LIFE CYCLE ASSESSMENT (LCA) OF CARBOLINE SPRAY-APPLIED FIRE-RESISTIVE MATERIALS

Status: Public report

Client: Carboline

Date: December 2022

Authors: Jui-Lung Li, Sustainable Minds
Kim Lewis, Sustainable Minds

Contents

1 INTRODUCTION 4
1.1 Opportunity 4
1.2 Life cycle assessment 5
1.3 Status 5
1.4 Team 5
1.5 Structure 5

2 GOAL AND SCOPE 6
2.1 Intended application and audience 6
2.2 Product description 6
2.3 Declared unit 7
2.4 System boundaries 8
2.4.1.Production stage (A1-A3) 8
2.5 Impact assessment characterization 9
2.6 Normalization and weighting 10
2.7 Software and database 10
2.8 Cut-off criteria 10
2.9 Allocation 11
2.10 Critical review 11

3 LIFE CYCLE INVENTORY ANALYSIS 12
3.1 Data collection procedures 12
3.2 Primary data 12
3.2.1.Raw materials acquisition and transportation 12
3.2.2.Manufacturing 13
3.3 Data selection and quality 17
3.4 Background data 18
3.4.1.Fuels and energy 18
3.4.2.Raw materials production 18
3.4.3.Transportation 20
3.4.4.Disposal 20
3.5 Limitations 21

4 ASSESSMENT AND INTERPRETATION 22
4.1 Resource use and waste flows 22
4.2 Life cycle impact assessment (LCIA) 31
4.2.1.Impact assessment results 32
4.2.1.1. Pyrocrete 239 32
4.2.1.2. Pyrocrete 241 34
4.2.1.3. Pyrocrete 341 35
4.2.1.4. Pyrocrete 40 36
4.2.1.5. Southwest Type 5GP 38
4.2.1.6. Southwest Type 5MD 39
4.2.1.7. Southwest Type 7GP 41
4.2.1.8. Southwest Type 7HD 42
4.2.1.9. Southwest Type 7TB 44
4.2.2.Sensitivity analyses 45
4.3 Overview of relevant findings 46
4.4 Discussion of data quality 46
4.5 Conclusions and recommendations 47

5 REFERENCES 48

ACRONYMS 49

GLOSSARY 49

APPENDIX 50

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 manufacturing. 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 spray-applied fire-resistive materials (SFRMs) using a cradle-to-gate approach. The products are either portland cement-based or gypsum-based fire-resistive materials. 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. Pyrocrete 239
2. Pyrocrete 241
3. Pyrocrete 341
4. Pyrocrete 40
5. Southwest Type 5GP
6. Southwest Type 5MD
7. Southwest Type 7GP
8. Southwest Type 7HD
9. Southwest Type 7TD

Carboline is interested in having LCA data available for its SFRM 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 to the requirements of ISO 14040/14044 [1], ISO 21930 standards [2], and the ASTM PCR for Spray-applied Fire Resistive Materials (SFRM) [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.

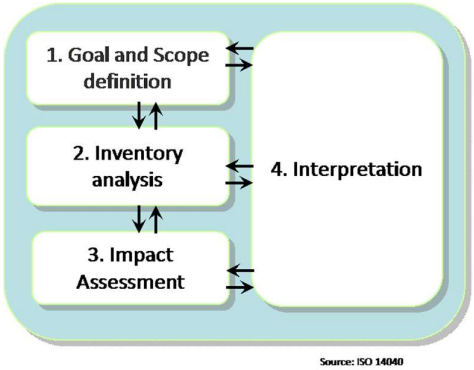


Figure 1. Life cycle assessment approach

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 Louisa, Virginia. Where data was missing, assumptions were made from manufacturing data for the facility based upon expertise from Carboline employees.

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

The LCA review and Sustainable Minds Transparency Reports / EPDs verification will be 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 goal and scope of the study. The aim of the goal and scope is to define the product under study and the depth and breadth 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 SM Transparency Reports / EPDs will undergo critical review for conformance to the PCR.

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 coatings, fire-resistive materials, and fireproofing products, Carboline is interested in demonstrating its sustainability leadership and leveraging business value associated with transparent reporting of its products' cradle-to-gate environmental impacts. For more information on Carboline products, go to https://www.carboline.com/.

Carboline's SFRM products are designed for the fire protection of structural steel in various areas, occupancy classification, and site conditions. The manufacturing location for these products is located 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
Pyrocrete 239	Louisa, Virginia, USA
Pyrocrete 241	
Pyrocrete 341	
Pyrocrete 40	
Southwest Type 5GP	
Southwest Type 5MD	
Southwest Type 7GP	
Southwest Type 7HD	
Southwest Type 7TB	

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

Product name	CSI MasterFormat® classification	Transparency Report	Type of declaration
Pyrocrete 239	07 81 00	Pyrocrete Series	Product-specific declaration from a manufacturer's plant
Pyrocrete 241			
Pyrocrete 341			
Pyrocrete 40			
Southwest Type 5GP	07 81 00	Southwest Type 5 Series	
Southwest Type 5MD			
Southwest Type 7GP	07 81 00	Southwest Type 7 Series	
Southwest Type 7HD			
Southwest Type 7TB			

Table 1c. Other product information

Product name	Application environment
Pyrocrete 239	A medium density, portland cement-based, cementitious fireproofing. It provides 1–4-hour fire protection for structural steel members and upgrades the fire resistance of existing concrete. It can also be used as a thermal barrier over polyurethane foam. Recommended areas of application include pharmaceutical facilities, pulp and paper mills, nuclear and conventional power plants, factories, warehouses, stadiums, institutional and biomedical facilities, and acoustical applications.
Pyrocrete 241	A 55 lb./ft³ (881 kg/m³) density, portland cement-based, cementitious fireproofing. It provides both hydrocarbon and cellulosic fire protection for structural steel and can also be used to upgrade the fire resistance of existing concrete. Recommended areas of application include refineries, petrochemical, pharmaceutical facilities, pulp and paper mills, offshore platforms, nuclear and conventional power plants, factories, warehouses, and institutional and biomedical facilities.
Pyrocrete 341	A minimum average 52 lb./ft³ (833 kg/m³) density, portland cement-based fireproofing material that provides hydrocarbon pool fire, jet fire, and cryogenic spill protection for structural steel. Recommended areas of application include refineries, petrochemical, and LNG facilities.
Pyrocrete 40	A 40 lb./ft³ (640 kg/m³) density, portland cement-based, cementitious fireproofing. It provides both hydrocarbon and cellulosic fire protection for structural steel and can also be used to upgrade the fire resistance of existing concrete. Recommended areas of application include refineries, petrochemical, pharmaceutical facilities, pulp and paper mills, offshore platforms, nuclear and conventional power plants, factories, warehouses, and institutional and biomedical facilities.
Southwest Type 5GP	A 15 lb./ft³ (240 kg/m³) SFRM intended for the fire protection of interior structural columns, beams, joists, decks, walls, roofs, girders, floors, and pre-cast concrete units.
Southwest Type 5MD	A medium density SFRM intended for the fire protection of interior structural columns, beams, joists, decks, walls, roofs, girders, floors, and pre-cast concrete units.
Southwest Type 7GP	A 22 lb./ft³ (352 kg/m³) density (average) SFRM intended for the fire protection of structural columns, beams, joists, decks, walls, roofs, girders, floors, and pre-cast concrete units. It was specifically formulated for either unconditioned or conditioned areas such as mechanical rooms, elevator shafts, and parking garages.
Southwest Type 7HD	A 40 lb./ft³ (640 kg/m³) density (average) SFRM intended for the fire protection of structural columns, beams, joists, decks, walls, roofs, girders, floors, and pre-cast concrete units. It was specifically formulated for high humidity areas such as mechanical rooms, elevator shafts, and parking garages and is resistant to damage and moisture.
Southwest Type 7TB	A 22 lb./ft³ (352 kg/m³) density (average) SFRM designed for use as a thermal barrier fire protection material over foam plastics. A secondary use is for fire protection of steel. It was specifically formulated to resist exposure to high humidity and moisture and for direct application to rigid foam plastic urethane, and polystyrene insulation.

2.3 Declared unit

The LCA only covers the cradle-to-gate stage for Carboline's SFRM products. According to the ASTM PCR, the declared unit in this study was determined to be 1,000

kg of product. The results in this report are expressed in terms of potential impacts per 1,000 kg of product from cradle to gate.

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 gate. Therefore, the life cycle activities and related processes shall include modules A1, A2, and A3. This includes raw materials extraction, processing, transportation, and manufacturing/final assembly for both the product and its associated packaging.

PRODUCT STAGE			CONSTRUCTION PROCESS STAGE		USE STAGE							END OF LIFE STAGE			
Raw material supply	Transport	Manufacturing	Transport	Construction-installation process	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4

Figure 2. Applied system boundary

Table 2 lists specific inclusions and exclusions for the system boundary.

Table 2. System boundary inclusions and exclusions

Included	Excluded
• Raw material extraction for components • Transport of raw materials • Processing of raw materials into components • Packaging of raw materials and their disposal • Energy production • Transport of components to assembly locations • Manufacturing scrap and its disposal • Outbound transportation of product • Packaging for the final product and its transportation	• 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. Production stage (A1-A3)

The production stage starts when raw materials are extracted from nature and ends when the product is packaged and ready to be loaded onto a transport vehicle at the Carboline facility.

The production stage includes three product life cycle modules:

- Raw material supply (A1)
  - Extraction and processing of raw materials
  - Transport of raw materials from extraction/production to manufacturer
  - Energy and water consumption for raw material manufacturing
- Transport (A2)
  - Transport of components to Carboline's manufacturing facility
  - Raw material packaging inputs

- Manufacturing (A3)
  - Energy and water consumption for product manufacturing
  - Product packaging inputs
  - Releases to environmental media (air, soil, ground, and surface water)
  - Manufacturing waste, scrap
  - Manufacturing waste transportation from plant to disposal sites
  - Manufacturing waste disposal/recycling/reuse/energy recovery

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 3). The impact indicators are derived using the 100-year time horizon[1] 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 3. 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 declared 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 declared unit. The two periods are related as follows: all environmental impacts that are created in the period of the declared unit 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 4 conforming to the SM 2013 Methodology were applied.

Table 4. 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 1% 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; therefore, these criteria have been met. Fungicide is considered a regulated hazardous substance and has not been excluded from 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 manufacturing inputs that needed allocation were electricity and natural gas since there are only one electric use meter and one gas use meter that include the production of multiple Carboline fire-resistive materials. The allocation of electricity and natural gas were based on the percentage of production for the individual product divided by total site production output.

2.10 Critical review

This is a supporting LCA report for Carboline Transparency Report and was evaluated for conformance to the PCR according to ISO 14025 [8] and the ISO 14040/14044 [1] standards.

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 5a-i below.

3.1 Data collection procedures

Data used for this project represents a mix of primary data collected from Carboline on the production of the applied 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 fire-resistive materials 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 at Carboline's Louisa facility in Virginia. 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 includes 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 applied fire-resistive materials are produced in the Louisa manufacturing facility 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 chart in Figure 3 illustrates the life cycle of Carboline's products produced in the Louisa facility.



Figure 3. Life cycle flow chart of applied fire-resistive materials production in Louisa facility

3.2.1. Raw materials acquisition and transportation

Raw materials extraction, manufacturing, and transportation represents the first stage of the fire-resistive material 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 transported raw materials along with the associated packaging to Carboline's manufacturing plant in Louisa, Virginia. Most of the ingredients are transported via truck and trailer within the U.S., but some of the ingredients such as the vinyl copolymer and hydroxyethyl cellulose are imported overseas. Raw materials sourced in the U.S. were assumed to come directly from the supplier and not from a distribution center. Raw materials sourced outside of the U.S. were assumed to travel by sea to a port before traveling by truck to the manufacturing facility.

Raw materials and the associated packaging inputs for Carboline's fire-resistive materials are listed in the Appendix.

3.2.2. Manufacturing

Primary raw material data were provided in weight per gallon of product, primary manufacturing data were provided in use per 1,000 gallons of product, and primary transportation data were provided in weight and distance per year. Using the provided density values, these data were converted to manufacturing inputs per pound of product as presented in Tables 6a-6i. Life cycle impact assessment results presented in section 4 were scaled to be presented per the declared unit of 1,000kg.

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 mixer and ribbon blender. At the end of the line, the mixed product is complete.

Carboline's Louisa facility produces various products in any given year. To accurately allocate purchased electricity and natural gas to the individual products, the total annual 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 6a-6i. Raw materials are considered confidential business information and are therefore reported as ranges of main components, with the exception of fungicide, which is considered a regulated hazardous substance and is disclosed at its specific percentage. Actual formulations were provided to the third-party reviewer.

