2.88E-03	1.46E-03	5.12E-02	9.84E+00
Acidification	kg SO ₂ eq	6.91E-01	5.31E-02	4.49E-02	2.94E-02	8.10E-03	0	3.04E-05	0	3.34E-04	1.13E-04	3.70E-03	8.31E-01
Eutrophication	kg N eq	1.77E-01	6.82E-03	5.17E-03	6.12E-03	1.69E-03	0	2.54E-06	0	2.79E-05	2.36E-05	2.73E-02	2.24E-01
Carcinogenics	CTUh	7.22E-06	1.52E-08	9.22E-07	1.55E-08	4.27E-09	0	1.49E-11	0	1.64E-10	5.98E-11	1.41E-07	8.32E-06
Non carcinogenics	CTUh	1.52E-05	2.25E-06	4.82E-07	2.37E-06	6.54E-07	0	2.51E-10	0	2.76E-09	9.16E-09	2.42E-07	2.12E-05
Respiratory effects	kg PM _{2.5} eq	9.78E-02	7.10E-03	9.88E-03	5.92E-03	1.63E-03	0	1.78E-06	0	1.96E-05	2.28E-05	2.80E-04	1.23E-01
Ecotoxicity	CTUe	1.81E+02	4.53E+01	1.76E+01	4.80E+01	1.32E+01	0	5.88E-04	0	6.47E-03	1.85E-01	8.28E+00	3.14E+02
Fossil fuel depletion	MJ surplus	2.60E+02	3.56E+01	2.01E+01	3.58E+01	9.87E+00	0	1.03E-02	0	1.13E-01	1.38E-01	3.44E-01	3.62E+02

Table 22b. Percent contributions of each stage to each impact category for Thermo-Lag 3000

Impact category	Unit	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	Total
Ozone depletion	kg CFC-11 eq	61.29%	15.91%	2.17%	15.99%	4.41%	0%	0.00%	0%	0.01%	0.06%	0.15%	100.00%
Global warming	kg CO ₂ eq	60.68%	7.31%	7.01%	7.32%	2.02%	0%	0.00%	0%	0.04%	0.03%	15.60%	100.00%
Smog	kg O ₃ eq	69.58%	8.02%	5.19%	3.83%	1.06%	0%	0.00%	11.75%	0.03%	0.01%	0.52%	100.00%
Acidification	kg SO ₂ eq	83.19%	6.39%	5.41%	3.53%	0.97%	0%	0.00%	0%	0.04%	0.01%	0.45%	100.00%
Eutrophication	kg N eq	78.96%	3.05%	2.31%	2.73%	0.75%	0%	0.00%	0%	0.01%	0.01%	12.18%	100.00%
Carcinogenics	CTUh	86.79%	0.18%	11.09%	0.19%	0.05%	0%	0.00%	0%	0.00%	0.00%	1.70%	100.00%
Non carcinogenics	CTUh	71.61%	10.63%	2.28%	11.20%	3.09%	0%	0.00%	0%	0.01%	0.04%	1.14%	100.00%
Respiratory effects	kg PM _{2.5} eq	79.74%	5.79%	8.05%	4.82%	1.33%	0%	0.00%	0%	0.02%	0.02%	0.23%	100.00%
Ecotoxicity	CTUe	57.78%	14.42%	5.62%	15.27%	4.21%	0%	0.00%	0%	0.00%	0.06%	2.64%	100.00%
Fossil fuel depletion	MJ surplus	71.80%	9.85%	5.55%	9.90%	2.73%	0%	0.00%	0%	0.03%	0.04%	0.10%	100.00%

Table 22c. SM millipoint scores for Thermo-Lag 3000 by life cycle stage per functional unit

Impact category	Unit	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	Total
SM single figure score	mPts	2.13E+01	1.10E+00	2.38E+00	1.10E+00	3.03E-01	0	2.69E-04	3.99E-02	2.96E-03	4.24E-03	9.61E-01	2.72E+01
	%	78.34%	4.04%	8.75%	4.04%	1.11%	0%	0.00%	0.15%	0.01%	0.02%	3.54%	100.00%

