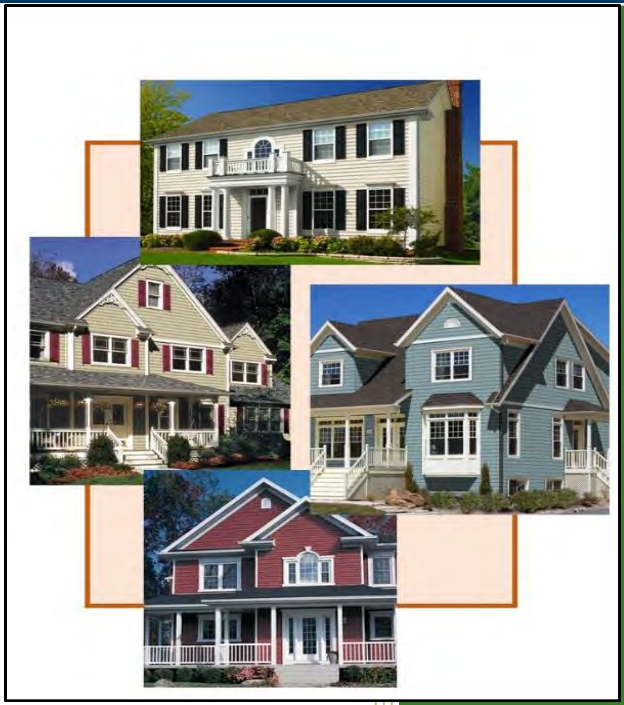
SustainableSolutions CORPORATION

Vinyl, Insulated Vinyl, and Polypropylene Siding Life Cycle Assessment



Prepared For:

VINYL SIDING INSTITUTE

7/18/2016

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Life Cycle Assessment

Vinyl Siding Institute

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Commissioned by Vinyl Siding Institute

LCA Practitioner: Sustainable Solutions Corporation

Conducted according to ISO 14044 International Standard

Life Cycle Assessment

Vinyl Siding Institute

Vinyl, Insulated Vinyl, and Polypropylene Siding

Executive Summary

This report documents the details and data used to develop the environmental product declarations (EPDs) for the Vinyl Siding Institute (VSI), and the three types of siding produced by its member companies: vinyl siding, insulated vinyl siding, and polypropylene siding. The LCA will enable the Vinyl Siding Institute and its member companies to understand the cradle-to-grave potential environmental impact for each product. This life cycle assessment was developed by the Vinyl Siding Institute with assistance from Sustainable Solutions Corporation. The inventory of materials and processing inputs was collected and developed by Sustainable Solutions Corporation based on input from each participating member facility and their understanding of the flow of materials and energy throughout the manufacturing process.

The objective of VSI in commissioning this study was to develop EPDs for each siding type that will contribute to the transparency requirements of LEED version 4 Materials and Resource credits for Building Design and Construction, the National Green Building Standard 2015, as well as other applications that value product transparency. This tool will also quantify and help VSI members to understand the environmental impacts throughout the life cycle of vinyl, insulated vinyl, and polypropylene siding.

LCA is a rigorous study of the inputs and outputs of a particular product which provides a scientific basis for evaluating the impacts throughout the life cycle. LCA is an alternative to the single-criterion decision-making that currently guides many environmental choices. It enables a deeper understanding of the environmental footprint, which benefits manufacturers in improving their product's environmental performance and their manufacturing processes, as well as enables consumers to make decisions on products and materials in regard to the associated impacts of the particular product.

Goals

The goals of this study were to:

- Develop a robust LCA model to assess the industry average environmental impacts of each type of siding produced by the members, based on site-specific manufacturing data and corresponding product data, provided by each participating member company.
- Develop an industry wide LCA report for the purpose of an independent critical review.
- Integrate LCA results into environmental product declarations (EPDs), one for each siding type.

Methodology

This study was conducted according to the life cycle inventory (LCI) and life cycle impact assessment (LCIA) standards established by the International Organization for Standardization (ISO) life cycle assessment standards ISO 14040 series. The geographic boundary for this study is primarily North America. This is a cradle-to-grave LCA study that can examine each type of siding produced at the various VSI member company's facilities in North America from raw materials extraction and processing through end of life. This LCA follows the Product Category Rule (PCR) for Preparing and Environmental Product Declaration (EPD) for Product Group: Cladding System Products.[1]

For this life cycle assessment, Vinyl Siding Institute member companies collected specific data on energy and material inputs, wastes, water use, emissions, and transportation impacts at each of the manufacturing plants. Production data was allocated for these inputs in collaboration with process experts. The US LCI and ecoinvent databases served as the source of secondary inventory data for energy, transportation, and raw materials processes not directly collected from the Vinyl Siding Institute and upstream vendors. Where data was not available in these databases, data and information from literature reviews and raw material suppliers were used to identify proxy materials in the database.

The LCI results were characterized into impact assessment indicator categories using cumulative energy demand and the US Environmental Protection Agency's (EPA) TRACI 2.1 (Tools for the Reduction and Assessment of Chemical and other environmental Impacts) factors.

The study and SimaPro LCA model have undergone an independent peer review by Brad McAllister, Director of WAP Sustainability Consulting, completed in July of 2016.

Key Findings

Assuming that vinyl siding lasts only 50 years, the replacement over a 75-year life of a building increase the life cycle by one half. Outside of replacement, the raw materials stage is the key driver of environmental impacts for vinyl, insulated vinyl, and polypropylene siding products, with the secondary driver of impacts being the manufacturing stage. Within the raw materials stage, the plastic components (either PVC or polypropylene) contribute most significantly to the environmental impacts due to their large proportion within the final product. Within vinyl siding specifically, titanium dioxide and pigments also contribute significantly despite their low concentrations, especially in the ecotoxicity, carcinogenics, and eutrophication categories. In polypropylene siding, the pigments also contribute significantly to the environmental impact in these same categories of ecotoxicity, carcinogens, and eutrophication. Reducing the amounts of titanium dioxide in vinyl and the amount of pigments in all siding types could be evaluated as a way to reduce the environmental impacts of these products. Additionally, increasing the proportion of calcium carbonate filler in polypropylene siding would lower its environmental

[1] Product Category Rule (PCR) for Preparing an Environmental Product Declaration (EPD) for Product Group Cladding System Products. Version: June 18, 2015. Underwriter Laboratories Inc.

impacts, as this material has relatively low impacts compared to the other constituents in this product.