In the case of products manufactured in the Louisa facility, scrap, raw material packaging waste, and non-hazardous waste are shipped to the Louisa County sanitary landfill site 7.1 miles away from Carboline's Louisa plant. Table 5 shows the information for the finished products and their packaging.

Table 5. Product and packaging information

Product	Weight of product (kg)	Packaging weight, kraft paper bag (kg)
Pyrocrete 239	22.7	1.66
Pyrocrete 241	22.7	1.54
Pyrocrete 341	22.7	0.56
Pyrocrete 40	22.7	1.66
Southwest Type 5GP	22.7	0.63
Southwest Type 5MD	22.7	0.63
Southwest Type 7GP	22.7	0.25
Southwest Type 7HD	22.7	0.66
Southwest Type 7TB	22.7	0.66

This study assumed that the kraft paper bags were delivered from Uline's New York/Philadelphia branch. The distance between Uline's New York/Philadelphia branch and Carboline's Louisa plant was assumed to be 435 km (270 miles).

Recyclables are shipped to the School Bus Road refuse and recycling center 3.5 km (2.2 miles) away from Carboline's Louisa plant.

There is no hazardous waste generated during the manufacturing process.

Table 6a. Pyrocrete 239 manufacturing inputs and outputs for 1 lb of Pyrocrete 239

Resource category	Flow	Amount	Unit
Electricity	Electricity	[redacted]	kWh
Fuels	Natural gas	[redacted]	MJ
Raw materials	Portland cement	50-60	%
	Vermiculite	20-30	%
	Mica	5-10	%
	Hydrated alumina	1-5	%
	Additives	1-5	%
Packaging	Kraft paper packaging for finished product	0.033	kg
	Transportation for Kraft paper packaging	0.014	tkm
Waste generation	Landfill Disposal – Manufacturing scrap	0.0036	kg
	Landfill Disposal – Non-hazardous waste	0.015	kg
	Landfill Disposal – Plastic packaging waste	0.00032	kg
	Recyclable – Paper packaging waste	0.0015	kg
	Recyclable – Steel packaging waste	0.00036	kg
Waste transport	Transportation for landfill – Scrap, Non-hazardous, and Plastic packaging waste	0.00021	tkm
	Transportation for recyclables	0.0000066	tkm

Table 6b. Pyrocrete 241 manufacturing inputs and outputs for 1 lb of Pyrocrete 241

Resource category	Flow	Amount	Unit
Electricity	Electricity	[redacted]	kWh
Fuels	Natural gas	[redacted]	MJ
Raw materials	Portland cement	40-50	%
	Mica	20-30	%
	Hydrated alumina	10-20	%
	Vermiculite	5-10	%
	Thickener	1-5	%
Packaging	Kraft paper packaging for finished product	0.031	kg
	Transportation for Kraft paper packaging	0.013	tkm
Waste generation	Landfill Disposal – Manufacturing Scrap	0.013	kg
	Landfill Disposal – Non-hazardous waste	0.015	kg
	Landfill Disposal – Plastic packaging waste	0.00059	kg
	Recyclable – Paper packaging waste	0.0048	kg
	Recyclable – Steel packaging waste	0	kg
Waste transport	Transportation for landfill – Scrap, Non-hazardous, and Plastic packaging waste	0.00032	tkm
	Transportation for recyclables	0.000017	tkm

Table 6c. Pyrocrete 341 manufacturing inputs and outputs for 1 lb of Pyrocrete 341

Resource category	Flow	Amount	Unit
Electricity	Electricity	[redacted]	kWh
Fuels	Natural gas	[redacted]	MJ
Raw materials	Portland cement	30-40	%
	Ceramic	20-30	%
	Hydrated alumina	10-20	%
	Mica	5-10	%
	Additives	1-5	%
Packaging	Kraft paper packaging for finished product	0.011	kg
	Transportation for Kraft paper packaging	0.0048	tkm
Waste generation	Landfill Disposal – Manufacturing Scrap	0.029	kg
	Landfill Disposal – Non-hazardous waste	0.015	kg
	Landfill Disposal – Plastic packaging waste	0.0015	kg
	Recyclable – Paper packaging waste	0.0062	kg
	Recyclable – Steel packaging waste	0	kg
Waste transport	Transportation for landfill – Scrap, Non-hazardous, and Plastic packaging waste	0.00052	tkm
	Transportation for recyclables	0.000016	tkm

Table 6d. Pyrocrete 40 manufacturing inputs and outputs for 1 lb of Pyrocrete 40

Resource category	Flow	Amount	Unit
Electricity	Electricity	[redacted]	kWh
Fuels	Natural gas	[redacted]	MJ
Raw materials	Portland cement	50-60	%
	Vermiculite	10-20	%
	Mica	10-20	%
	Calcium Carbonate	5-10	%
	Additives	1-5	%
Packaging	Kraft paper packaging for finished product	0.033	kg
	Transportation for Kraft paper packaging	0.014	tkm
Waste generation	Landfill Disposal – Manufacturing Scrap	0.013	kg
	Landfill Disposal – Non-hazardous waste	0.015	kg
	Landfill Disposal – Plastic packaging waste	0.00068	kg
	Recyclable – Paper packaging waste	0.0031	kg
	Recyclable – Steel packaging waste	0.000045	kg
Waste transport	Transportation for landfill – Scrap, Non-hazardous, and Plastic packaging waste	0.00031	tkm
	Transportation for recyclables	0.000011	tkm

Table 6e. Southwest Type 5GP manufacturing inputs and outputs for 1 lb of Southwest Type 5GP

Resource category	Flow	Amount	Unit
Electricity	Electricity	[redacted]	kWh
Fuels	Natural gas	[redacted]	MJ
Raw materials	Plaster	50-70	%
	Vermiculite	20-30	%
	Stucco	1-5	%
	Additives	1-5	%
Packaging	Kraft paper packaging for finished product	0.013	kg
	Transportation for Kraft paper packaging	0.0054	tkm
Waste generation	Landfill Disposal – Manufacturing Scrap	0.012	kg
	Landfill Disposal – Non-hazardous waste	0.015	kg
	Landfill Disposal – Plastic packaging waste	0.0015	kg
	Recyclable – Paper packaging waste	0.0000091	kg
	Recyclable – Steel packaging waste	0	kg
Waste transport	Transportation for landfill – Scrap, Non-hazardous, and Plastic packaging waste	0.00031	tkm
	Transportation for recyclables	0.000000032	tkm

Table 6f. Southwest Type 5MD manufacturing inputs and outputs for 1 lb of Southwest Type 5MD

Resource category	Flow	Amount	Unit
Electricity	Electricity	[redacted]	kWh
Fuels	Natural gas	[redacted]	MJ
Raw materials	Plaster	50-70	%
	Vermiculite	20-30	%
	Cellulose	1-5	%
	Stucco	1-5	%
	Additives	1-5	%
Packaging	Kraft paper packaging for finished product	0.013	kg
	Transportation for Kraft paper packaging	0.0054	tkm
Waste generation	Landfill Disposal – Manufacturing Scrap	0.0082	kg
	Landfill Disposal – Non-hazardous waste	0.015	kg
	Landfill Disposal – Plastic packaging waste	0.0015	kg
	Recyclable – Paper packaging waste	0.0000091	kg
	Recyclable – Steel packaging waste	0	kg
Waste transport	Transportation for landfill – Scrap, Non-hazardous, and Plastic packaging waste	0.00027	tkm
	Transportation for recyclables	0.000000032	tkm

Table 6g. Southwest Type 7GP manufacturing inputs and outputs for 1 lb of Southwest Type 7GP

Resource category	Flow	Amount	Unit
Electricity	Electricity	[redacted]	kWh
Fuels	Natural gas	[redacted]	MJ
Raw materials	Portland cement	60-70	%
	Vermiculite	20-30	%
	Cellulose	1-5	%
	Fungicide	0.1	%
	Additives	1-5	%
Packaging	Kraft paper packaging for finished product	0.0050	kg
	Transportation for Kraft paper packaging	0.0021	tkm
Waste generation	Landfill Disposal – Manufacturing Scrap	0.0018	kg
	Landfill Disposal – Non-hazardous waste	0.015	kg
	Landfill Disposal – Plastic packaging waste	0.0015	kg
	Recyclable – Paper packaging waste	0.00032	kg
	Recyclable – Steel packaging waste	0	kg
Waste transport	Transportation for landfill – Scrap, Non-hazardous, and Plastic packaging waste	0.00020	tkm
	Transportation for recyclables	0.0000011	tkm

Table 6h. Southwest Type 7HD manufacturing inputs and outputs for 1 lb of Southwest Type 7HD

Resource category	Flow	Amount	Unit
Electricity	Electricity	[redacted]	kWh
Fuels	Natural gas	[redacted]	MJ
Raw materials	Portland cement	60-80	%
	Vermiculite	10-20	%
	Cellulose	1-5	%
	Additives	1-5	%
Packaging	Kraft paper packaging for finished product	0.013	kg
	Transportation for Kraft paper packaging	0.0056	tkm
Waste generation	Landfill Disposal – Manufacturing Scrap	0.0059	kg
	Landfill Disposal – Non-hazardous waste	0.015	kg
	Landfill Disposal – Plastic packaging waste	0.0010	kg
	Recyclable – Paper packaging waste	0.00027	kg
	Recyclable – Steel packaging waste	0	kg
Waste transport	Transportation for landfill – Scrap, Non-hazardous, and Plastic packaging waste	0.00024	tkm
	Transportation for recyclables	0.00000095	tkm

Table 6i. Southwest Type 7TB manufacturing inputs and outputs for 1 lb of Southwest Type 7TB

Resource category	Flow	Amount	Unit
Electricity	Electricity	[redacted]	kWh
Fuels	Natural gas	[redacted]	MJ
Raw materials	Portland cement	50-60	%
	Vermiculite	20-30	%
	Mica	5-10	%
	Hydrated alumina	1-5	%
	Additives	1-5	%
Packaging	Kraft paper packaging for finished product	0.013	kg
	Transportation for Kraft paper packaging	0.0056	tkm
Waste generation	Landfill Disposal – Manufacturing Scrap	0.0059	kg
	Landfill Disposal – Non-hazardous waste	0.015	kg
	Landfill Disposal – Plastic packaging waste	0.0010	kg
	Recyclable – Paper packaging waste	0.00027	kg
	Recyclable – Steel packaging waste	0	kg
Waste transport	Transportation for landfill – Scrap, Non-hazardous, and Plastic packaging waste	0.00024	tkm
	Transportation for recyclables	0.00000095	tkm

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 other.
- 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 fire-resistive material production for 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, US-EI 2.2, and ELCD databases.

Technology coverage. Data were collected for fire-resistive materials production at Carboline's manufacturing plants in Louisa, Virginia.

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 facility which is responsible for production.

3.4 Background data

This section details background datasets used in modeling fire-resistive material environmental performance. Each table lists dataset purpose, name, source, reference year, and location. The background data which are more than 10 years old were chosen based on their being the most recent and technologically representative for those raw materials.

3.4.1. Fuels and energy

Electricity at the Louisa facility was modeled using regionally specific inventory data based on a subnational US consumption mix; Carboline did not have any manufacturing activities outside the US or Canada. National and regional averages for fuel inputs and electricity grid mixes were obtained from SimaPro. Table 7 shows the most relevant LCI datasets used in modeling the product systems. 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.

Table 7. 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
	Technical heat	Heat, natural gas, at boiler modulating >100kW/US- US-EI U	US EI 2.2	2018	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 8 lists the most relevant LCI datasets used in modeling the raw materials.