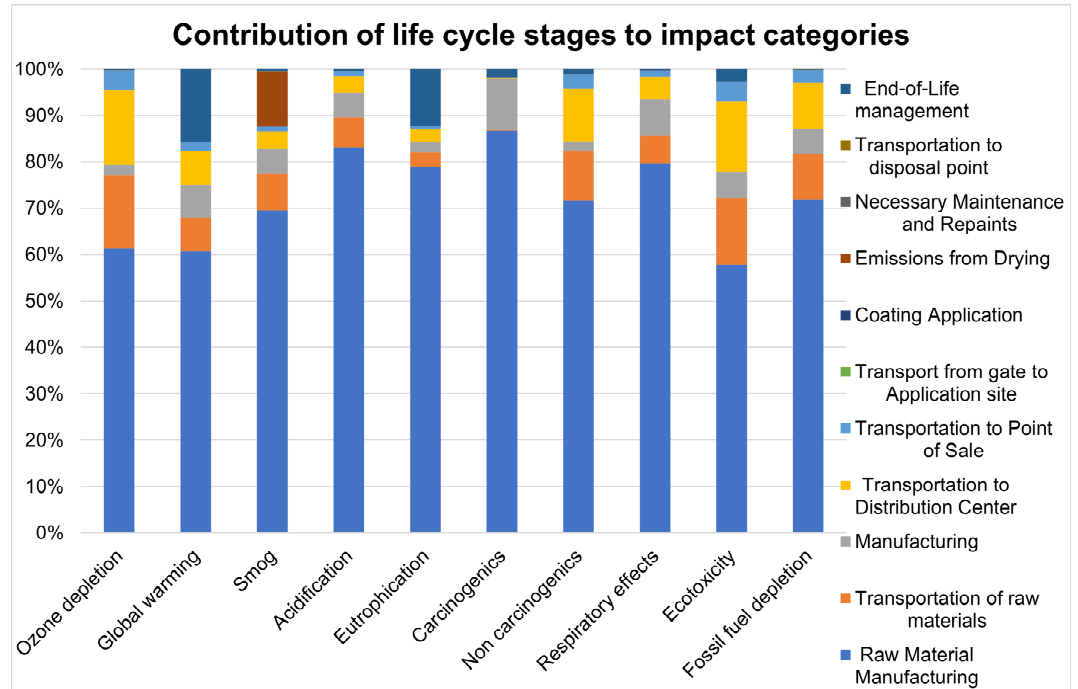


Figure 10. Contribution analysis of each impact category for Thermo-Lag 3000

4.2.1.8. Thermo-Lag 3000-SP

Table 23a shows the impact assessment results, and Table 23b and Figure 11 show the percent contribution of each stage to the overall impacts of Thermo-Lag E 3000-SP.

Broadly speaking, the upstream production stage (Stage 1) dominates the results for all the impact categories. The design & construction stage (Stage 2) is the next highest contributor for all impact categories except for global warming, smog formation, eutrophication, and carcinogenics impact categories. To go a step further, the raw material manufacturing phase (1-1) contributes the most of the total impacts in most of the impact categories.

For ozone depletion, the next highest impacts come from the transportation of raw materials phase (1-2) and the transportation to distribution center phase (2-1), which have a similar contribution. The contributions to transportation are caused by the use of trucks and trailer transportation. For the global warming and eutrophication impact categories, the next highest impacts come from the end-of-life management phase (4-2). The transportation of raw materials (1-2) and the coating manufacturing (1-3) phases have a similar contribution to acidification.

The VOC emissions released during the drying process make the emissions from drying phase (3-2) the second highest contributor, which accounts for 38.54% of the total smog impact.

The coating application (3-1), necessary maintenance and repaints (3-3), and transportation to disposal point (4-1) phases are small contributors to all product life cycle impacts. The transportation to application site (2-3) phase shall account for zero impacts for all impact categories because there were assumed to be no material and energy inputs in the stage.

The SM 2013 Methodology single figure millipoint (mPts) score by life cycle phase for this product is presented below (Table 23c). The scores are consistent with the result using the impact assessment results before normalization and weighting. The raw material manufacturing (1-1) dominates the results (70.56%).