Recommendations

The Vinyl Siding Institute and member companies should use the results of this life cycle impact assessment study for reducing impacts and product improvements including:

- Communicate results of the LCA to R&D personnel and new product development teams. Use these LCA results as a tool during the product development cycle with the intent of evaluating lower impact ingredients, suppliers, and design.
    - Evaluate opportunities to reduce the quantity of the most environmentally impactful materials such as pigments and titanium dioxide in vinyl and insulated vinyl siding.
    - If possible, consider increasing the quantity of relatively benign filler materials such as calcium carbonate in polypropylene siding products.
    - Use the siding life cycle assessment for evaluating alternate raw materials and source locations, recycled content, and alternate transportation modes as part of a sustainable product development process.
    - Reduce the amount of materials used in the packaging of siding of all types or consider integrating more recycled content into the packaging materials.
- Evaluate energy conservation opportunities, especially heat recovery and electricity reduction, to reduce energy consumption and related impacts in the manufacturing operation.
- Encourage suppliers to develop life cycle inventories and implement programs to reduce their own operational environmental impacts.
- Proceed with critical review (completed July 2016 by Brad McAllister, Director of WAP Sustainability Consulting) and development of industry average EPDs.

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1.0 Introduction

Life cycle assessment (LCA) is a powerful tool used to quantify the environmental impacts associated with the various stages of a product's life. Section 1 provides a background and overview of LCA methodology and benefits.

1.1 Background

The use of LCA is growing rapidly in the building and construction market. The Vinyl Siding Institute (VSI) and its member companies have been a leader in developing sustainable and innovative products. This report will baseline and benchmark the vinyl, insulated vinyl, and polypropylene siding products to assist with measuring and understanding the environmental impacts of the various siding types across the life cycle. The models and data developed by conducting this LCA will assist VSI member companies with integrating sustainable product design processes, including manufacturing improvements, alternate raw materials and raw material source locations, and other aspects to reduce environmental impacts across the life cycle for these products. This LCA is also very valuable to VSI as a tool for competitive positioning, and will provide valuable benchmarking for data for member companies completing their own LCAs. The LCA will prepare VSI and its member companies for sustainable supply chain requirements and other policy innovations. The LCA also allows VSI to understand and evaluate any future data or LCA published by competitors.

The following VSI member companies and facilities have participated in this study:

- American Original Building Products
  - Akron, Ohio, USA
- Associated Materials, Inc.
  - Burlington, Ontario, Canada
  - Ennis, Texas, USA
- CertainTeed Corporation
  - Jackson, Michigan, USA
  - Hagerstown, Maryland, USA
  - McPherson, Kansas, USA
- Novik, Inc.
  - St-Augustin-de-Desmaures, Québec, Canada
- Ply Gem Siding Group
  - Paris, Illinois, USA
  - Jasper, Tennessee, USA
- Progressive Foam Technologies, Inc.
  - Beach City, Ohio, USA
- ProVia Products
  - Booneville, Mississippi, USA
- Royal Building Products
  - Columbus, Ohio, USA

1.2 Overview of Life Cycle Assessment

Life Cycle Assessment (LCA)[2] is an analytical tool used to comprehensively quantify and interpret the environmental flows to and from the environment (including emissions to air, water and land, as well as the consumption of energy and other material resources) over the entire life cycle of a product (or process or service). By including the impacts throughout the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product and an accurate picture of the true environmental tradeoffs in product selection.

The standards in the ISO 14040-series set out a four-phase methodology framework for completing an LCA, as shown in Figure 1: (1) goal and scope definition, (2) life cycle inventory (LCI), (3) life cycle impact assessment (LCIA), and (4) interpretation. An LCA starts with an explicit statement of the goal and scope of the study; the functional unit; the system boundaries; the assumptions, limitations and allocation methods used; and the impact categories chosen. In the inventory analysis, a flow model of the technical system is constructed using data on inputs and outputs. The input and output data needed for the construction of the model are collected (including resources, energy requirements, emissions to air and water, and waste generation for all activities within the system boundaries). Then, the environmental loads of the system are calculated and related to the functional unit, to finalize the flow model. Inventory analysis is followed by impact assessment, where the LCI data are characterized in terms of their potential environmental impact (e.g., acidification, eutrophication and global warming potential effects). The impact assessment phase of LCA is used to evaluate the significance of potential environmental impacts based on the LCI results. The impact assessment data is interpreted and validated by sensitivity analysis by the LCA practitioner to provide useful data to the company that commissioned the LCA.

[2] This introduction is based on international standards in the ISO-14040 series, *Environmental Management – Life Cycle Assessment.*

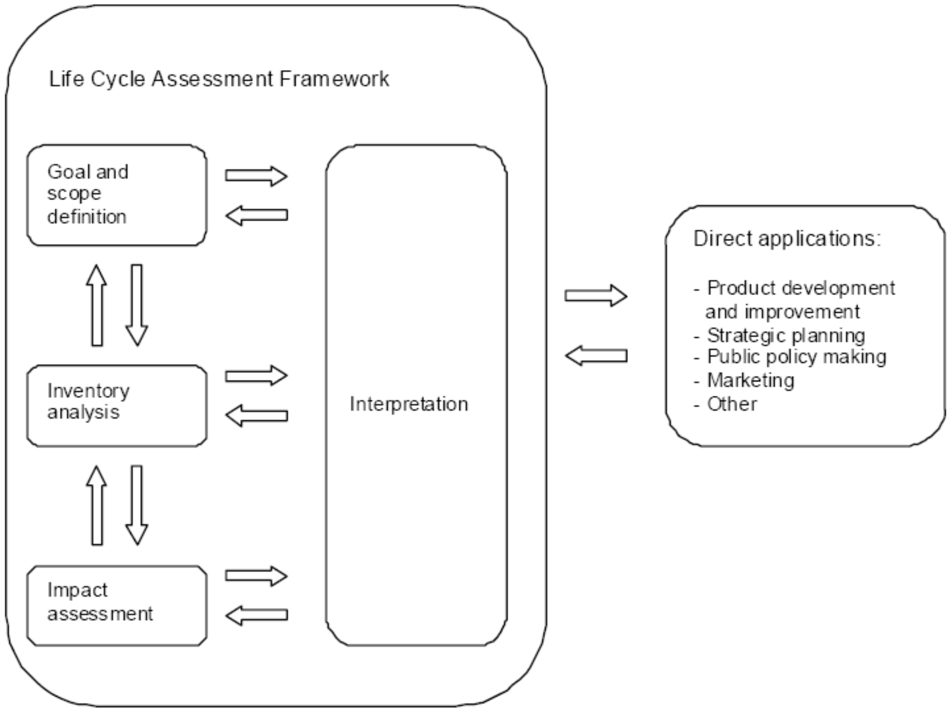


Figure 1.1 – The four stages of life cycle assessment

The working procedure of LCA is iterative, as illustrated with the back-and-forth arrows in Figure 1.1. The iteration means that information gathered in a later stage can cause effects in a former stage. When this occurs, the former stage and the following stages have to be reworked, taking into account the new information. Therefore, it is common for an LCA practitioner to work at several stages at the same time.