Table 8. Key material datasets used in inventory analysis

Raw material	Dataset name	Content (W/W)	Source	Reference year	Geography
[redacted]	[redacted]	[redacted]	ecoinvent v3	2018	Rest of World (non-Europe)
[redacted]	[redacted]	[redacted]	ecoinvent v3	2021	Rest of World (non-Europe)
[redacted]	[redacted]	[redacted]	ecoinvent v3	2011	Global
	[redacted]	[redacted]	ecoinvent v3	2019	Rest of World (non-Europe)

	[redacted]	[redacted]	ecoinvent v3	2012	Global
	[redacted]	[redacted]	US EI 2.2	2019	US
[redacted]	[redacted]	[redacted]	ecoinvent v3	2012	Rest of World (non-Europe
[redacted]	[redacted]	[redacted]	Refer to description above		
	[redacted]	[redacted]	US EI 2.2	2018	US
	[redacted]	[redacted]	ecoinvent v3	2020	Rest of World (non-Europe)
[redacted]	[redacted]	[redacted]	ecoinvent v3	2021	Rest of World (non-Europe)
[redacted]	[redacted]	[redacted]	ecoinvent v3	2021	Rest of World (non-Europe)
[redacted]	[redacted]	[redacted]	ecoinvent v3	2021	Rest of World (non-Europe)
[redacted]	[redacted]	[redacted]	ELCD	2006	Europe
[redacted]	[redacted]	[redacted]	ecoinvent v3	2021	Rest of World (non-Europe)
[redacted]	[redacted]	[redacted]	ecoinvent v3	2021	Rest of World (non-Europe)
[redacted]	[redacted]	[redacted]	US EI 2.2	2018	US
[redacted]	[redacted]	[redacted]	ecoinvent v3	2021	Global
[redacted]	[redacted]	[redacted]	ecoinvent v3	2012	US
[redacted]	[redacted]	[redacted]	ecoinvent v3	2021	Rest of World (non-Europe)
[redacted]	[redacted]	[redacted]	ecoinvent v3	2020	Rest of World (non-Europe)
[redacted]	[redacted]	[redacted]	ecoinvent v3	2020	Rest of World (non-Europe)
[redacted]	[redacted]	[redacted]	ecoinvent v3	2021	Rest of World (non-Europe)
[redacted]	[redacted]	[redacted]	ecoinvent v3	2018	Global
[redacted]	[redacted]	[redacted]	ecoinvent v3	2012	Global
	[redacted]	[redacted]	ecoinvent v3	2011	Global
[redacted]	[redacted]	[redacted]	ecoinvent v3	2012	Global
	[redacted]	[redacted]	ecoinvent v3	2011	Global
[redacted]	[redacted]	[redacted]	ecoinvent v3	2012	Global
	[redacted]	[redacted]	ecoinvent v3	2011	Global
[redacted]	[redacted]	[redacted]	ecoinvent v3	2020	Rest of World (non-Europe)
	[redacted]	[redacted]	ecoinvent v3	2011	Global
[redacted]	[redacted]	[redacted]	ecoinvent v3	2021	Rest of World (non-Europe)
[redacted]	[redacted]	[redacted]	ecoinvent v3	2011	Rest of World (non-Europe)

	[redacted]	[redacted]	ecoinvent v3	2011	Rest of World (non-Europe)
	[redacted]	[redacted]	ecoinvent v3	2018	Rest of World (non-Europe)
	[redacted]	[redacted]	ecoinvent v3	2011	Global
[redacted]	[redacted]	[redacted]	Proxy sourced using ecoinvent v3	2018	US
[redacted]	[redacted]	[redacted]	ecoinvent v3	2021	Rest of World (non-Europe)
[redacted]	[redacted]	[redacted]	US EI 2.2	2018	US
[redacted]	[redacted]	[redacted]	ecoinvent v3	2021	Rest of World (non-Europe)
[redacted]	[redacted]	[redacted]	ecoinvent v3	2020	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. As the transportation datasets represent load factors as an average of empty and fully loaded (i.e., average load factor), empty backhauls are accounted for in the model. Table 9 shows the most relevant LCI datasets used in modeling the transportation.

Table 9. 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 wastes to disposal point (U.S. region)				
Transport of recyclables to recycling center (U.S. region)				
Transport of raw material and packaging to manufacturing facility (Overseas)	Transport, freight, sea, bulk carrier for dry goods	ecoinvent v3	2019	Global

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 plastic raw material packaging, scrap, and non-hazardous waste. Table 10 reviews the relevant disposal datasets used in the model.

Table 10. Key disposal datasets used in inventory analysis

Material disposed	Dataset name	Source	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				
Raw material packaging waste - plastic	Disposal, plastic plaster, 0% water, to inert material landfill	US-EI 2.2	2018	US

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.
- Since energy inputs were not available on a per-product basis, electricity and natural gas consumption were allocated proportionately based on the percentage of production for individual products versus total site outputs. However, the manufacturing processes for the studied products are expected to use different proportions of energy inputs based on manufacturing differences like time, temperature, etc. for other products made at the site.
- 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 fire-resistive materials, which was later scaled to meet the declared unit, 1,000 kg of the product. The results are presented per declared unit.

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 SERC eGRID dataset, 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 mentioned in the PCR. Unrecyclable wastes end up landfilled.

Tables 11a-i show resource use and waste flows for all products per declared unit.

Table 11a. Resource use and waste flows for Pyrocrete 239 per declared unit

Parameter	Unit	Raw material supply	Transport	Mfg	Total
Renewable primary energy used as energy carrier (fuel)	MJ, HHV	1.19E+02	7.20E-01	3.88E+01	1.59E+02
Renewable primary resources with energy content used as material	MJ, HHV	4.90E+02	2.62E-01	2.54E+03	3.03E+03
Total use of renewable primary resources with energy content	MJ, HHV	6.10E+02	9.82E-01	2.58E+03	3.19E+03
Non-renewable primary resources used as an energy carrier (fuel)	MJ, HHV	3.63E+03	8.01E+02	2.15E+03	6.58E+03
Non-renewable primary resources with energy content used as material	MJ, HHV	2.92E+01	2.26E-03	2.77E-01	2.95E+01
Total use of non-renewable primary resources with energy content	MJ, HHV	3.66E+03	8.01E+02	2.15E+03	6.61E+03
Secondary materials	kg	0	0	0	0
Renewable secondary fuels	MJ, HHV	0	0	0	0
Non-renewable secondary fuels	MJ, HHV	0	0	0	0
Recovered energy	MJ, HHV	0	0	0	0
Use of net fresh water resources	m^3	2.34E+01	2.30E-01	9.25E+00	3.28E+01
Output flows and waste category indicators					
Hazardous waste disposed	kg	0	0	0	0
Non-hazardous waste disposed	kg	0	0	1.94E-01	1.94E-01
High-level radioactive waste, conditioned, to final repository	kg	7.56E-02	2.60E-04	1.82E-02	9.40E-02
Intermediate- and low-level radioactive waste, conditioned, to final repository	kg	2.55E-04	1.12E-04	6.07E-05	4.28E-04
Components for re-use	kg	0	0	0	0
Materials for recycling	kg	0	0	0	0
Materials for energy recovery	kg	0	0	0	0
Exported energy	MJ, HHV	0	0	0	0
Carbon emissions and removals					
Biogenic Carbon Removal from Product	kg CO_2	0	0	0	0
Biogenic Carbon Emission from Product	kg CO_2	0	0	0	0
Biogenic Carbon Removal from Packaging	kg CO_2	0	0	3.22E+01	3.22E+01
Biogenic Carbon Emission from Packaging	kg CO_2	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
Calcination Carbon Emissions	kg CO_2	0	0	0	0
Carbonation Carbon Removals	kg CO_2	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

Table 11b. Resource use and waste flows for Pyrocrete 241 per declared unit

Parameter	Unit	Raw material supply	Transport	Mfg	Total
Renewable primary energy used as energy carrier (fuel)	MJ, HHV	8.59E+02	1.08E+00	3.66E+01	8.97E+02
Renewable primary resources with energy content used as material	MJ, HHV	3.61E+01	3.92E-01	2.36E+03	2.40E+03
Total use of renewable primary resources with energy content	MJ, HHV	8.95E+02	1.47E+00	2.40E+03	3.29E+03
Non-renewable primary resources used as an energy carrier (fuel)	MJ, HHV	4.12E+03	1.20E+03	2.11E+03	7.43E+03
Non-renewable primary resources with energy content used as material	MJ, HHV	3.44E-01	3.37E-03	2.58E-01	6.05E-01
Total use of non-renewable primary resources with energy content	MJ, HHV	4.12E+03	1.20E+03	2.11E+03	7.43E+03
Secondary materials	kg	0	0	0	0
Renewable secondary fuels	MJ, HHV	0	0	0	0
Non-renewable secondary fuels	MJ, HHV	0	0	0	0
Recovered energy	MJ, HHV	0	0	0	0
Use of net fresh water resources	m^3	2.46E+01	2.97E-01	6.56E+00	3.15E+01
Output flows and waste category indicators					
Hazardous waste disposed	kg	0	0	0	0
Non-hazardous waste disposed	kg	0	0	5.13E-02	5.13E-02
High-level radioactive waste, conditioned, to final repository	kg	3.05E-01	3.88E-04	1.70E-02	3.23E-01
Intermediate- and low-level radioactive waste, conditioned, to final repository	kg	2.59E-04	1.67E-04	5.87E-05	4.84E-04
Components for re-use	kg	0	0	0	0
Materials for recycling	kg	0	0	0	0
Materials for energy recovery	kg	0	0	0	0
Exported energy	MJ, HHV	0	0	0	0
Carbon emissions and removals					
Biogenic Carbon Removal from Product	kg CO_2	0	0	0	0
Biogenic Carbon Emission from Product	kg CO_2	0	0	0	0
Biogenic Carbon Removal from Packaging	kg CO_2	0	0	2.99E+01	2.99E+01
Biogenic Carbon Emission from Packaging	kg CO_2	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
Calcination Carbon Emissions	kg CO_2	0	0	0	0
Carbonation Carbon Removals	kg CO_2	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

Table 11c. Resource use and waste flows for Pyrocrete 341 per declared unit

Parameter	Unit	Raw material supply	Transport	Mfg	Total
Renewable primary energy used as energy carrier (fuel)	MJ, HHV	3.25E+02	1.61E+00	1.80E+01	3.45E+02
Renewable primary resources with energy content used as material	MJ, HHV	1.07E+02	5.89E-01	8.63E+02	9.70E+02
Total use of renewable primary resources with energy content	MJ, HHV	4.32E+02	2.20E+00	8.81E+02	1.32E+03
Non-renewable primary resources used as an energy carrier (fuel)	MJ, HHV	1.20E+04	1.80E+03	1.76E+03	1.55E+04
Non-renewable primary resources with energy content used as material	MJ, HHV	7.37E-01	5.06E-03	9.36E-02	8.36E-01
Total use of non-renewable primary resources with energy content	MJ, HHV	1.20E+04	1.80E+03	1.76E+03	1.55E+04
Secondary materials	kg	0	0	0	0
Renewable secondary fuels	MJ, HHV	0	0	0	0
Non-renewable secondary fuels	MJ, HHV	0	0	0	0
Recovered energy	MJ, HHV	0	0	0	0
Use of net fresh water resources	m^3	3.60E+01	3.62E-01	2.03E+00	3.83E+01
Output flows and waste category indicators					
Hazardous waste disposed	kg	0	0	0	0
Non-hazardous waste disposed	kg	0	0	4.59E-01	4.59E-01
High-level radioactive waste, conditioned, to final repository	kg	1.94E-01	5.83E-04	7.34E-03	2.02E-01
Intermediate- and low-level radioactive waste, conditioned, to final repository	kg	3.21E-04	2.50E-04	4.07E-05	6.12E-04
Components for re-use	kg	0	0	0	0
Materials for recycling	kg	0	0	0	0
Materials for energy recovery	kg	0	0	0	0
Exported energy	MJ, HHV	0	0	0	0
Carbon emissions and removals					
Biogenic Carbon Removal from Product	kg CO_2	0	0	0	0
Biogenic Carbon Emission from Product	kg CO_2	0	0	0	0
Biogenic Carbon Removal from Packaging	kg CO_2	0	0	9.88E+00	9.88E+00
Biogenic Carbon Emission from Packaging	kg CO_2	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
Calcination Carbon Emissions	kg CO_2	0	0	0	0
Carbonation Carbon Removals	kg CO_2	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

Table 11d. Resource use and waste flows for Pyrocrete 40 per declared unit

Parameter	Unit	Raw material supply	Transport	Mfg	Total
Renewable primary energy used as energy carrier (fuel)	MJ, HHV	2.02E+03	1.22E+00	3.88E+01	2.06E+03
Renewable primary resources with energy content used as material	MJ, HHV	9.26E+01	4.46E-01	2.54E+03	2.63E+03
Total use of renewable primary resources with energy content	MJ, HHV	2.11E+03	1.67E+00	2.58E+03	4.70E+03
Non-renewable primary resources used as an energy carrier (fuel)	MJ, HHV	4.92E+03	1.36E+03	2.15E+03	8.44E+03
Non-renewable primary resources with energy content used as material	MJ, HHV	3.81E+00	3.84E-03	2.77E-01	4.09E+00
Total use of non-renewable primary resources with energy content	MJ, HHV	4.92E+03	1.36E+03	2.15E+03	8.44E+03
Secondary materials	kg	0	0	0	0
Renewable secondary fuels	MJ, HHV	0	0	0	0
Non-renewable secondary fuels	MJ, HHV	0	0	0	0
Recovered energy	MJ, HHV	0	0	0	0
Use of net fresh water resources	m^3	2.47E+01	4.18E-01	9.73E+00	3.49E+01
Output flows and waste category indicators					
Hazardous waste disposed	kg	0	0	0	0
Non-hazardous waste disposed	kg	0	0	5.76E-01	5.76E-01
High-level radioactive waste, conditioned, to final repository	kg	6.70E-01	4.42E-04	1.82E-02	6.88E-01
Intermediate- and low-level radioactive waste, conditioned, to final repository	kg	3.03E-04	1.90E-04	6.09E-05	5.54E-04
Components for re-use	kg	0	0	0	0
Materials for recycling	kg	0	0	0	0
Materials for energy recovery	kg	0	0	0	0
Exported energy	MJ, HHV	0	0	0	0
Carbon emissions and removals					
Biogenic Carbon Removal from Product	kg CO_2	0	0	0	0
Biogenic Carbon Emission from Product	kg CO_2	0	0	0	0
Biogenic Carbon Removal from Packaging	kg CO_2	0	0	3.22E+01	3.22E+01
Biogenic Carbon Emission from Packaging	kg CO_2	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
Calcination Carbon Emissions	kg CO_2	0	0	0	0
Carbonation Carbon Removals	kg CO_2	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