The coating manufacturing (1-3) phase accounts for the second highest score result (15.09%), followed by the transportation of raw materials to plants (1-2), the transportation to distribution center (2-1), and the end-of-life management (4-2) phases. These three phases come up with similar score results.

Table 23a. Thermo-Lag 3000-SP coating impact potential results per functional unit

Impact category	Unit	Stage 1 - Product Stage			Stage 2 - Design & Construction Stage			Stage 3 - Use & Maintenance Stage			Stage 4 - End-of-Life Stage		Total
		1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	
Ozone depletion	kg CFC-11 eq	1.15E-05	3.58E-06	6.40E-07	3.34E-06	9.34E-07	0	2.55E-10	0	2.80E-09	1.31E-08	3.03E-08	2.00E-05
Global warming	kg CO ₂ eq	1.07E+02	1.45E+01	1.68E+01	1.40E+01	3.92E+00	0	6.23E-03	0	6.85E-02	5.49E-02	2.83E+01	1.84E+02
Smog	kg O ₃ eq	5.24E+00	7.47E-01	6.04E-01	3.12E-01	8.75E-02	0	2.09E-04	4.41E+00	2.30E-03	1.22E-03	4.02E-02	1.15E+01
Acidification	kg SO ₂ eq	5.24E-01	4.44E-02	4.83E-02	2.43E-02	6.81E-03	0	2.43E-05	0	2.67E-04	9.54E-05	2.91E-03	6.51E-01
Eutrophication	kg N eq	1.20E-01	6.16E-03	6.09E-03	5.07E-03	1.42E-03	0	2.03E-06	0	2.23E-05	1.99E-05	2.14E-02	1.60E-01
Carcinogenics	CTUh	5.34E-06	1.55E-08	1.42E-06	1.28E-08	3.60E-09	0	1.19E-11	0	1.31E-10	5.04E-11	1.11E-07	6.90E-06
Non carcinogenics	CTUh	1.17E-05	2.78E-06	5.84E-07	1.97E-06	5.51E-07	0	2.00E-10	0	2.20E-09	7.71E-09	1.90E-07	1.78E-05
Respiratory effects	kg PM _{2.5} eq	7.35E-02	8.19E-03	1.41E-02	4.90E-03	1.37E-03	0	1.42E-06	0	1.56E-05	1.92E-05	2.20E-04	1.02E-01
Ecotoxicity	CTUe	1.36E+02	5.75E+01	2.69E+01	3.97E+01	1.11E+01	0	4.69E-04	0	5.16E-03	1.56E-01	6.50E+00	2.78E+02
Fossil fuel depletion	MJ surplus	2.07E+02	3.18E+01	1.74E+01	2.97E+01	8.31E+00	0	8.22E-03	0	9.04E-02	1.16E-01	2.70E-01	2.95E+02

Table 23b. Percent contributions of each stage to each impact category for Thermo-Lag 3000-SP

Impact category	Unit	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	Total
Ozone depletion	kg CFC-11 eq	57.35%	17.88%	3.20%	16.67%	4.67%	0%	0.00%	0%	0.01%	0.07%	0.15%	100.00%
Global warming	kg CO ₂ eq	57.85%	7.88%	9.14%	7.59%	2.13%	0%	0.00%	0%	0.04%	0.03%	15.34%	100.00%
Smog	kg O ₃ eq	45.79%	6.52%	5.27%	2.73%	0.76%	0%	0.00%	38.54%	0.02%	0.01%	0.35%	100.00%
Acidification	kg SO ₂ eq	80.48%	6.82%	7.41%	3.74%	1.05%	0%	0.00%	0%	0.04%	0.01%	0.45%	100.00%
Eutrophication	kg N eq	74.89%	3.85%	3.80%	3.17%	0.89%	0%	0.00%	0%	0.01%	0.01%	13.38%	100.00%
Carcinogenics	CTUh	77.41%	0.22%	20.52%	0.19%	0.05%	0%	0.00%	0%	0.00%	0.00%	1.61%	100.00%
Non carcinogenics	CTUh	65.78%	15.64%	3.29%	11.07%	3.10%	0%	0.00%	0%	0.01%	0.04%	1.07%	100.00%
Respiratory effects	kg PM _{2.5} eq	71.86%	8.01%	13.74%	4.79%	1.34%	0%	0.00%	0%	0.02%	0.02%	0.22%	100.00%
Ecotoxicity	CTUe	48.93%	20.70%	9.66%	14.30%	4.01%	0%	0.00%	0%	0.00%	0.06%	2.34%	100.00%
Fossil fuel depletion	MJ surplus	70.30%	10.77%	5.90%	10.05%	2.82%	0%	0.00%	0%	0.03%	0.04%	0.09%	100.00%