This LCA study is characterized as a "cradle-to-grave" study, examining the vinyl, insulated vinyl, and polypropylene siding from raw material extraction through final disposal. For this life cycle assessment, Sustainable Solutions Corporation (SSC) collected specific data on energy and material inputs, wastes, water use, emissions, and transportation impacts for the participating member companies siding production for the calendar year 2015. This LCA was conducted using SimaPro software with the National Renewable Energy Lab (NREL) US LCI database serving as the primary source of life cycle inventory data for raw materials and processes not directly collected from VSI. Where data was not available in the US LCI database, data from the ecoinvent LCI database, private SSC LCI databases, and published reports were used. Data from European databases was adapted using US electricity impacts. The TRACI version 4.0 impact assessment methodology was used to calculate the environmental impacts in this LCA. TRACI was developed by the US Environmental Protection Agency (EPA) as a tool to assist in impact analysis in Life Cycle Assessments, process design, and pollution prevention. Impact categories include:

1. Global Warming Potential
2. Acidification
3. Carcinogens
4. Non-carcinogens
5. Respiratory Effects
6. Eutrophication

7. Ozone Depletion
8. Ecotoxicity
9. Smog

Potential benefits of a life cycle assessment include: better materials sourcing, manufacturing process environmental impact reduction, education, evaluation of raw materials, impacts to product standards, decreased air emissions, waste reduction, increased recycling, reduced water use, and cost savings, among many others.

2.0 Goal and Scope Definition

The nature of life cycle assessment is to include a wide range of inputs associated with the products being analyzed. Constraining the LCA scope is an essential part of the study. The following section defines the goal, scope, and boundaries of this LCA study.

2.1 Goal of the Study

The goal of this analysis is to identify and quantify the environmental impacts associated with each stage in the life cycle of the vinyl, insulated vinyl, and polypropylene siding including raw material extraction, processing, and shipping; manufacturing; final product shipping; product use; and end-of-life disposition.

Intended Uses

LCA is a tool that can effectively be applied for manufacturing process improvements, education and market support, environmental management, and sustainable reporting. VSI, which is the primary audience of the study, intends to use the study results mainly for the following purposes:

- Provide a baseline LCA in order to understand and evaluate the impacts of the vinyl, insulated vinyl, and polypropylene siding across the product life cycle.
- As a basis for publication of an industry wide siding EPD for primarily business-to-consumer (B-to-C) communication.
- For marketing or competitive purposes and to satisfy the transparency requirements in the various green building codes and standards.
- Product Stewardship – LCA is a tool in the VSI product stewardship program. The siding LCA will be used by the VSI team members to quantify and understand the impacts of the products and processes throughout the life cycle in order to integrate sustainable product design techniques to reduce the impacts, to the extent possible.
- Process Improvements and New Technology Evaluation – VSI can use the completed LCA to evaluate possible process improvements in the manufacture of vinyl, insulated vinyl, and polypropylene siding. Based on the results, they can evaluate alternate ingredients or raw materials, opportunities for integration of recycled content or bio based materials, and opportunities for designing a closed loop product in the future.
- Prepare VSI for sustainable supply chain requirements, carbon taxes, and other potential policy requirements.
- Competitive analysis and positioning in order to analyze and evaluate claims or LCA/EPD information published in the future by competitors.

- As a tool to illustrate the reduced environmental impacts to regulatory agencies (for example, the US EPA) of process, facility or raw material improvements.
- To meet future requirements for green purchasing programs for the Unites States Government (such as DoD/GSA procurement practices), corporations, or other businesses.

2.2 Functional Unit

All flows to and from the environment within the system boundary (see Section 2.3 below) are normalized to a unit summarizing the function of the system. The function of all three types of siding is to protect the building structure and interior from exterior elements (such as water, temperature, wind, etc.) in addition to providing aesthetic design.

Once the primary functions of the systems are defined, a functional unit is selected in order to provide a similar basis, consistent with the above mentioned goals, for summarizing the LCA. The functional unit utilized for this study is 100 square feet of cladding with a service life of 50 years, including end-of-life disposition, per the Cladding System Products Product Category Rule published by UL Environment. Siding is typically sold in 12-foot panel lengths in a variety of profiles. Table 2.1, 2.2, and 2.3 list the specific details of the three industry average siding types. These products represent industry averaged products as an average from multiple manufacturers and multiple facilities. Data was collected from each facility and a weighted average, based on production, was calculated for each input and output throughout the life cycle of the three cladding products.

Table 2.1 – Industry Average Vinyl Siding Product Details

Name	Value	Unit
Functional Unit	100	ft^2
Size of 1 Panel (Piece)	12 x 9	ft x in
Panels per Functional Unit	11.11	panels
Length	12	ft
Width	0.75	ft
Thickness	0.040	in
Functional Unit Weight	42.4	$lbs/100ft^2$
Material Density	89.27	lb/ft^3
Tensile Strength		lbf/in^2 (PSI)
Modulus of Elasticity		lbf/in^2 (PSI)
U-value of assembly including interruptions to insulation		BTU/(ft^2·°F·hr/
R-value of typical materials where continuous		ft^2·°F·hr/BTU
Water vapor permeance		Perm (inch-pound)
Liquid Water absorption		% of dry weight
Airborne sound reduction		dB
Sound absorption coefficient		%

**items not described are not standard details required or known by the industry*

Table 2.2 – Industry Average Insulated Vinyl Siding Product Details

Name	Value	Unit
Functional Unit	100	ft^2
Size of 1 Panel (Piece)	12 x 9	ft x in
Panels per Functional Unit	11.11	panels
Length	12	ft
Width	0.75	ft
Thickness	1.5	in
Functional Unit Weight	49.33	lbs
Material Density	89.27 (vinyl siding) 1.0 (EPS foam)	lb/ft^3
Tensile Strength		lbf/in^2 (PSI)
Modulus of Elasticity		lbf/in^2 (PSI)
U-value of Assembly Including Interruptions to Insulation	0.31	BTU/(h*F*ft^2)
R-value of Typical Material Where Continuous	3.2	ft^2*F*hr/BTU
Water Vapor Permeance		Perm (inch-pound)
Liquid Water Absorption		% of dry weight
Airborne Sound Reduction		dB
Lifetime	50	years

**items not described are not standard details required or known by the industry*

Table 2.3 – Industry Average Polypropylene Siding Product Details

Name	Value	Unit
Functional Unit	100	ft^2
Size of 1 Panel (Piece)	12 x 7	ft x in
Panels per Functional Unit	14.29	panels
Length	12	Ft
Width	0.583	Ft
Thickness	0.085	In
Functional Unit Weight	71.3	lbs
Material Density	64.3	lb/ft^3
Tensile Strength		lbf/in^2 (PSI)
Modulus of Elasticity		lbf/in^2 (PSI)
U-value of Assembly Including Interruptions to Insulation		BTU/(h*F*ft^2)
R-value of Typical Material where Continuous		ft^2*F*hr/BTU
Water Vapor Permeance		Perm (inch-pound)
Liquid Water Absorption		% of dry weight
Airborne Sound Reduction		dB
Lifetime	50	years

**items not described are not standard details required or known by the industry*

The functional unit of 100 square feet represents 11.11 pieces of 12' by 9" vinyl siding, and 14.29 pieces of 12' by 7" polypropylene siding. This functional unit is consistent with the goal and scope of the study. The functional unit determines the environmental impacts and is the basis for comparison in an LCA. It provides a unit of analysis and comparison for all environmental impacts.