Table 11e. Resource use and waste flows for Southwest Type 5GP per declared unit

Parameter	Unit	Raw material supply	Transport	Mfg	Total
Renewable primary energy used as energy carrier (fuel)	MJ, HHV	5.01E+01	1.52E-01	1.93E+01	6.95E+01
Renewable primary resources with energy content used as material	MJ, HHV	1.14E+02	5.56E-02	9.67E+02	1.08E+03
Total use of renewable primary resources with energy content	MJ, HHV	1.64E+02	2.08E-01	9.86E+02	1.15E+03
Non-renewable primary resources used as an energy carrier (fuel)	MJ, HHV	1.59E+03	1.70E+02	1.74E+03	3.50E+03
Non-renewable primary resources with energy content used as material	MJ, HHV	3.12E+00	4.77E-04	1.05E-01	3.22E+00
Total use of non-renewable primary resources with energy content	MJ, HHV	1.60E+03	1.70E+02	1.74E+03	3.51E+03
Secondary materials	kg	0	0	0	0
Renewable secondary fuels	MJ, HHV	0	0	0	0
Non-renewable secondary fuels	MJ, HHV	0	0	0	0
Recovered energy	MJ, HHV	0	0	0	0
Use of net fresh water resources	m^3	2.39E+01	1.01E-01	7.22E+00	3.13E+01
Output flows and waste category indicators					
Hazardous waste disposed	kg	0	0	0	0
Non-hazardous waste disposed	kg	0	0	2.31E-03	2.31E-03
High-level radioactive waste, conditioned, to final repository	kg	3.20E-02	5.50E-05	8.00E-03	4.00E-02
Intermediate- and low-level radioactive waste, conditioned, to final repository	kg	1.45E-04	2.36E-05	3.58E-05	2.04E-04
Components for re-use	kg	0	0	0	0
Materials for recycling	kg	0	0	0	0
Materials for energy recovery	kg	0	0	0	0
Exported energy	MJ, HHV	0	0	0	0
Carbon emissions and removals					
Biogenic Carbon Removal from Product	kg CO_2	0	0	0	0
Biogenic Carbon Emission from Product	kg CO_2	0	0	0	0
Biogenic Carbon Removal from Packaging	kg CO_2	0	0	1.22E+01	1.22E+01
Biogenic Carbon Emission from Packaging	kg CO_2	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
Calcination Carbon Emissions	kg CO_2	0	0	0	0
Carbonation Carbon Removals	kg CO_2	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

Table 11f. Resource use and waste flows for Southwest Type 5MD per declared unit

Parameter	Unit	Raw material supply	Transport	Mfg	Total
Renewable primary energy used as energy carrier (fuel)	MJ, HHV	5.52E+01	1.81E-01	1.93E+01	7.47E+01
Renewable primary resources with energy content used as material	MJ, HHV	1.11E+02	6.60E-02	9.67E+02	1.08E+03
Total use of renewable primary resources with energy content	MJ, HHV	1.66E+02	2.47E-01	9.86E+02	1.15E+03
Non-renewable primary resources used as an energy carrier (fuel)	MJ, HHV	1.65E+03	2.01E+02	1.74E+03	3.59E+03
Non-renewable primary resources with energy content used as material	MJ, HHV	2.60E+00	5.69E-04	1.05E-01	2.70E+00
Total use of non-renewable primary resources with energy content	MJ, HHV	1.65E+03	2.01E+02	1.74E+03	3.59E+03
Secondary materials	kg	0	0	0	0
Renewable secondary fuels	MJ, HHV	0	0	0	0
Non-renewable secondary fuels	MJ, HHV	0	0	0	0
Recovered energy	MJ, HHV	0	0	0	0
Use of net fresh water resources	m^3	2.48E+01	1.12E-01	6.62E+00	3.16E+01
Output flows and waste category indicators					
Hazardous waste disposed	kg	0	0	0	0
Non-hazardous waste disposed	kg	0	0	8.50E-03	8.50E-03
High-level radioactive waste, conditioned, to final repository	kg	3.47E-02	6.54E-05	8.00E-03	4.28E-02
Intermediate- and low-level radioactive waste, conditioned, to final repository	kg	1.42E-04	2.81E-05	3.57E-05	2.06E-04
Components for re-use	kg	0	0	0	0
Materials for recycling	kg	0	0	0	0
Materials for energy recovery	kg	0	0	0	0
Exported energy	MJ, HHV	0	0	0	0
Carbon emissions and removals					
Biogenic Carbon Removal from Product	kg CO_2	0	0	0	0
Biogenic Carbon Emission from Product	kg CO_2	0	0	0	0
Biogenic Carbon Removal from Packaging	kg CO_2	0	0	1.22E+01	1.22E+01
Biogenic Carbon Emission from Packaging	kg CO_2	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
Calcination Carbon Emissions	kg CO_2	0	0	0	0
Carbonation Carbon Removals	kg CO_2	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

Table 11g. Resource use and waste flows for Southwest Type 7GP per declared unit

Parameter	Unit	Raw material supply	Transport	Mfg	Total
Renewable primary energy used as energy carrier (fuel)	MJ, HHV	1.13E+02	7.38E-01	1.21E+01	1.26E+02
Renewable primary resources with energy content used as material	MJ, HHV	1.74E+02	2.69E-01	3.91E+02	5.66E+02
Total use of renewable primary resources with energy content	MJ, HHV	2.88E+02	1.01E+00	4.03E+02	6.92E+02
Non-renewable primary resources used as an energy carrier (fuel)	MJ, HHV	3.45E+03	8.22E+02	1.59E+03	5.86E+03
Non-renewable primary resources with energy content used as material	MJ, HHV	1.44E+01	2.32E-03	4.18E-02	1.44E+01
Total use of non-renewable primary resources with energy content	MJ, HHV	3.46E+03	8.22E+02	1.59E+03	5.87E+03
Secondary materials	kg	0	0	0	0
Renewable secondary fuels	MJ, HHV	0	0	0	0
Non-renewable secondary fuels	MJ, HHV	0	0	0	0
Recovered energy	MJ, HHV	0	0	0	0
Use of net fresh water resources	m^3	2.50E+01	4.39E-01	3.56E+00	2.90E+01
Output flows and waste category indicators					
Hazardous waste disposed	kg	0	0	0	0
Non-hazardous waste disposed	kg	0	0	1.38E-02	1.38E-02
High-level radioactive waste, conditioned, to final repository	kg	7.36E-02	2.67E-04	4.27E-03	7.81E-02
Intermediate- and low-level radioactive waste, conditioned, to final repository	kg	2.65E-04	1.15E-04	2.64E-05	4.06E-04
Components for re-use	kg	0	0	0	0
Materials for recycling	kg	0	0	0	0
Materials for energy recovery	kg	0	0	0	0
Exported energy	MJ, HHV	0	0	0	0
Carbon emissions and removals					
Biogenic Carbon Removal from Product	kg CO_2	0	0	0	0
Biogenic Carbon Emission from Product	kg CO_2	0	0	0	0
Biogenic Carbon Removal from Packaging	kg CO_2	0	0	4.85E+00	4.85E+00
Biogenic Carbon Emission from Packaging	kg CO_2	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
Calcination Carbon Emissions	kg CO_2	0	0	0	0
Carbonation Carbon Removals	kg CO_2	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

Table 11h. Resource use and waste flows for Southwest Type 7HD per declared unit

Parameter	Unit	Raw material supply	Transport	Mfg	Total
Renewable primary energy used as energy carrier (fuel)	MJ, HHV	1.14E+02	7.38E-01	1.99E+01	1.35E+02
Renewable primary resources with energy content used as material	MJ, HHV	1.76E+02	2.69E-01	1.02E+03	1.19E+03
Total use of renewable primary resources with energy content	MJ, HHV	2.90E+02	1.01E+00	1.04E+03	1.33E+03
Non-renewable primary resources used as an energy carrier (fuel)	MJ, HHV	3.48E+03	8.22E+02	1.75E+03	6.05E+03
Non-renewable primary resources with energy content used as material	MJ, HHV	1.45E+01	2.32E-03	1.10E-01	1.46E+01
Total use of non-renewable primary resources with energy content	MJ, HHV	3.49E+03	8.22E+02	1.75E+03	6.07E+03
Secondary materials	kg	0	0	0	0
Renewable secondary fuels	MJ, HHV	0	0	0	0
Non-renewable secondary fuels	MJ, HHV	0	0	0	0
Recovered energy	MJ, HHV	0	0	0	0
Use of net fresh water resources	m^3	2.41E+01	4.17E-01	7.24E+00	3.18E+01
Output flows and waste category indicators					
Hazardous waste disposed	kg	0	0	0	0
Non-hazardous waste disposed	kg	0	0	2.05E-01	2.05E-01
High-level radioactive waste, conditioned, to final repository	kg	7.42E-02	2.67E-04	8.31E-03	8.28E-02
Intermediate- and low-level radioactive waste, conditioned, to final repository	kg	2.67E-04	1.15E-04	3.65E-05	4.18E-04
Components for re-use	kg	0	0	0	0
Materials for recycling	kg	0	0	0	0
Materials for energy recovery	kg	0	0	0	0
Exported energy	MJ, HHV	0	0	0	0
Carbon emissions and removals					
Biogenic Carbon Removal from Product	kg CO_2	0	0	0	0
Biogenic Carbon Emission from Product	kg CO_2	0	0	0	0
Biogenic Carbon Removal from Packaging	kg CO_2	0	0	1.28E+01	1.28E+01
Biogenic Carbon Emission from Packaging	kg CO_2	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
Calcination Carbon Emissions	kg CO_2	0	0	0	0
Carbonation Carbon Removals	kg CO_2	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

Table 11i. Resource use and waste flows for Southwest Type 7TB per declared unit

Parameter	Unit	Raw material supply	Transport	Mfg	Total
Renewable primary energy used as energy carrier (fuel)	MJ, HHV	1.72E+02	1.03E+00	1.99E+01	1.93E+02
Renewable primary resources with energy content used as material	MJ, HHV	1.06E+02	3.73E-01	1.02E+03	1.12E+03
Total use of renewable primary resources with energy content	MJ, HHV	2.77E+02	1.40E+00	1.04E+03	1.31E+03
Non-renewable primary resources used as an energy carrier (fuel)	MJ, HHV	6.84E+03	1.14E+03	1.75E+03	9.73E+03
Non-renewable primary resources with energy content used as material	MJ, HHV	6.64E+00	3.23E-03	1.10E-01	6.75E+00
Total use of non-renewable primary resources with energy content	MJ, HHV	6.85E+03	1.14E+03	1.75E+03	9.74E+03
Secondary materials	kg	0	0	0	0
Renewable secondary fuels	MJ, HHV	0	0	0	0
Non-renewable secondary fuels	MJ, HHV	0	0	0	0
Recovered energy	MJ, HHV	0	0	0	0
Use of net fresh water resources	m^3	3.03E+01	3.36E-01	3.79E+00	3.44E+01
Output flows and waste category indicators					
Hazardous waste disposed	kg	0	0	0	0
Non-hazardous waste disposed	kg	0	0	3.45E-01	3.45E-01
High-level radioactive waste, conditioned, to final repository	kg	1.04E-01	3.71E-04	8.31E-03	1.12E-01
Intermediate- and low-level radioactive waste, conditioned, to final repository	kg	3.00E-04	1.59E-04	3.66E-05	4.96E-04
Components for re-use	kg	0	0	0	0
Materials for recycling	kg	0	0	0	0
Materials for energy recovery	kg	0	0	0	0
Exported energy	MJ, HHV	0	0	0	0
Carbon emissions and removals					
Biogenic Carbon Removal from Product	kg CO_2	0	0	0	0
Biogenic Carbon Emission from Product	kg CO_2	0	0	0	0
Biogenic Carbon Removal from Packaging	kg CO_2	0	0	1.28E+01	1.28E+01
Biogenic Carbon Emission from Packaging	kg CO_2	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
Calcination Carbon Emissions	kg CO_2	0	0	0	0
Carbonation Carbon Removals	kg CO_2	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

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 declared 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 fire resistive materials. 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

Impact assessment results are presented per the declared unit of 1,000kg.