Table 23c. SM millipoint scores for Thermo-Lag 3000-SP by life cycle stage per functional unit

Impact category	Unit	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2	Total
SM single figure score	mPts	1.59E+01	1.16E+00	3.41E+00	9.09E-01	2.55E-01	0	2.15E-04	1.52E-01	2.36E-03	3.56E-03	7.55E-01	2.26E+01
	%	70.56%	5.14%	15.09%	4.03%	1.13%	0%	0.01%	0.68%	0.00%	0.02%	3.35%	100.00%

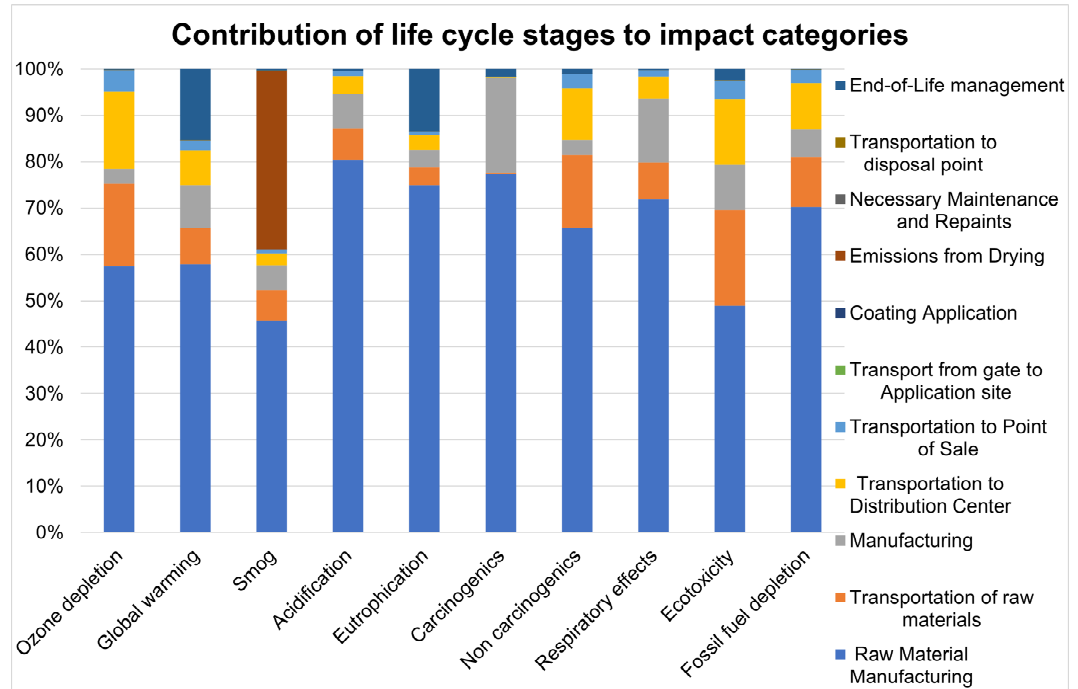


Figure 11. Contribution analysis of each impact category for Thermo-Lag 3000-SP

4.2.2. Sensitivity analyses

Sensitivity analyses were performed to check the robustness of the results where the highest potential environmental impacts are occurring. Global warming potential was evaluated for sensitivity since Carboline is interested in the potential CO₂-equivalent emissions of its products.

As the bulk of the impacts are attributed to raw materials acquisition and processing, the mass of specified raw materials was changed by +/-20%. These raw materials were chosen based on a combination of relatively higher contribution to the results and relatively lower representativeness of background data sets used to model the raw material. As shown in Table 24, these changes resulted in a +/-1-9% change in total life cycle impacts.