2.3 System Boundary

This project considers the life cycle activities from resource extraction through product use for a 50-year life cycle inclusive of maintenance and end-of-life effects. Maintenance during the product's use phase is limited to periodic cleaning with soap and water. Figure 2.1 defines the system boundary for all three types of siding. The study system boundary includes the transportation of major inputs to (and within) each activity stage including the shipment of final products to the use site, based on logistics data provided by VSI, by common modes, as well as transportation to a landfill at the end of the service life. Any site-generated energy and purchased electricity is included in the system boundary. The extraction, processing and delivery of purchased primary fuels, e.g., natural gas and primary fuels used to generate purchased electricity, are also included within the boundaries of the system. Purchased electricity consumed at the various site locations is modeled based on US and Canadian grid averages, using the models published in the NREL US LCI database.

Product			Construction Installation		Use							End-of-Life				Benefits of Loads Beyond the System Boundary		
Raw Material Extraction and Processing	Transport	Manufacturing	Transport	Construction/ Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Operational Energy Use	Operational Water Use	De-Construction/ Demolition	Transport	Waste Processing	Disposal	Reuse	Recovery	Recycling
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	D	D
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	MND	MND	MND

Figure 2.1 – System Boundary for Siding Products

Both human activity and capital equipment were excluded from the system boundary. The environmental effects of manufacturing and installing capital equipment and buildings have generally been shown to be minor relative to the throughput of materials and components over the useful lives of the buildings and equipment. Human activity involved in the manufacture of siding products and their component materials no doubt has a burden on the environment; however, the data collection required to properly quantify human involvement is particularly complicated, and allocating such flows to the production of the siding, as opposed to other societal activities, was not feasible for a study of this nature. Typically, human activity is only considered within the system boundary when value-added judgments or substituting capital for labor decisions are considered to be within the scope of the study; however, these types of decisions are outside this study's goal and scope. The details of the data excluded from the system boundary can be found in the subsequent inventory sections.

Table 2.4 – System Boundary Description

Included	Excluded
Raw material acquisition and processing **Processing of materials** **Transport of raw materials** **Energy used in production (lighting, heating, cooling, etc.) at manufacturing facilities** **Interplant and final product shipping** **Packaging** **Manufacturing waste and emissions** **Product installation** **Product use** **Product replacement** **Product disposal**	Construction of capital equipment Maintenance of operation and support equipment Human labor and employee commute

2.3.1 Cut-off Criteria

Processes whose total contribution to the final result, with respect to their mass and in relation to all considered impact categories, is less than 1% can be neglected. The sum of the neglected processes may not exceed 5% by mass and by 5% of the considered impact categories. For that a documented assumption is admissible.

For Hazardous Substances, as defined by the U.S. Occupational Health and Safety Act, the following requirements apply:

- The Life Cycle Inventory (LCI) of hazardous substances will be included, if the inventory is available.
- If the LCI for a hazardous substance is not available, the substance will appear as an input in the LCI of the product, if its mass represents more than 0.1% of the product composition.
- If the LCI of a hazardous substance is approximated by modeling another substance, documentation will be provided.

This LCA is in compliance with the cut-off criteria since no known processes were neglected or excluded from this analysis outside of the specific items listed under "Excluded" in Table 2.4.

For the disposal phase, the product was modeled as 20% incineration and 80% landfilled based on EPA statistics.[3]

[3] US Environmental Protection Agency; Advancing Sustainable Materials Management: Facts and Figures https://www.epa.gov/smm/advancing-sustainable-materials-management-facts-and-figures ; Accessed – April, 22 2016.

3.0 Data Sources and Modeling Software

The quality of results in an LCA study are directly dependent on the quality of input data used in the model. This section describes the data quality guidelines used in this study, the sources from which the data was selected, the software used to model the environmental impacts, and any data excluded from the scope of the study.

3.1 Data Quality

Wherever secondary data is used, the study adopts critically reviewed data for consistency, precision, and reproducibility to limit uncertainty. The data sources used are complete and representative of North America in terms of the geographic and technological coverage and are a recent vintage (i.e., less than ten years old). Any deviations from these initial data quality requirements for secondary data are documented in the report.

The results of an LCA are only as good as the quality of input data used. Important data quality factors include precision (measured, calculated or estimated), completeness (e.g., unreported emissions or excluded flows), consistency (uniformity of the applied methodology throughout the study), and reproducibility (ability for another researcher to reproduce the results based on the methodological information provided). The primary data from the manufacturer was from the latest data available. Each dataset used was taken from SimaPro databases, either US LCI or ecoinvent. These databases are widely distributed and referenced within the LCA community and are either partially or fully critically reviewed.

Precision

The data used for primary data are based on direct information sources of the manufacturer. The energy and water usage data was collected directly from the manufacturers, who use utility meters to track their consumption of electricity, fuels and water. Allocation by production weight was used to determine the life cycle inputs per pound of material. The precision for primary data is considered high; however, the uncertainty of the primary data has not been quantified.

Secondary data sets were used for raw materials extraction and processing, end of life, transportation, and energy production flows. The US ecoinvent v2.2 database was used for most of the raw material data sets. Since the inventory flows for ecoinvent processes are very often accompanied by a series of data quality ratings, a general indication of precision can be inferred. Using these ratings, the data sets used generally have medium-to-high precision. Precision for the datasets used from the US LCI database was not formally quantified. However, many data sets from the US LCI were developed based on well-documented industry averages with data quality indicators provided for each flow.

Completeness

The processes modeled represent the specific situations in the vinyl, insulated vinyl, and polypropylene siding life cycles. System boundaries and exclusions are clearly defined in the sections above, and no other data gaps were identified.

Consistency

Primary data was collected from each member company as tracked by automated systems and records. Since most of the data is reported by year, the consistency is considered high. Secondary data was consistently modeled using either US LCI or ecoinvent databases as available. Proxies were only identified and used if secondary data was not available in these or other databases. This methodology provides consistency throughout the model.

Reproducibility

Most datasets are from nationally accepted and publicly available databases, ensuring reproducibility by an average practitioner. Confidential data from the plant would inhibit reproducing these results without access to the data.

Representativeness

The representativeness of the datasets is chosen to be representative of North America, average technologies of the major producers and distributors and of recent and modern vintage.