4.2.1.1. Pyrocrete 239

Table 12a shows the contributions, and Table 12b and Figure 4 show the percent contribution of each stage of the production for Pyrocrete 239.

The raw material supply stage dominates the results for all impact categories. The total potential CO_2-equivalent emissions generated during the cradle-to-gate stage of Pyrocrete 239 are 872 kg (~0.87 tonnes). Raw material supply contributes to 641 kgCO_2-eq, about 73.49% of the total CO_2-equivalent emissions. Raw material acquisition accounts for 94.51% of carcinogenics, the highest contribution among 10 impact categories.

The next highest impact contributor to most (nine tenths) of the impact categories is the manufacturing stage. That is to say, transportation of raw materials is the second highest impact contributor only for ozone depletion. It accounts for 26.04% of ozone depletion impacts.

The SM 2013 Methodology single figure millipoint (mPts) score by life cycle phase for this product is presented below (Table 12c). The scores are consistent with the result using the impact assessment results before normalization and weighting. The raw

material supply phase dominates the results (81.69%), followed by the manufacturing phase. The phase accounts for 13.47% of the score result.

Table 12a. Life cycle impact assessment results per declared unit for Pyrocrete 239

Impact category	Unit	Raw material supply	Transport	Mfg	Total
Ozone depletion	kg CFC-11 eq	2.85E-05	1.27E-05	7.59E-06	4.88E-05
Global warming	kg CO_2 eq	6.41E+02	5.33E+01	1.78E+02	8.72E+02
Smog	kg O_3 eq	3.73E+01	1.32E+00	6.97E+00	4.56E+01
Acidification	kg SO_2 eq	2.10E+00	1.00E-01	4.73E-01	2.68E+00
Eutrophication	kg N eq	3.36E-01	1.95E-02	1.52E-01	5.08E-01
Carcinogenics	CTUh	1.89E-05	4.89E-08	1.05E-06	2.00E-05
Non-carcinogenics	CTUh	6.01E-05	7.45E-06	8.85E-06	7.64E-05
Respiratory effects	kg $PM_{2.5}$ eq	2.80E-01	1.91E-02	6.86E-02	3.68E-01
Ecotoxicity	CTUe	4.10E+02	1.51E+02	2.14E+02	7.75E+02
Fossil fuel depletion	MJ surplus	3.38E+02	1.13E+02	2.44E+02	6.95E+02

Table 12b. Percent contributions of each stage to each impact category for Pyrocrete 239

Impact category	Raw material supply	Transport	Manufacturing	Total
Ozone depletion	58.41%	26.04%	15.55%	100.00%
Global warming	73.49%	6.11%	20.39%	100.00%
Smog	81.83%	2.89%	15.28%	100.00%
Acidification	78.61%	3.74%	17.65%	100.00%
Eutrophication	66.22%	3.85%	29.93%	100.00%
Carcinogenics	94.51%	0.24%	5.24%	100.00%
Non-carcinogenics	78.66%	9.76%	11.58%	100.00%
Respiratory effects	76.14%	5.19%	18.67%	100.00%
Ecotoxicity	52.89%	19.44%	27.67%	100.00%
Fossil fuel depletion	48.65%	16.27%	35.08%	100.00%

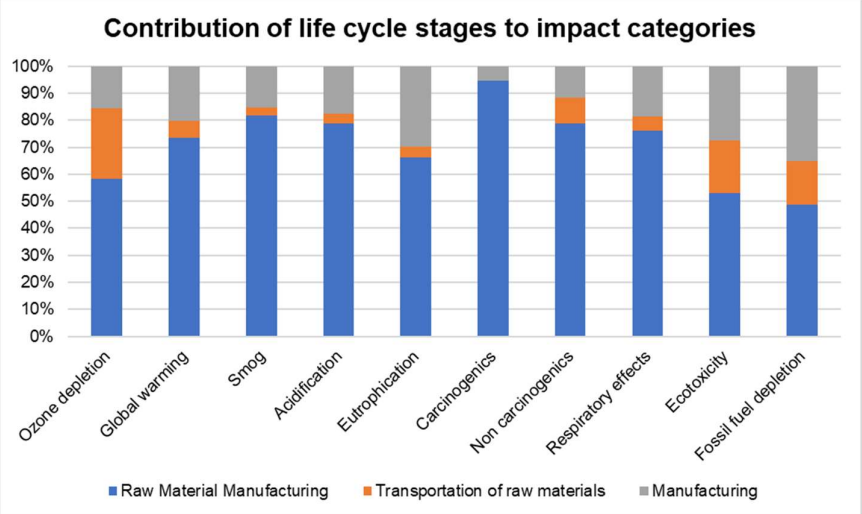


Figure 4. Contribution analysis of each impact category for Pyrocrete 239

Table 12c. Averaged SM millipoint scores for Pyrocrete 239 by life cycle stage per declared unit

Impact category	Unit	Raw material supply	Transport	Mfg	Total
SM single figure score	mPts	5.85E+01	3.47E+00	9.64E+00	7.16E+01
	-	81.69%	4.84%	13.47%	100.00%

4.2.1.2. Pyrocrete 241

Table 13a shows the contributions, and Table 13b and Figure 5 show the percent contribution of each stage of the production for Pyrocrete 241.

The raw material supply stage dominates the results for all impact categories. The total potential CO_2 equivalent emissions generated during the cradle-to-gate of Pyrocrete 241 are 851 kg (~0.85 tonnes). Raw material supply contributes to 578 kg CO_2 eq, 69.88% of the total CO_2 equivalent emissions. Raw material supply accounts for 98.65% of the Carcinogenics, the highest contribution among 10 impact categories.

We can find that the next highest impact contributor to most (seven tenths) of the impact categories is the Manufacturing stage.

For Ozone depletion, Non-carcinogenics, and Ecotoxicity categories, the second impact contributor comes from the transportation of raw materials. It accounts for 31.96% to Ozone depletion, 6.18% to Non-carcinogenics, and 14.55% to Ecotoxicity.

The SM 2013 Methodology single figure millipoint (mPts) score by life cycle phase for this product is presented below (Table 13c). The scores are consistent with the result using the impact assessment results before normalization and weighting. The raw material supply phase dominates the results (92.71%), followed by the manufacturing phase. The phase accounts for 4.77% of the score result.

Table 13a. Life cycle impact assessment results per declared unit for Pyrocrete 241

Impact category	Unit	Raw material supply	Transport	Mfg	Total
Ozone depletion	kg CFC-11 eq	3.31E-05	1.90E-05	7.33E-06	5.94E-05
Global warming	kg CO_2 eq	5.78E+02	7.97E+01	1.94E+02	8.51E+02
Smog	kg O_3 eq	3.18E+01	1.78E+00	6.61E+00	4.02E+01
Acidification	kg SO2 eq	2.19E+00	1.38E-01	4.52E-01	2.78E+00
Eutrophication	kg N eq	1.88E-01	2.89E-02	1.59E-01	3.75E-01
Carcinogenics	CTUh	8.32E-05	7.31E-08	1.07E-06	8.44E-05
Non-carcinogenics	CTUh	1.61E-04	1.12E-05	8.48E-06	1.81E-04
Respiratory effects	kg $PM_{2.5}$ eq	3.09E-01	2.79E-02	6.46E-02	4.01E-01
Ecotoxicity	CTUe	1.12E+03	2.26E+02	2.05E+02	1.55E+03
Fossil fuel depletion	MJ surplus	3.39E+02	1.69E+02	2.41E+02	7.49E+02

Table 13b. Percent contributions of each stage to each impact category for Pyrocrete 241

Impact category	Raw material supply	Transport	Manufacturing	Total
Ozone depletion	55.70%	31.96%	12.34%	100.00%
Global warming	67.88%	9.36%	22.77%	100.00%
Smog	79.13%	4.42%	16.45%	100.00%
Acidification	78.74%	4.98%	16.27%	100.00%
Eutrophication	50.03%	7.69%	42.28%	100.00%
Carcinogenics	98.65%	0.09%	1.26%	100.00%
Non-carcinogenics	89.14%	6.18%	4.68%	100.00%
Respiratory effects	76.94%	6.96%	16.10%	100.00%
Ecotoxicity	72.25%	14.55%	13.20%	100.00%
Fossil fuel depletion	45.28%	22.56%	32.16%	100.00%

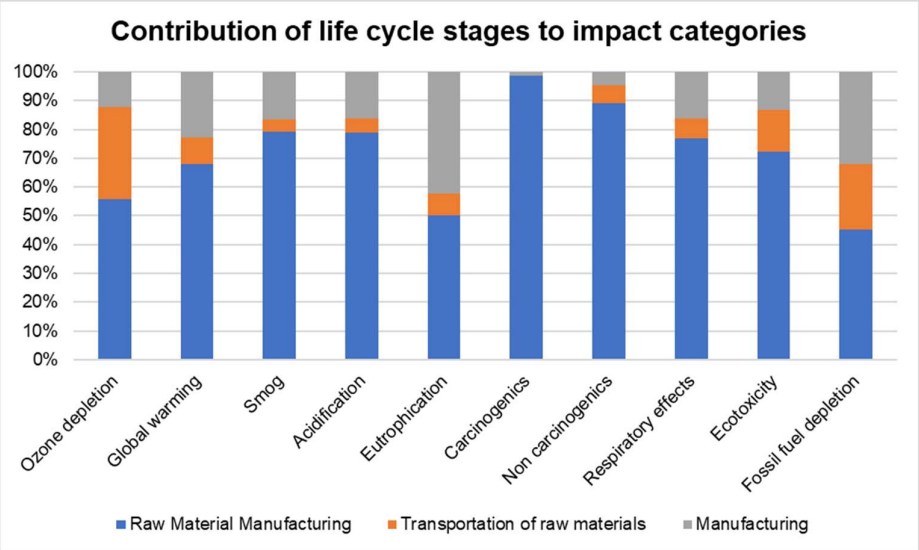


Figure 5. Contribution analysis of each impact category for Pyrocrete 241

Table 13c. Averaged SM millipoint scores for Pyrocrete 241 by life cycle stage per declared unit

Impact category	Unit	Raw material supply	Transport	Mfg	Total
SM single figure score	mPts	1.90E+02	5.17E+00	9.77E+00	2.05E+02
	-	92.71%	2.52%	4.77%	100.00%

4.2.1.3. Pyrocrete 341

Table 14a shows the contributions, and Table 14b and Figure 6 show the percent contribution of each stage of the production for Pyrocrete 341.

The raw material supply stage dominates the results for all impact categories. The total potential CO_2 equivalent emissions generated during the cradle-to-gate of Pyrocrete 341 are 1,237kg (~1.27 tonnes). Raw material supply contributes to 957 kg CO_2 eq, 75.09% of the total CO_2 equivalent emissions. Raw material supply accounts for 98.91% of the Carcinogenic, the highest contribution among 10 impact categories.

We can find that the next highest impact contributor to most (six tenths) of the impact categories is the Manufacturing stage.

For Ozone depletion, Non-carcinogenics, Ecotoxicity categories, and Fossil fuel depletion the second impact contributor comes from the transportation of raw materials. It accounts for 27.52% to Ozone depletion, 8.99% to Non-carcinogenics, 21.19% to Ecotoxicity, and 14.28% to Fossil fuel depletion.

The SM 2013 Methodology single figure millipoint (mPts) score by life cycle phase for this product is presented below (Table 14c). The raw material supply phase dominates the results (92.77%), followed by the transport phase. The phase accounts for 3.70% of the score result.