Table 24. Sensitivity analyses of LCIA results per functional unit

Product name	Raw material studied	Base total life cycle impacts (kgCO ₂ -eq)	After 20% decrease in mass (kgCO ₂ -eq)	After 20% increase in mass (kgCO ₂ -eq)	Range of change in total life cycle impacts
Firefilm III	■	9.40E+01	8.88E+01	9.91E+01	+/- 5%
Firefilm IV	■	1.86E+02	1.70E+02	2.03E+02	+/- 9%
Thermo-Sorb VOC	■	1.09E+02	1.05E+02	1.13E+02	+/- 3%
Thermo-Sorb 263	■	9.32E+01	8.87E+01	9.77E+01	+/- 5%
Thermo-Lag E100	■	2.28E+02	2.20E+02	2.36E+02	+/- 3%
Thermo-Lag E100-S	■	1.80E+02	1.75E+02	1.86E+02	+/- 3%
Thermo-Lag 3000	■	2.31E+02	2.23E+02	2.38E+02	+/- 3%
Thermo-Lag 3000-SP	■	1.84E+02	1.78E+02	1.90E+02	+/- 3%

4.3 Overview of relevant findings

The goal of this study was to conduct a cradle-to-grave LCA on several intumescent fireproofing coatings so as to develop SM Transparency Reports™ / EPDs. The creation of these Transparency Reports will allow consumers in the building and construction industry to make better informed decisions about the environmental impacts associated with the products they choose. Overall, the study found that raw material manufacturing accounts for a notable contribution to all impact categories.

The raw material manufacturing phase (1-1) is the largest contributor for all impact categories. This holds true for the LCA results of each of Carboline's intumescent fireproofing products.

In most cases, the transportation of raw materials to plants (1-2) and transportation to distribution center (2-1) phases are the second highest contributors to ozone depletion. The end-of-life management phase (4-2) is in most cases the second highest contributor to the global warming and eutrophication impact categories.

For smog formation, the study found that the emissions from drying phase (3-2) is the major impact contributor only for the Thermo-Sorb series. The reason for the finding is that the Thermo-Sorb series emits relatively more VOCs than other series of Carboline products (See Table 9). The VOC volume came from the product data sheets generated by Carboline. Although other series products emit relatively lesser VOC, the emissions from drying phase (3-2) is still the second largest contributor among most of the products except for Firefilm IV and Thermo-Lag E 100. For acidification, the transportation of raw materials (1-2) and the coating manufacturing (1-3) phases have a similar contribution..

The coating application (3-1) and necessary maintenance and repaints (3-3) account for a small fraction of overall life cycle impacts given that product unpacking, sprayer assembling, sprayers tank filling, and thickness testing are manual processes. Since the steel pail for finished products is recyclable, the only impacts associated with installation are from sprayer operation. There is a minimum impact associated with the use stage because of the low electricity consumption required for coating application.

While coatings can influence building energy performance, this aspect is assumed to be outside the scope of this study. Additionally, it is assumed that Carboline's intumescent fireproofing coatings require one initial coating application plus eleven recoats to achieve the reference service life (60 years), which is modeled as being equal to that of the building. The results are presented per one square meter of covered and protected substrate at a recommended coating thickness.

At the end of life, intumescent fireproofing coatings are removed from the building and landfilled as demolition waste. For all products, waste impacts were largely attributed to the final disposal of the product.

4.4 Discussion on data quality

Inventory data quality is judged by its precision (measured, calculated, or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied on a study serving as a data source), and representativeness (geographical, temporal, and technological).

To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent background LCA information from SimaPro Analyst 9.4 and the ecoinvent v3, US-EI 2.2, and ELCD databases were used.

Precision and completeness

- Precision: As the relevant foreground data is primary data or modeled based on primary information sources of the owner of the technology, precision is considered to be high. Background data are from ecoinvent v3, US-EI 2.2, and ELCD databases with documented precision to the extent available.
- Completeness: The product system was checked for mass balance and completeness of the inventory. Personnel impacts, R&D activities, business travel, secondary packaging, point of sale infrastructure, and the coating applicator were excluded as required by the PCR. Otherwise, no data were knowingly omitted.