Uncertainty

Most of the secondary data sets in US LCI and ecoinvent databases have some uncertainty information documented and varies per model. Uncertainty for primary data was not quantified. However, the collected data and allocation methodologies were judged by the operations personnel to be accurate, so the uncertainty is considered low.

The primary data from the manufacturer was from the latest data available, incorporating the most recent updates to the process into the model. Each dataset used was taken from SimaPro databases, either US LCI or ecoinvent. These databases are widely distributed and referenced within the LCA community. The datasets use relevant yearly averages of primary industry data or primary information sources of the manufacturer and technologies. The uncertainty of each dataset is not formally quantitatively known. Each dataset is from publicly available databases, ensuring reproducibility. The representativeness of the datasets is chosen to be representative of North America, average technologies of the major producers and distributors and of recent and modern vintage. Below is a more detailed description of the datasets used in the model of raw materials extraction and processing for the major components of siding.

3.2 Data Sources

North America, specifically the United States and Canada, is considered as the geographic boundary of this study. The reference year is 2015 since the primary siding manufacturing data were gathered for that calendar year. Both primary and secondary LCI and metadata are used throughout the study. All secondary data is taken from literature, previous LCI studies, and life cycle databases. The US LCI database (www.nrel.gov/lci) is frequently used in this analysis. Much of the LCI data residing in the US LCI database pertain to common fuels – their combustion in utility, stationary and mobile equipment inclusive of upstream or pre-combustion effects (i.e., back to earth). Generally, these modular data are of a recent vintage (less than ten years old). This study draws on these data for combustion processes, electricity generation, and transportation on a regional North American basis. These data are free and publicly available, and thus, offer both a high degree of transparency and an ability to replicate the results of the study; however, there are limitations, as some processes are missing for some of the products available in this LCI database, creating an issue with respect to completeness.

When North American data was not available for a product or process, the European ecoinvent LCI database was utilized. This database contains over 3,500 LCI modules for processes and products, all of which have undergone peer review. The basic assumption when using these data is that North American and European production processes are generally similar, but that these data need to be adapted for North American circumstances (e.g., electricity grids, fuels, and transportation modes and distances need to be modified to better reflect the North American operations). Such adaptation was conducted whenever necessary.

Table 3.1 – Data sources for VSI Siding LCA Model

Material Input	Database(s) and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type and Quality
PVC	US LCI: 2012 NREL USLCI RVC Resin	2012	North America	Based on US average PVC resin production	Secondary
ASA	US-EI 2.2: Acrylonitrile-butadiene-styrene copolymer resin, at plant, NREL /RNA	2012	North America	Based on US average ASA resin production	Secondary
Polypropylene	US-EI 2.2: Polypropylene resin, at plant NREL	2008	North America	Combination of liquid monomer and gas phase processes	Secondary
Acrylic Impact Modifier	US-EI 2.2: Acrylic filler, at plant/RER with US Electricity	2012	North America	Transport of raw materials and production of filler	Secondary
Calcium Carbonate	US LCI: Limestone, at mine/US	2012	North America	Blasting, mechanical crushing, and screening	Secondary
Calcium Stearate	91% US LCI: Quicklime, at plant/US	2012	North America	Limestone mining and lime production	Secondary
	9% US-EI 2.2: Fatty acids, from vegetarian oil, at plant/RER with US Electricity	2012	North America	Based on the oil from soya, palm, palm kernel, and coco nuts	Secondary

Material Input	Database(s) and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type and Quality
Impact Modifier (Chlorinated Polyethylene)	61% US LCI: High density polyethylene resin, at plant NREL	2012	North America	UNIPOL gas and slurry process	Secondary
	39% US-EI 2.2: Chlorine, PVC producer average, at plant NREL	2010	North America	98% diaphragm and membrane cell electrolysis and 2% mercury cell electrolysis.	Secondary
Lubricant	40% US LCI: Paraffin, at plant/RER with US Electricity	2010	North America	Based on average technology mix	Secondary
	32.5% Calcium Stearate (see above)	see above	See above	See above	See above
	20% US-EI 2.2: Fatty acids, from vegetarian oil, at plant/RER with US Electricity	2010	North America	Based on the oil from soya, palm, palm kernel, and coco nuts	Secondary
	7.5% US LCI: High density polyethylene resin, at plant NREL	2012	North America	UNIPOL gas and slurry process	Secondary
Paraffin Wax	EI v3: default, recycled content, unit: Paraffin, at plant/ROW	2015	Global, except Europe	Based on average US paraffin production	Secondary

Material Input	Database(s) and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type and Quality
Pigments	50% EI v3: Chromium, {RoW} production/Alloc Rec, S	2015	Global, except Europe	Metallic chromium is produced by aluminothermic process (75%) and electrolysis of dissolved ferrochromium (25%)	Secondary
	25% EI v3: Antimony {RoW}, productionCN	2015	China	Data represent a mixture of blast furnace, rotary kiln and electrowinning process	Secondary
	25% Titanium Dioxide (see above)	See above	See above	See above	See above
Process Aid	50% US-EI 2.2: Methyl methacrylate, at plant/RER with US Electricity	2010	North America	Product out of hydrogen cyanide and acetone	Secondary
	50% Methyl acrylate, at plant/GLO with US Electricity	2007	North America	Esterification of acrylic acid	Secondary
Tin Stabilizer	9.5% EI v3: Tin, {RoW} production/ Alloc, S	2015	Global, except Europe	Data relate to an assumed average technology for mining, beneficiation, smelting and refining	Secondary

Material Input	Database(s) and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type and Quality
	11.3% USEI 2.2: Chlorine, production mix, at plant/kg NREL	2008	North America	85% diaphragm and membrane cell electrolysis and 15% mercury cell electrolysis	Secondary
	7.7% EI v3: Magnesium{RoW} magnesium production, eletrolysis , Alloc, U	2015	Global, except Europe	Production of magnesium from via electrolysis	Secondary
	68.5% US-EI 2.2: Fatty acids, from vegetarian oil, at plant/Alloc, U	2010	North America	Based on the oil from soya, palm, palm kernel, and coco nuts	Secondary
	1.3% US-EI 2.2: Hydrogen sulfide, H2S, at plant/RER with US Electricity	2007	North America	Production from sulfur and hydrogen. Inventory bases on literature values	Secondary
	1.7% US-EI 2.2: Ethylene Oxide, at plant	2008	Europe	Direct oxidation of ethylene using silver catalyst	Secondary
Titanium Dioxide	US-EI 2.2: Titanium dioxide, production mix, at plant/RER with US Electricity	2012	North America	50% by sulfate process and 50% by chloride process	Secondary