Table 14a. Life cycle impact assessment results per declared unit for Pyrocrete 341

Impact category	Unit	Raw material supply	Transport	Mfg	Total
Ozone depletion	kg CFC-11 eq	7.00E-05	2.85E-05	5.01E-06	1.04E-04
Global warming	kg CO_2 eq	9.57E+02	1.20E+02	1.98E+02	1.27E+03
Smog	kg O_3 eq	4.18E+01	2.99E+00	3.43E+00	4.83E+01
Acidification	kg SO2 eq	2.91E+00	2.26E-01	2.70E-01	3.41E+00
Eutrophication	kg N eq	3.36E-01	4.39E-02	1.17E-01	4.96E-01
Carcinogenics	CTUh	7.33E-05	1.10E-07	6.96E-07	7.41E-05
Non-carcinogenics	CTUh	1.65E-04	1.67E-05	4.51E-06	1.86E-04
Respiratory effects	kg $PM_{2.5}$ eq	2.58E+00	4.28E-02	3.02E-02	2.65E+00
Ecotoxicity	CTUe	1.16E+03	3.38E+02	9.94E+01	1.59E+03
Fossil fuel depletion	MJ surplus	1.31E+03	2.53E+02	2.13E+02	1.78E+03

Table 14b. Percent contributions of each stage to each impact category for Pyrocrete 341

Impact category	Raw material supply	Transport	Manufacturing	Total
Ozone depletion	67.64%	27.52%	4.84%	100.00%
Global warming	75.09%	9.38%	15.53%	100.00%
Smog	86.70%	6.19%	7.11%	100.00%
Acidification	85.45%	6.63%	7.91%	100.00%
Eutrophication	67.61%	8.84%	23.55%	100.00%
Carcinogenics	98.91%	0.15%	0.94%	100.00%
Non-carcinogenics	88.58%	8.99%	2.43%	100.00%
Respiratory effects	97.25%	1.61%	1.14%	100.00%
Ecotoxicity	72.57%	21.19%	6.24%	100.00%
Fossil fuel depletion	73.72%	14.28%	12.01%	100.00%

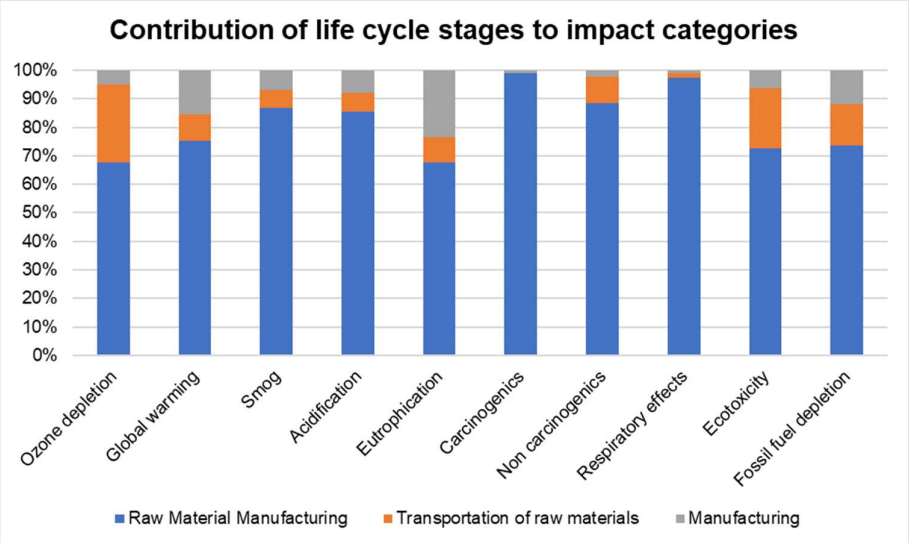


Figure 6. Contribution analysis of each impact category for Pyrocrete 341

Table 14c. Averaged SM millipoint scores for Pyrocrete 341 by life cycle stage per declared unit

Impact category	Unit	Raw material supply	Transport	Mfg	Total
SM single figure score	mPts	1.95E+02	7.77E+00	7.43E+00	2.10E+02
	--	92.77%	3.70%	3.53%	100.00%

4.2.1.4. Pyrocrete 40

Table 15a shows the contributions, and Table 15b and Figure 7 show the percent contribution of each stage of the production for Pyrocrete 40.

The raw material supply stage dominates the results for all impact categories. The total potential CO_2 equivalent emissions generated during the cradle-to-gate of Pyrocrete 40 are 946.51 kg (~0.95 tonnes). Raw material supply contributes to 660 kg CO_2 eq, about 69.68% of the total CO_2 equivalent emissions. Raw material supply accounts for 97.62% of the Carcinogenics, the highest contribution among 10 impact categories.

We can find that the next highest impact contributor to most (seven tenth) of the impact categories is the Manufacturing stage. For Ozone depletion, Non-carcinogenics, and Ecotoxicity categories, the second impact contributor comes from the transportation of raw materials. It accounts for 36.63% to Ozone depletion, 13.97% to Non-carcinogenics, and 21.81% to Ecotoxicity.

The SM 2013 Methodology single figure millipoint (mPts) score by life cycle phase for this product is presented below (Table 15c). The scores are consistent with the result using the impact assessment results before normalization and weighting. The raw material supply phase dominates the results (88.24%), followed by the manufacturing phase. The phase accounts for 7.44% of the score result.

Table 15a. Life cycle impact assessment results per declared unit for Pyrocrete 40

Impact category	Unit	Raw material supply	Transport	Mfg	Total
Ozone depletion	kg CFC-11 eq	2.98E-05	2.16E-05	7.61E-06	5.90E-05
Global warming	kg CO_2 eq	6.60E+02	9.07E+01	1.96E+02	9.47E+02
Smog	kg O_3 eq	3.39E+01	2.15E+00	7.00E+00	4.31E+01
Acidification	kg SO2 eq	2.13E+00	1.65E-01	4.75E-01	2.77E+00
Eutrophication	kg N eq	2.82E-01	3.31E-02	1.66E-01	4.82E-01
Carcinogenics	CTUh	4.95E-05	8.31E-08	1.12E-06	5.07E-05
Non-carcinogenics	CTUh	6.92E-05	1.27E-05	8.97E-06	9.09E-05
Respiratory effects	kg $PM_{2.5}$ eq	3.13E-01	3.21E-02	6.88E-02	4.14E-01
Ecotoxicity	CTUe	7.01E+02	2.57E+02	2.19E+02	1.18E+03
Fossil fuel depletion	MJ surplus	4.79E+02	1.92E+02	2.44E+02	9.16E+02

Table 15b. Percent contributions of each stage to each impact category for Pyrocrete 40

Impact category	Raw material supply	Transport	Manufacturing	Total
Ozone depletion	50.46%	36.63%	12.91%	100.00%
Global warming	69.68%	9.58%	20.74%	100.00%
Smog	78.76%	4.99%	16.25%	100.00%
Acidification	76.91%	5.95%	17.13%	100.00%
Eutrophication	58.66%	6.87%	34.48%	100.00%
Carcinogenics	97.62%	0.16%	2.21%	100.00%
Non-carcinogenics	76.15%	13.97%	9.87%	100.00%
Respiratory effects	75.61%	7.77%	16.63%	100.00%
Ecotoxicity	59.60%	21.81%	18.58%	100.00%
Fossil fuel depletion	52.35%	20.99%	26.66%	100.00%

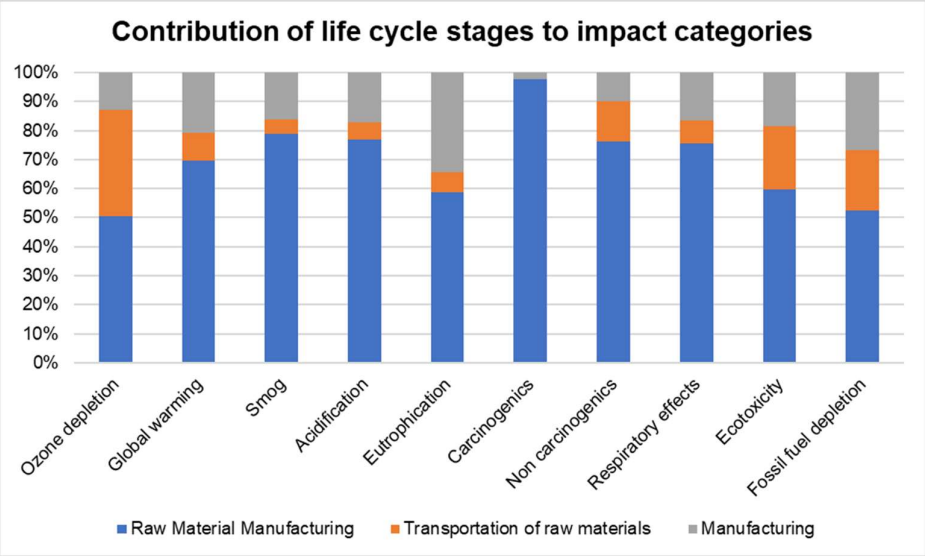


Figure 7. Contribution analysis of each impact category for Pyrocrete 40

Table 15c. Averaged SM millipoint scores for Pyrocrete 40 by life cycle stage per declared unit

Impact category	Unit	Raw material supply	Transport	Mfg	Total
SM single figure score	mPts	1.20E+02	5.89E+00	1.01E+01	1.36E+02
	--	88.24%	4.32%	7.44%	100.00%

4.2.1.5. Southwest Type 5GP

Table 16a shows the contributions, and Table 16b and Figure 8 show the percent contribution of each stage of the production for Southwest Type 5GP.

The raw material supply stage dominates the results for all impact categories. The total potential CO_2 equivalent emissions generated during the cradle-to-gate of Southwest Type 5GP are 384 kg (~0.38 tonnes). Raw material supply contributes to 211 kg CO_2 eq, 54.91% of the total CO_2 equivalent emissions. Raw material supply accounts for 85.76% of the smog formation impact, the highest contribution among 10 impact categories.

We can then find that the next highest impact contributor to all the impact categories is the Manufacturing stage. In Eutrophication, Ecotoxicity, and Fossil fuel depletion categories, Manufacturing is even the major impact contributor. It accounts for 50.21% to Eutrophication, 46.47% to Ecotoxicity, and 53.28% to Fossil fuel depletion.

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 result using the impact assessment results before normalization and weighting. The raw material supply phase dominates the results (56.01%), followed by the manufacturing phase. The phase accounts for 39.56% of the score result.

Table 16a. Life cycle impact assessment results per declared unit for Southwest Type 5GP

Impact category	Unit	Raw material supply	Transport	Mfg	Total
Ozone depletion	kg CFC-11 eq	1.48E-05	2.69E-06	4.48E-06	2.20E-05
Global warming	kg CO_2 eq	2.11E+02	1.13E+01	1.62E+02	384.89
Smog	kg O_3 eq	2.29E+01	2.58E-01	3.54E+00	2.67E+01
Acidification	kg SO2 eq	1.25E+00	2.00E-02	2.74E-01	1.55E+00
Eutrophication	kg N eq	8.92E-02	4.10E-03	9.41E-02	1.87E-01
Carcinogenics	CTUh	8.88E-07	1.04E-08	5.91E-07	1.49E-06
Non-carcinogenics	CTUh	1.17E-05	1.58E-06	4.18E-06	1.75E-05
Respiratory effects	kg $PM_{2.5}$ eq	1.36E-01	3.97E-03	3.14E-02	1.71E-01
Ecotoxicity	CTUe	7.32E+01	3.20E+01	9.14E+01	1.97E+02
Fossil fuel depletion	MJ surplus	1.59E+02	2.39E+01	2.09E+02	3.92E+02

Table 16b. Percent contributions of each stage to each impact category for Southwest Type 5GP

Impact category	Raw material supply	Transport	Mfg	Total
Ozone depletion	67.39%	12.24%	20.38%	100.00%
Global warming	54.91%	2.93%	42.16%	100.00%
Smog	85.76%	0.97%	13.27%	100.00%
Acidification	80.99%	1.29%	17.72%	100.00%
Eutrophication	47.60%	2.19%	50.21%	100.00%
Carcinogenics	59.61%	0.70%	39.70%	100.00%
Non-carcinogenics	67.08%	9.05%	23.87%	100.00%
Respiratory effects	79.31%	2.32%	18.37%	100.00%
Ecotoxicity	37.25%	16.28%	46.47%	100.00%
Fossil fuel depletion	40.61%	6.10%	53.28%	100.00%

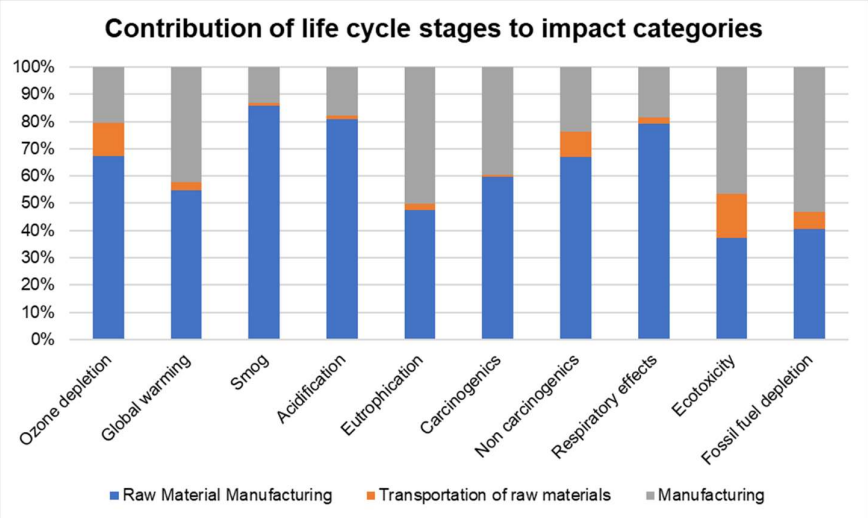


Figure 8. Contribution analysis of each impact category for Southwest Type 5GP

Table 16c. Averaged SM millipoint scores for Southwest Type 5GP by life cycle stage per declared unit

Impact category	Unit	Raw material supply	Transport	Mfg	Total
SM single figure score	mPts	9.26E+00	7.33E-01	6.54E+00	1.65E+01
	--	56.01%	4.43%	39.56%	100.00%

4.2.1.6. Southwest Type 5MD

Table 17a shows the contributions, and Table 17b and Figure 9 show the percent contribution of each stage of the production for Southwest Type 5MD.