Consistency and reproducibility

- Consistency: Primary data were collected with a similar level of detail, while background data were sourced primarily from the ecoinvent database, while other databases were used if data were not available in ecoinvent or the data set was judged to be more representative. Other methodological choices were made consistently throughout the model.
- Reproducibility: Reproducibility is warranted as much as possible through the disclosure of input-output data, dataset choices, and modeling approaches in this report. Based on this information, a knowledgeable third party should be able to approximate the results of this study using the same data and modeling approaches.

Representativeness

- Temporal: All primary data were collected for calendar year 2021 in order to ensure representativeness of post-consumer content. Secondary data were obtained from the ecoinvent v3, US-EI 2.2, and ELCD databases and are typically representative of the recent years.
- Geographical: Primary data are representative of Carboline's production facilities in Lake Charles and Dayton. Differences in electric grid mix were taken into account with appropriate secondary data. In general, secondary data were collected specific to the country under study. Where country-specific data were unavailable, proxy data were used. Geographical representativeness is considered to be high.
- Technological: All primary and secondary data were modeled to be specific to the technologies under study. Technological representativeness is considered to be high.

4.5 Completeness, sensitivity, and consistency

Completeness

- All relevant process steps for the product system were considered and modeled. The process chain is considered sufficiently complete with regards to the goal and scope of this study.

Sensitivity

- Carboline's intumescent fireproofing coatings are considered primer coatings and are used indoors. Therefore, only a 5-year market-based lifetime was used in the modeling. The model includes one initial coating application and 11 recoats to cover the usage time of 60 years (the assumed average lifetime of a building). The study also constructed sensitivity analyses to assess the robustness of the model by adjusting the mass of material, which accounts for high potential environmental impacts.

Consistency

- Assumption, methods, and data were found to be consistent with the study's goal and scope. Differences in background data quality were minimized by using LCI data from the ecoinvent and otherwise standard databases. System boundaries, allocation rules, and impact assessment methods have been applied consistently throughout the study

4.6 Conclusions and recommendations

The goal of this study was to conduct a cradle-to-grave LCA on Carboline's intumescent fireproofing coatings. The creation of the LCA report allows Carboline to make better informed decisions about the environmental impacts associated with its products.

The raw materials for manufacturing Carboline's intumescent coating products are purchased directly from suppliers. These raw materials are shipped to Carboline's manufacturing facilities and stored and mixed at the plants. The product stage (stage 1) accounts for the highest contribution to impacts, primarily because of the impacts associated with raw material manufacturing.

Once the IFRM products arrive at the site of application, they are spray-applied to structural steel beams, columns, tubes, and pipes, and in the case of a fire, soften and expand to form thick layers which insulate the structure and protect the steel from fire. The use stage (stage 3) accounts for a smaller contribution to life cycle performance due to the energy required for spray application and the emissions from drying.

Since the raw materials purchased from suppliers for product manufacturing make up the bulk of the impacts, Carboline should explore opportunities to substitute these components with materials that have a lower impact on the environment or should explore suppliers who use sustainable manufacturing techniques or who integrate more renewable energy into their manufacturing processes.

5 REFERENCES

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ACRONYMS

IFRM	Intumescent fire-resistive material
ISO	International Standardization Organization
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact analysis
NSF	National Sanitation Foundation
PCR	Product Category Rule document
TR	Transparency Report™ / EPD

GLOSSARY

For the purposes of this report, the terms and definitions given in ISO 14020, ISO 14025, the ISO 14040 series, and ISO 21930 apply. The most important ones are included here:

Allocation	Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems
Close loop & open loop	A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials. An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties.
Cradle to grave	Addresses the environmental aspects and potential environmental impacts (e.g., use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition until the end of life
Cradle to gate	Addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition until the end of the production process ("gate of the factory"). It may also include transportation until use phase
Declared unit	Quantity of a product for use as a reference unit in an EPD based on one or more information modules
Functional unit	Quantified performance of a product system for use as a reference unit
Life cycle	Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal
Life cycle assessment - LCA	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle
Life cycle impact assessment - LCIA	Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product
Life cycle inventory - LCI	phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle
Life cycle interpretation	Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations

APPENDIX

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