Material Input	Database(s) and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type and Quality
Cardboard	US-EI 2.2: Corrugated board, mixed fibre, single wall, at plant/RER with US Electricity	2007	North America	Based on average US production processes	Secondary
Glue	US-EI 2.2: Adhesive for metals, at plant/DE with US Electricity	2008	North America	Adapted for US conditions	Secondary
Ink	EI 3: Printing ink, offset, without solvent, in 47.5 solution state	2013	Europe	Based on black and colored mix of printing ink	Secondary
Nail	EI v3: Steel, chromium steel 18/8 {RoW} steel production, converter, chromium steel 18/8/Alloc, U	2015	North America	Based on industry average data	Secondary
	Steel product manufacturing, average metal working, RER with US Electricity	2010	European, adapted to US Conditions	Based on industry average data	Secondary
Paper Label	US-EI 2.2: Kraft paper, bleached, at plant/RER with US Electricity	2015	Global, except Europe	Based on one producer's production data	Secondary

Material Input	Database(s) and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type and Quality
Plastic Bag	US-EI 2.2: Low density polyethylene resin, at plant NREL	2008	North America	Combination of free-radical or ionic polymerization in autoclaves or tubular reactors	Secondary
Plastic Wrap	US LCI: High density polyethylene resin, RER	2010	Global, except Europe	Based on current technologies	Secondary
	Extrusion, plastic film, production/ Alloc Rec, U	2015	Global, except Europe	Average extrusion process	Secondary
Styrofoam	EPS insulation board, at plant/U SLCI	2010	North America	European average EPS production, adapted for US conditions	Secondary
Wood Pallet	US-EI 2.2: Plywood, at plywood plant, US SE/kg NREL	2008	North America	Typical production process	Secondary
Biocide	US-EI 2.2: Biocides, for paper production, unspecified, at plant/RER with US Electricity	2007	North America	Mixture of two oxidizing agents (chlorine dioxide, hydrogen peroxide) and two highly toxic organics (dithiocarbamate, cyanazin)	Secondary

Material Input	Database(s) and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type and Quality
Citric Acid	EI 3: Citric acid production	2013	North America	Based on fermentation process	Secondary
Hypochlorite	EI v3 Sodium hypochlorite, 15% in H2O, at plant/Alloc Rec, S	2015	Global, except Europe	Based on literature and plant data in Europe and North America	Secondary
Softener Salt	US LCI: Sodium chloride, at plant/RNA	2010	North America	95% solution mining and 5% rock salt mining	Secondary

Process Input	Database(s)and Source	Temporal Information	Regional Coverage	Technology Coverage	Data Type and Quality
Electricity - US	US LCI: Electricity, at grid, US, 2010	2010	United States	Representative of the US fuel mix	Secondary
Electricity - Canada	US LCI: Electricity, at grid, NPCC, 2010	2010	Canada	Representative of the Canadian fuel mix	Secondary
Electricity - Quebec	US LCI – 99% Electricity, at grid, hydrpower, 2010	2010	Quebec	Representative of the Quebec fuel mix	Secondary
Natural Gas	US LCI: Natural gas, combusted in industrial equipment	2010	North America	Representative of US consumption of natural gas in industrial equipment	Secondary
Propane	US LCI: Liquefied petroleum gas, combusted in industrial boiler	2010	North America	LPG combustion in average industrial boiler	Secondary
Gasoline	US-EI 2.2: Gasoline, combusted in equipment NREL	20	North America	Combusted in equipment such as refrigeration units, generators, pumps, and drilling equipment	Secondary
Water	US-EI 2.2: Tap water, at user/RER with US Electricity	2005	North America	Infrastructure and energy use for water treatment and transportation to the end user	Secondary
Polystyrene Resin	US-EI 2.2: High impact polystyrene resin, at plant NREL	2008	North America	Polymerization by mass suspension	Secondary

Insecticides	US-EI 2.2: Insecticides, at regional storehouse/RER with US Electricity	2010	North America	Production of pesticides	Secondary
Transportation	**Database(s) and Source**	**Temporal Information**	**Regional Coverage**	**Technology Coverage**	**Data Type and Quality**
Truck Transportation	US LCI: Transport, combination truck, diesel powered/US	2008	North America	Combustion of diesel in a combination truck	Secondary
Rail Transportation	US LCI: Transport, freight, rail, diesel/US with US Electricity	2007	North America	Based on average rail transport technology	Secondary
End of Life	**Database(s) and Source**	**Temporal Information**	**Regional Coverage**	**Technology Coverage**	**Data Type and Quality**
Landfill	EI v3; Disposal, inert waste, 5% water, to inert material landfill/ / Alloc Rec U	2015	Global except Europe	Landfill with renaturation after closure	Secondary
Incineration	EI v3: Disposal, polyvinylchloride, 0.2% water, to municipal incineration/ Alloc Rec U	2015	Global except Europe	Representative of modern incineration processes	Secondary

3.3 Modeling Software

SimaPro v7.3 software was utilized for modeling the complete cradle-to-grave LCI for all siding products. All process data including inputs (raw materials, energy, and water) and outputs (emissions, waste water, solid waste, and final products) are evaluated and modeled to represent each process that contributes to the life cycle of the siding products. The study's geographical and technological coverage has been limited to North America, based on siding manufacturing locations. SimaPro was used to generate life cycle impact assessment (LCIA) results utilizing the TRACI impact assessment methodologies as well as single flow environmental scores (Global Warming Potential and Cumulative Energy Demand). See Section 5.2 for a description of the selected LCIA categories and characterization measures used in this study.

4.0 Life Cycle Inventory Analysis

This section describes the cradle-to-grave life cycle inventory of the vinyl, insulated vinyl, and polypropylene siding. Primary manufacturing data was collected from surveys completed by personnel from each manufacturing plant participating in this study for the 2015 calendar production year. The participating manufacturing plants provided resource transportation mode and distance data to support the calculation of raw material transportation flows. The transportation LCI data from the US LCI database (kg-km basis) were used to develop the resource transportation LCI profile.

4.1 A1. Raw Materials and Product Recipe Overview

A thorough analysis of the material inputs and the product recipe was completed for the inventory of this study. The vinyl siding product recipe is listed in Table 4.1 below.

Table 4.1 - Vinyl Siding Formulation

Constituent	% in Siding with PVC Capstock	% in Siding with ASA Capstock
PVC	80.4%	69%
ASA	--	12%
Calcium Carbonate	11.1%	10%
Impact Modifier	1.9%	1.1%
Titanium Dioxide	1.4%	0.9%
Tin Stabilizer	0.6%	0.7%
Process Aid	0.5%	0.0%
Lubricant	1.7%	1.7%
Chlorinated Polyethylene	0.7%	2.4%
Sealant	0.8%	0%
Calcium Stearate	0.6%	0.0%
Pigments	.1%	0.2%

The insulated vinyl siding product recipe is listed in Table 4.2 below.