The raw material supply stage dominates the results for all impact categories. The total potential CO_2 equivalent emissions generated during the cradle-to-gate of Southwest Type 5MD are 386 kg (~0.39 tonnes). Raw material supply contributes to 218 kg CO_2 eq, 56.41% of the total CO_2 equivalent emissions. Raw material supply accounts for 84.98% of the smog formation impact, the highest contribution among 10 impact categories.

We can then find that the next highest impact contributor to all the impact categories is the Manufacturing stage. Manufacturing is even the major impact contributor in Ecotoxicity and Fossil fuel depletion categories. It accounts for 42.01% to Ecotoxicity and 52.29% to Fossil fuel depletion.

Raw material supply and Manufacturing stages account for a relative even share of contribution to Eutrophication. 48.69% of the impact comes from Raw material supply stage and 48.53% comes from the Manufacturing stage.

The SM 2013 Methodology single figure millipoint (mPts) score by life cycle phase for this product is presented below (Table 17c). The scores are consistent with the result using the impact assessment results before normalization and weighting. The raw material supply phase dominates the results (57.77%), followed by the manufacturing phase. The phase accounts for 37.12% of the score result.

Table 17a. Life cycle impact assessment results per declared unit for Southwest Type 5MD

Impact category	Unit	Raw material supply	Transport	Mfg	Total
Ozone depletion	kg CFC-11 eq	1.46E-05	3.20E-06	4.47E-06	2.23E-05
Global warming	kg CO_2 eq	2.18E+02	1.34E+01	1.55E+02	3.86E+02
Smog	kg O_3 eq	2.23E+01	4.12E-01	3.53E+00	2.63E+01
Acidification	kg SO2 eq	1.23E+00	2.98E-02	2.74E-01	1.53E+00
Eutrophication	kg N eq	8.88E-02	5.06E-03	8.85E-02	1.82E-01
Carcinogenics	CTUh	1.02E-06	1.22E-08	5.62E-07	1.59E-06
Non-carcinogenics	CTUh	1.48E-05	1.85E-06	4.13E-06	2.08E-05
Respiratory effects	kg $PM_{2.5}$ eq	1.37E-01	5.03E-03	3.13E-02	1.73E-01
Ecotoxicity	CTUe	8.63E+01	3.74E+01	8.96E+01	2.13E+02
Fossil fuel depletion	MJ surplus	1.62E+02	2.84E+01	2.09E+02	3.99E+02

Table 17b. Percent contributions of each stage to each impact category for Southwest Type 5MD

Impact category	Raw material supply	Transport	Manufacturing	Total
Ozone depletion	65.60%	14.34%	20.05%	100.00%
Global warming	56.41%	3.48%	40.11%	100.00%
Smog	84.98%	1.57%	13.45%	100.00%
Acidification	80.21%	1.95%	17.85%	100.00%
Eutrophication	48.69%	2.78%	48.53%	100.00%
Carcinogenics	63.93%	0.77%	35.30%	100.00%
Non-carcinogenics	71.23%	8.92%	19.85%	100.00%
Respiratory effects	79.03%	2.90%	18.07%	100.00%
Ecotoxicity	40.45%	17.54%	42.01%	100.00%
Fossil fuel depletion	40.59%	7.12%	52.29%	100.00%

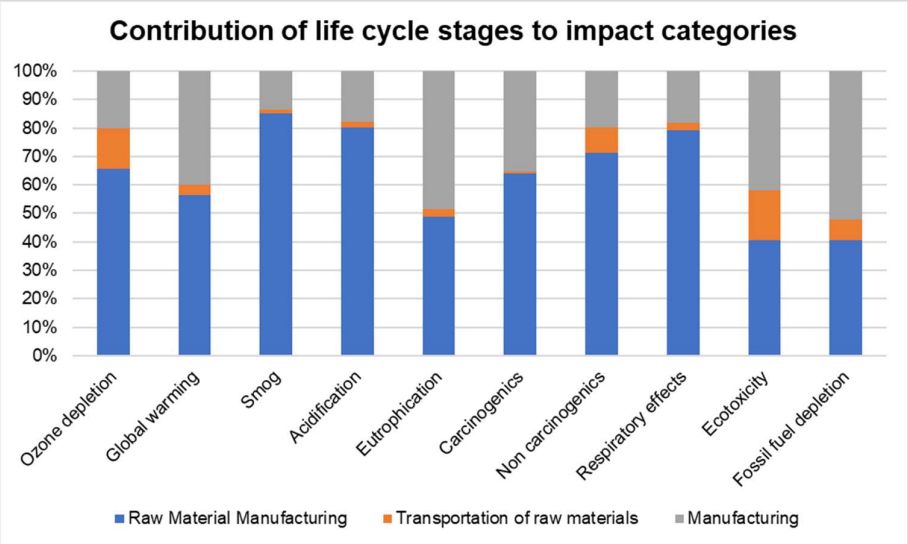


Figure 9. Contribution analysis of each impact category for Southwest Type 5MD

Table 17c. Averaged SM millipoint scores for Southwest Type 5MD by life cycle stage per declared unit

Impact category	Unit	Raw material supply	Transport	Mfg	Total
SM single figure score	mPts	9.87E+00	8.73E-01	6.34E+00	1.71E+01
	--	57.77%	5.11%	37.12%	100.00%

4.2.1.7. Southwest Type 7GP

Table 18a shows the contributions, and Table 18b and Figure 10 show the percent contribution of each stage of the production for Southwest Type 7GP.

The raw material supply stage dominates the results for all impact categories. The total potential CO_2 equivalent emissions generated during the cradle-to-gate of Southwest Type 7GP are 844 kg (~0.84 tonnes). Raw material supply contributes to 659 kg CO_2 eq, 78.08% of the total CO_2 equivalent emissions. Raw material supply accounts for 90.99% of the smog formation impact, the highest contribution among 10 impact categories. We can find that the next highest impact contributor to most of (seven tenths) the impact categories is the Manufacturing stage.

For Ozone depletion, Non-carcinogenics, and Ecotoxicity categories, the second impact contributor comes from the transportation of raw materials. It accounts for 29.19% to Ozone depletion, 15.24% to Non-carcinogenics, and 43.00% to Ecotoxicity.

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 supply phase dominates the results (75.95%), followed by the manufacturing phase. The phase accounts for 13.70% of the score result.

Table 18a. Life cycle impact assessment results per declared unit for Southwest Type 7GP

Impact category	Unit	Raw material supply	Transport	Mfg	Total
Ozone depletion	kg CFC-11 eq	2.83E-05	1.30E-05	3.30E-06	4.47E-05
Global warming	kg CO_2 eq	6.59E+02	5.47E+01	1.30E+02	8.44E+02
Smog	kg O_3 eq	3.66E+01	1.38E+00	2.25E+00	4.03E+01
Acidification	kg SO2 eq	1.95E+00	1.04E-01	1.99E-01	2.25E+00
Eutrophication	kg N eq	1.83E-01	2.01E-02	5.29E-02	2.56E-01
Carcinogenics	CTUh	3.69E-06	5.01E-08	3.20E-07	4.06E-06
Non-carcinogenics	CTUh	4.02E-05	7.64E-06	2.29E-06	5.02E-05
Respiratory effects	kg $PM_{2.5}$ eq	2.56E-01	1.96E-02	1.76E-02	2.93E-01
Ecotoxicity	CTUe	1.64E+02	1.54E+02	4.02E+01	3.59E+02
Fossil fuel depletion	MJ surplus	3.22E+02	1.16E+02	1.96E+02	6.34E+02

Table 18b. Percent contributions of each stage to each impact category for Southwest Type 7GP

Impact category	Raw material supply	Transport	Manufacturing	Total
Ozone depletion	63.41%	29.19%	7.40%	100.00%
Global warming	78.08%	6.49%	15.44%	100.00%
Smog	90.99%	3.42%	5.59%	100.00%
Acidification	86.55%	4.62%	8.83%	100.00%
Eutrophication	71.52%	7.84%	20.64%	100.00%
Carcinogenics	90.88%	1.23%	7.89%	100.00%
Non-carcinogenics	80.20%	15.24%	4.56%	100.00%
Respiratory effects	87.30%	6.70%	6.00%	100.00%
Ecotoxicity	45.80%	43.00%	11.20%	100.00%
Fossil fuel depletion	50.80%	18.30%	30.90%	100.00%

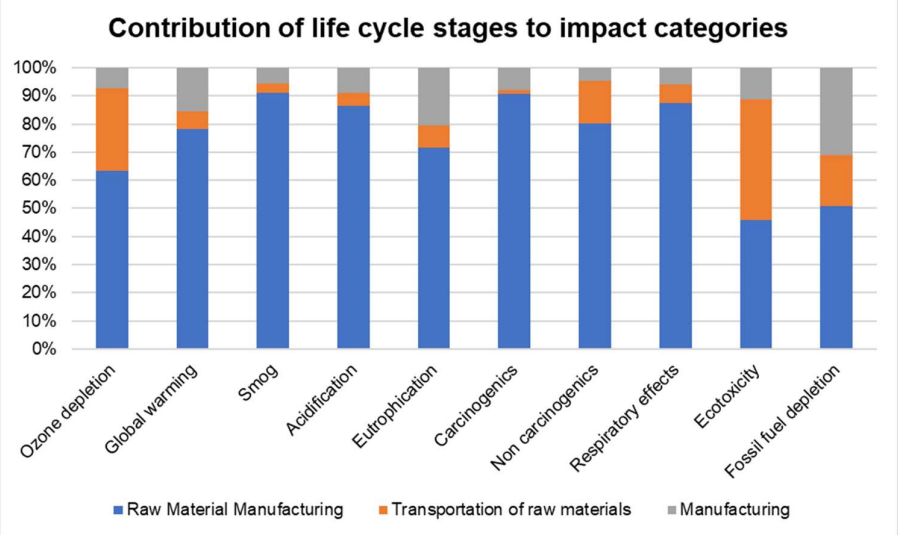


Figure 10. Contribution analysis of each impact category for Southwest Type 7GP

Table 18c. Averaged SM millipoint scores for Southwest Type 7GP by life cycle stage per declared unit

Impact category	Unit	Raw material supply	Transport	Mfg	Total
SM single figure score	mPts	2.61E+01	3.56E+00	4.70E+00	3.43E+01
	--	75.95%	10.35%	13.70%	100.00%

4.2.1.8. Southwest Type 7HD

Table 19a shows the contributions, and Table 19b and Figure 11 show the percent contribution of each stage of the production for Southwest Type 7HD.

The raw material supply stage dominates the results for all impact categories. The total potential CO_2 equivalent emissions generated during the cradle-to-gate of Southwest Type 7HD are 871 kg (~0.87 tonnes). Raw material supply contributes to 665 kg CO_2 eq, 76.34% of the total CO_2 equivalent emissions. Raw material supply accounts for 88.07% of the smog formation impact, the highest contribution among 10 impact categories.

We can find that the next highest impact contributor to most of (seven tenths) the impact categories is the Manufacturing stage.

For Ozone depletion, Non-carcinogenics, and Ecotoxicity categories, the second impact contributor comes from the transportation of raw materials. It accounts for 28.24% to Ozone depletion, 14.56% to Non-carcinogenics, and 37.40% to Ecotoxicity.

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 supply phase dominates the results (72.70%), followed by the manufacturing phase. The phase accounts for 17.48% of the score result.