Table 4.2 – Insulated Vinyl Siding Formulation

Component	Weight (lb/100sf)	% of Product
Vinyl Siding	42.4	86%
Foam Insulation	6.2	13%
Glue	0.73	1%
Constituent	**% in Siding with PVC Capstock**	**% in Siding with ASA Capstock**
PVC	80.4%	69%
ASA	--	12%
Calcium Carbonate	11.1%	10%
Impact Modifier	1.9%	1.1%
Titanium Dioxide	1.4%	0.9%
Tin Stabilizer	0.6%	0.7%
Process Aid	0.5%	0.0%
Lubricant	1.7%	1.7%
Chlorinated Polyethylene	0.7%	2.4%
Sealant	0.8%	0%
Calcium Stearate	0.6%	0.0%
Pigments	.1%	0.2%

The polypropylene siding product recipe is listed in Table 4.3 below.

Table 4.3 – Polypropylene Siding Formulation

Constituent	% in Siding
Polypropylene	85%
Calcium Carbonate	12%
Pigments and Additives	3%

4.2 A2. Raw Materials Transportation

Each manufacturer provided supplier location data so that the transportation of each raw material was calculated on a kg-km basis for a kg of final product. This includes manufacturing materials not used as ingredients in the final product but as support to maintain the operations at each facility. A weighted average between all facilities was conducted in terms of kg-km (weight and distance) based on production from the reference year (calendar year 2015).

Table 4.4 – Weighted Average Raw Material Transportation Distances

	kgkm per kg product		kgkm per 100 sf	
Product	**Truck**	**Rail**	**Truck**	**Rail**
Vinyl Siding	170	150	3,272	2,887
Insulated Vinyl Siding	420	150	9,416	3,359
Polypropylene Siding	37	1,210	1,184	39,168

4.3 A3. Manufacturing Process Overview

A manufacturer chooses the raw materials and processes that will be used to produce a product, but their ability to directly influence the processing, and thus environmental impact, of raw materials is typically outside of the manufacturer's control. Figure 4.1 below illustrates the total life cycle of a product from raw materials extraction and processing through installation, use and end-of-life. Environmental impacts that occur in raw material shipping, manufacturing, and final product shipping are directly under the manufacturer's control. This puts much of the environmental impact of the final product out of the control of the manufacturer unless material substitutions can be made.

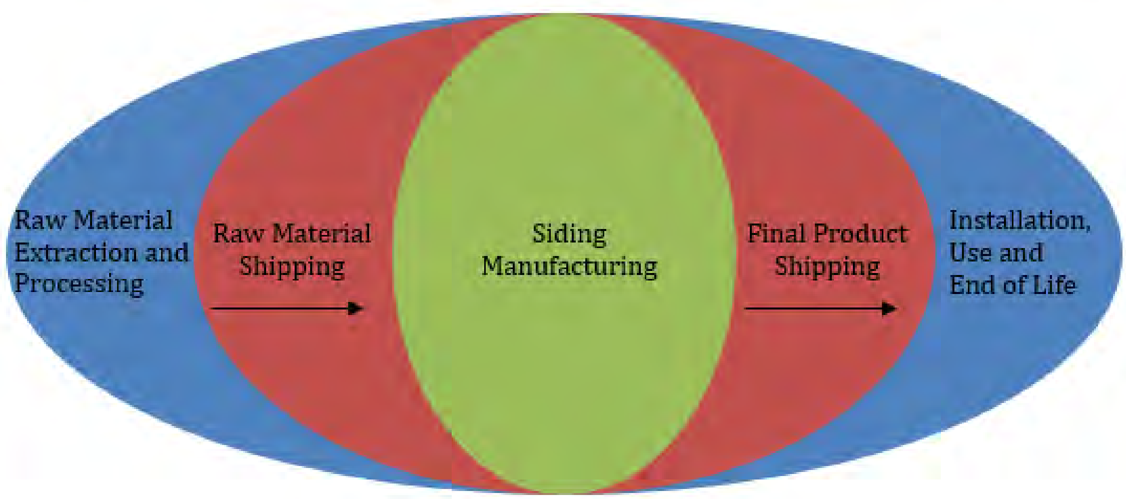


Figure 4.1 – Vinyl Siding Life Cycle Control Diagram

A detailed analysis of the manufacturing process was completed by Sustainable Solutions Corporation. A process flow diagram is attached in Appendix A and illustrates all process steps, inputs, and outputs including material, energy, emissions, and wastes.

Vinyl siding manufacturing is an extremely efficient extrusion process requiring relatively low inputs of energy and water and, the ability to immediately return scrap and off-specification materials (regrind) directly into the manufacturing process results in virtually no manufacturing waste. Water is not one of the constituents of vinyl and is only used for cooling the siding after it has been extruded.

Modern technology in the manufacturing phase allows for vinyl siding to be co-extruded with a substrate and a capstock. Co-extrusion allows for a more durable product, enabling colors and textures to retain its original appearance and performance capabilities over time.

To produce insulated vinyl siding, the same manufacturing process is supplemented by the addition of a foam backing layer applied directly to the vinyl siding layer.

To produce polypropylene siding, polypropylene compound beads are melted and injected into molds derived from actual cedar shakes. The polymer cures into the shape from the mold. Various pigments can be added for color variations. Polypropylene siding manufacturing is an extremely efficient injection molding process requiring relatively low inputs of energy and water and the ability to immediately return scrap and off-specification materials (regrind) directly into the manufacturing process results in virtually no manufacturing waste.

The facilities included in this study produce mostly similar siding products within a given facility, so mass allocation was conducted based on weight of siding produced per year.

To produce vinyl, insulated vinyl, and polypropylene siding, energy, water and materials go into the process and waste and emissions are outputs from the manufacturing process. Table 4.5 detail the manufacturing process inputs and outputs for vinyl siding and polypropylene siding respectively. The manufacturing inventory for progressive foam is not displayed here, as this portion of the lifecycle is considered as a raw material input for insulated siding in the context of this study.

Table 4.5 – Vinyl and Polypropylene Siding Manufacturing Inventory

Energy Inputs	Vinyl Siding Quantity	Polypropylene Siding Quantity	Unit (per kg of siding produced)
Electricity	2.49E-01	1.60E+00	kWh/kg
Natural Gas	1.10E-01	2.06E+00	scf/kg
Propane	6.23E-04	3.46E-05	gal/kg
Gasoline	3.99E-07	0.0E+00	gal/kg
Water	**Vinyl Siding Quantity**	**Polypropylene Siding Quantity**	**Unit**
Water Inflow	2.19E-01	3.93E-01	gal/kg
Water Outflow	1.43E-01	1.26E-01	gal/kg
Waste	**Vinyl Siding Quantity**	**Polypropylene Siding Quantity**	**Unit**
Landfill	2.69E-02	5.56E-03	Kg/kg
Incineration	0.0E+00	2.07E-03	Kg/kg

As there were multiple facilities participating for each product, the average US electricity grid and the Canadian electricity grid were used to represent electricity fuel sources, using a weighted average between the facilities. However, for polypropylene, only one manufacturer was located in Canada, so that specific region (Quebec) was modeled while the remaining US facilities assumed the average national US electricity grid.