Table 19a. Life cycle impact assessment results per declared unit for Southwest Type 7HD

Impact category	Unit	Raw material supply	Transport	Mfg	Total
Ozone depletion	kg CFC-11 eq	2.86E-05	1.30E-05	4.56E-06	4.62E-05
Global warming	kg CO_2 eq	6.65E+02	5.47E+01	1.51E+02	8.71E+02
Smog	kg O_3 eq	3.70E+01	1.38E+00	3.63E+00	4.20E+01
Acidification	kg SO2 eq	1.97E+00	1.04E-01	2.79E-01	2.35E+00
Eutrophication	kg N eq	1.85E-01	2.01E-02	8.72E-02	2.92E-01
Carcinogenics	CTUh	3.72E-06	5.01E-08	5.60E-07	4.33E-06
Non-carcinogenics	CTUh	4.06E-05	7.64E-06	4.24E-06	5.25E-05
Respiratory effects	kg $PM_{2.5}$ eq	2.58E-01	1.96E-02	3.25E-02	3.10E-01
Ecotoxicity	CTUe	1.66E+02	1.54E+02	9.25E+01	4.13E+02
Fossil fuel depletion	MJ surplus	3.25E+02	1.16E+02	2.10E+02	6.51E+02

Table 19b. Percent contributions of each stage to each impact category for Southwest Type 7HD

Impact category	Raw material supply	Transport	Manufacturing	Total
Ozone depletion	61.89%	28.24%	9.87%	100.00%
Global warming	76.34%	6.28%	17.37%	100.00%
Smog	88.07%	3.28%	8.65%	100.00%
Acidification	83.71%	4.43%	11.87%	100.00%
Eutrophication	63.31%	6.87%	29.82%	100.00%
Carcinogenics	85.91%	1.16%	12.93%	100.00%
Non-carcinogenics	77.36%	14.56%	8.08%	100.00%
Respiratory effects	83.21%	6.33%	10.47%	100.00%
Ecotoxicity	40.20%	37.40%	22.40%	100.00%
Fossil fuel depletion	49.93%	17.83%	32.25%	100.00%

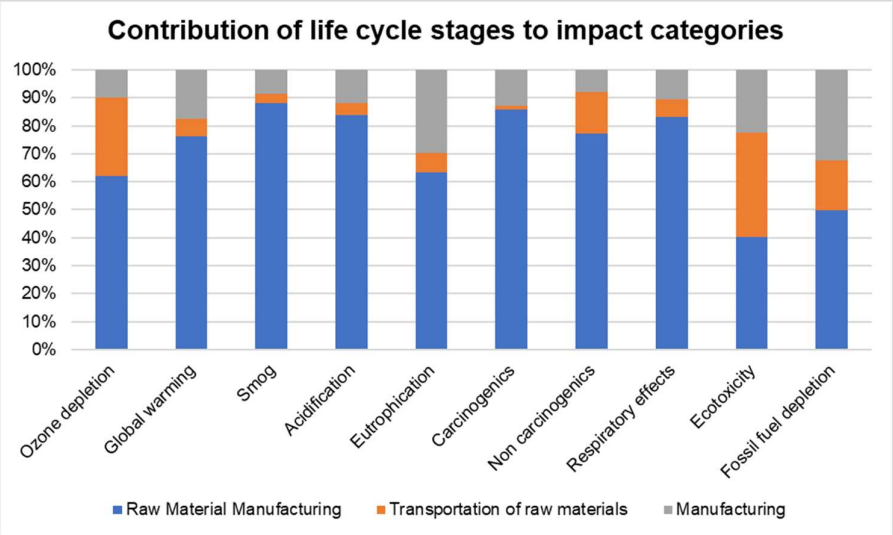


Figure 11. Contribution analysis of each impact category for Southwest Type 7HD

Table 19c. Averaged SM millipoint scores for Southwest Type 7HD by life cycle stage per declared unit

Impact category	Unit	Raw material supply	Transport	Mfg	Total
SM single figure score	mPts	2.63E+01	3.56E+00	6.33E+00	3.62E+01
	--	72.70%	9.82%	17.48%	100.00%

4.2.1.9. Southwest Type 7TB

Table 20a shows the contributions, and Table 20b and Figure 12 show the percent contribution of each stage of the production for Southwest Type 7TB.

The raw material supply stage dominates the results for all impact categories. The total potential CO_2 equivalent emissions generated during the cradle-to-gate of Southwest Type 7TB are 1,020 kg (~1.02 tonnes). Raw material supply contributes to 781 kg CO_2 eq, 76.41% of the total CO_2 equivalent emissions. Raw material supply accounts for 87.43% of the Carcinogenics impact, the highest contribution among 10 impact categories.

We can find that the next highest impact contributor to most (seven tenth) of the impact categories is the Manufacturing stage.

For Ozone depletion, Non-carcinogenics, and Ecotoxicity categories, the second impact contributor comes from the transportation of raw materials. It accounts for 32.01% to Ozone depletion, 12.95% to Non-carcinogenics, and 35.08% to Ecotoxicity.

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 supply phase dominates the results (75.98%), followed by the manufacturing phase. The phase accounts for 13.82% of the score result.

Table 20a. Life cycle impact assessment results per declared unit for Southwest Type 7TB

Impact category	Unit	Raw material supply	Transport	Mfg	Total
Ozone depletion	kg CFC-11 eq	3.38E-05	1.81E-05	4.58E-06	5.65E-05
Global warming	kg CO_2 eq	7.81E+02	7.61E+01	1.65E+02	1.02E+03
Smog	kg O3 eq	4.37E+01	2.63E+00	3.65E+00	5.00E+01
Acidification	kg SO2 eq	2.47E+00	1.86E-01	2.81E-01	2.94E+00
Eutrophication	kg N eq	2.56E-01	2.92E-02	9.76E-02	3.83E-01
Carcinogenics	CTUh	5.05E-06	6.92E-08	6.15E-07	5.73E-06
Non-carcinogenics	CTUh	6.57E-05	1.04E-05	4.34E-06	8.04E-05
Respiratory effects	kg $PM_{2.5}$ eq	3.43E-01	2.94E-02	3.26E-02	4.05E-01
Ecotoxicity	CTUe	2.93E+02	2.10E+02	9.57E+01	5.99E+02
Fossil fuel depletion	MJ surplus	7.37E+02	1.61E+02	2.10E+02	1.11E+03

Table 20b. Percent contributions of each stage to each impact category for Southwest Type 7TB

Impact category	Raw material supply	Transport	Manufacturing	Total
Ozone depletion	59.88%	32.01%	8.10%	100.00%
Global warming	76.41%	7.44%	16.15%	100.00%
Smog	87.43%	5.27%	7.30%	100.00%
Acidification	84.12%	6.33%	9.55%	100.00%
Eutrophication	66.87%	7.62%	25.50%	100.00%
Carcinogenics	88.07%	1.21%	10.72%	100.00%
Non-carcinogenics	81.65%	12.95%	5.39%	100.00%
Respiratory effects	84.72%	7.24%	8.04%	100.00%
Ecotoxicity	48.93%	35.08%	15.99%	100.00%
Fossil fuel depletion	66.52%	14.53%	18.95%	100.00%

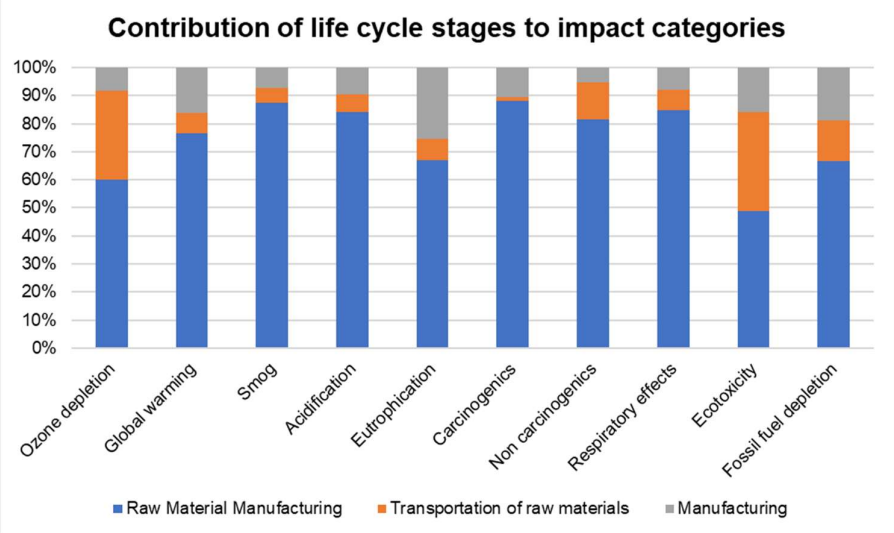


Figure 12. Contribution analysis of each impact category for Southwest Type 7TB

Table 20c. Averaged SM millipoint scores for Southwest Type 7TB by life cycle stage per declared unit

Impact category	Unit	Raw material supply	Transport	Mfg	Total
SM single figure score	mPts	3.68E+01	4.95E+00	6.70E+00	4.85E+01
	--	75.98%	10.20%	13.82%	100.00%

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 since Carboline is interested in the potential CO_2 equivalent emissions of its products.

As the bulk of 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 21, these changes resulted in a +/-6-14% change in total life cycle impacts.

Table 21. Sensitivity analyses of LCIA results per declared 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
Pyrocrete 239	[redacted]	8.72E+02	7.71E+02	9.74E+02	+/-12%
Pyrocrete 241	[redacted]	8.51E+02	7.73E+02	9.30E+02	+/-9%
Pyrocrete 341	[redacted]	1.27E+03	1.19E+03	1.35E+03	+/-6%
Pyrocrete 40	[redacted]	9.47E+02	8.49E+02	1.04E+03	+/-10%
Southwest Type 5GP	[redacted]	3.85E+02	3.50E+02	4.20E+02	+/-9%
Southwest Type 5MD	[redacted]	3.86E+02	3.51E+02	4.22E+02	+/-9%
Southwest Type 7GP	[redacted]	8.44E+02	7.26E+02	9.62E+02	+/-14%
Southwest Type 7HD	[redacted]	8.71E+02	7.52E+02	9.90E+02	+/-14%
Southwest Type 7TB	[redacted]	1.02E+03	9.05E+02	1.14E+03	+/-11%

4.3 Overview of relevant findings

This study assessed a multitude of inventory and environmental indicators.

The primary finding for all of Carboline's fire-resistive material products, across the environmental indicators, was that the raw material extraction and upstream processing stage (A1) is responsible for much of the impacts in each impact category.

For the Pyrocrete series, raw material supply is the major contributor to all impact categories. For the Southwest Type 5 and 7 series, raw material supply is the major contributor to seven impact categories.

In addition to raw material supply, the next highest impact contributor is manufacturing in most of the impact categories. Manufacturing is also a major contributor to eutrophication, ecotoxicity, and fossil fuel depletion for the Southwest Type 5 series.

However, there are some exceptions. For example, the transportation of raw materials is the second highest contributor to ozone depletion, non-carcinogenics, and ecotoxicity categories for the Pyrocrete and Southwest Type 7 series.

4.4 Discussion of 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. Capital equipment was 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 in Louisa, Virginia. Differences in electric grid mix are 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 Conclusions and recommendations

The goal of this study was to conduct a cradle-to-gate LCA on Carboline's spray-applied fire-resistive materials. The creation of the LCA report allows Carboline to make better informed decisions about the upstream environmental impacts associated with its products.

The raw materials for manufacturing Carboline's fire-resistive material products are purchased directly from suppliers. These raw materials are shipped to Carboline's manufacturing facility in Louisa. These materials are then stored and mixed at the plant. Raw material extraction and processing make up the largest share of each of the end impact categories. The potential impacts of transportation from material suppliers to Carboline's facility represent an insignificant share when compared to the impacts generated from the raw materials.

On analyzing potential CO_2-equivalent emissions, over 70% of these comes from the raw material supply phase (A1) for the Pyrocrete and Southwest Type 7 series. Both the raw material supply phase (A1) and manufacturing phase (A3) contribute to about 50% of potential CO_2-equivalent emissions for the Southwest Type 5 series. Transportation of raw materials is a relatively small contributor to all product life cycle impacts.

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

[1] ISO 14044, “Environmental management - Life cycle assessment - Requirements and guidelines”, ISO14044:2006.

[2] ISO 21930, “Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services”, ISO 21930:2017.

[3] ASTM International, Product Category Rules (PCR) For Preparing an Environmental Product Declaration for Spray- applied Fire-Resistive Materials (SFRM), Mar. 2017.

[4] Joep Meijer, Sustainable Minds SM2013 Methodology and Database, April 25, 2013. For a summary, see the Sustainable Minds single score page: http://www.sustainableminds.com/showroom/shared/learn-single-score.html

[5] Bare, J. 2014. Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) TRACI version 2.1 User’s Guide. US EPA Office of Research and Development, Washington, DC, EPA/600/R-12/554, http://nepis.epa.gov/Adobe/PDF/P100HN53.pdf

[6] Ryberg, M., Vieira, M.D.M., Zgola, M. et al. (2014). ‘Updated US and Canadian normalization factors for TRACI 2.1.’ Clean Technologies and Environmental Policy 16: 329. doi:10.1007/s10098-013-0629-z

[7] Gloria, T. P., B. C. Lippiatt & J. Cooper (2007). ‘Life cycle impact assessment weights to support environmentally preferable purchasing in the United States.’ Environmental Science & Technology, 41(21), 7551-7557

ACRONYMS

ASTM	American Society for Testing and Materials
ISO	International Standardization Organization
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact analysis
PCR	Product Category Rule document
SFRM	Spray-applied fire-resistive material
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

- [redacted]