4.4 A4. Final Product Transportation

The final product distribution distance was based on data provided by VSI member companies. The weighted average distribution distance for vinyl and insulated vinyl siding is modeled as 508.8 km, and the weighted average distribution distance for polypropylene siding is modeled as 1,107.9 km.

4.5 A5. Construction and Installation

Installation of siding is done primarily by manual labor. Nails or screws can be used to install the siding; nails are more common and would typically be the type installed by hand. Installation is modeled for nails placed 41 cm (16 in) on center; nail use is 0.0024 kg (0.0053 lb) per 0.09 m2 (per ft2) of siding. Installation waste with a mass fraction of 5% is assumed, and this waste is assumed to go to a landfill.
While sheathing, weather resistive barriers, and other ancillary materials are required to complete the exterior wall system, these materials are not included in the system boundaries.

VSI has developed a certification program for polypropylene siding installers. Certified Polypropylene Siding Installers have at least two years of installation experience and have demonstrated knowledge of proper installation techniques. This program follows the ASTM D4756 standard for the Standard Practice for Installation of Rigid Poly(Vinyl Chloride) (PVC) Siding and Soffit.

4.6 Module B. Use Stage

B1. Use

During the life cycle of vinyl, insulated vinyl and polypropylene siding, there are no energy inputs required as the products are passive products.

B2. Maintenance

No routine maintenance is required to prolong the lifetime of the product, although cleaning is recommended to maintain appearance. Cleaning would normally be done with water and household cleaners. An estimate was made that 4.5 liters of water and 2.6 grams of soap would be consumed via cleaning on the siding products.

B3. Repair

Since vinyl, insulated vinyl and polypropylene siding are passive exterior cladding products, no repair is typically required during the life of the product.

B4. Replacement

The average assumed reference service life of the products is 50 years. Per the Product Category Rule, the assumed lifetime of the life cycle is 75 years so the products will require a replacement factor rate of 1.5 of the overall life cycle impacts.

B5. Refurbishment

No refurbishment is required for these three industry wide exterior cladding product types.

B6 and B7. Operational Energy and Water Use

During the life cycle of vinyl, insulated vinyl and polypropylene siding, there are no energy inputs required as the products are passive products. No water is consumed during the use of the product either. Any water consumed from washing the product during regular maintenance is accounted for in Module B2.

4.7 Module C. End of Life

Final products were modeled as being shipped 80 km by truck for Module C2 (End-of-life Transport) and the products end-of-life assumed to be 80% inert in a landfill, and 20% incinerated (Module C4 End-of-life Disposal), based on EPA data cited above in section 2.3.1. This gate-to-grave flow data were combined with resource extraction and processing data.

5.0 Life Cycle Impact Assessment (LCIA)

The environmental impacts of a product can be categorized and presented in many ways. This section briefly describes the methodology used to develop the impact assessment and defines the selected impact categories used to present the results. This section also lists assumptions of the study and describes the inherent limitations and uncertainty of the LCA results.

5.1 Impact Categories/Impact Assessment

As defined in ISO 14040:2006, "the impact assessment phase of an LCA is aimed at evaluating the significance of potential impacts using the results of the LCI analysis". In the LCIA phase, SSC modeled a set of selected environmental issues referred to as impact categories and used category indicators to aggregate similar resource usage and emissions to explain and summarize LCI results data. These category indicators are intended to "characterize" the relevant environmental flows for each environmental issue category to represent the potential or possible environmental impacts of a product system. The category indicators do not predict impacts for category endpoints, the exceeding of thresholds, safety margins or risks.

ISO 14044 does not specify any specific methodology or support the underlying value choices used to group the impact categories. The value-choices and judgments within the grouping procedures are the sole responsibilities of the commissioner of the study.

The framework surrounding LCIA includes three steps that convert LCI results to category indicator results. These include the following:

1. Selection of impact categories, category indicators and models.
2. Assignment of the LCI results to the impact categories (classification) – the identification of individual inventory flow results contributing to each selected impact indictor.
3. Calculation of category indicator results (characterization) – the actual calculation of the potential or possible impact of a set of inventory flows identified in the previous classification step.

To maximize the reliability and flexibility of the results, SSC used an established impact methodology for assigning and calculating impacts. The Tools for Reduction and Assessment of

Chemical and other environmental Impacts (TRACI) methodology was used for all calculations of environmental impact. TRACI was developed by the US EPA to assist in impact analysis in Life Cycle Assessments, process design, and pollution prevention.

5.2 Selected Impact Categories

While LCI practice holds to a consistent methodology, the LCIA phase is an evolving science and there is no overall generally accepted methodology for calculating all of the impact categories that might be included in an LCIA. Typically, the LCIA is completed in isolation of the LCI. The LCI involves the collection of a complete mass and energy balance for each unit process under consideration. Once completed, the LCI flows are sifted through various possible LCIA indicator methods and categories to determine possible impacts. Due to the North American focus of this LCA study, the TRACI LCIA methodology was used to characterize the study's LCI flows. Impact categories include:

1. *Ozone depletion* (kg CFC-11 eq) – Certain chemicals, when released into the atmosphere, can cause depletion of the stratospheric ozone layer, which protects the Earth and its inhabitants from ultraviolet radiation. This radiation can have a negative impact on crops, materials, and marine life, as well as contributing to cancer and cataracts. This impact measures the releases of those chemicals.
2. *Global warming* (kg CO_2 eq) – The methodology and science behind the Global Warming Potential calculation can be considered one of the most accepted LCIA categories. Because this study also tracks an overall life cycle carbon balance, the carbon dioxide emissions associated with biomass combustion are included in the Global Warming Potential calculation, but the sequestering of carbon is treated as a negative emission in the calculation as per the IPCC methodology. Carbon dioxide and other greenhouse gasses are emitted at every stage in the manufacturing process. These gasses can trap heat close to the Earth, contributing to global warming.
3. *Smog* (kg O_3 eq) – Under certain climatic conditions, air emissions from industry and transportation can be trapped at ground level where, in the presence of sunlight, they produce photochemical smog, a symptom of photochemical ozone creation potential (POCP). While ozone is not emitted directly, it is a product of interactions of volatile organic compounds (VOCs) and nitrogen oxides (NOx). The Smog indicator is expressed as a mass of equivalent ozone (O_3).
4. *Acidification* (moles H+ eq) – Acidification is a more regional rather than global impact affecting fresh water and forests as well as human health when high concentrations of SO_2 are attained. Acidification is a result of processes that contribute to increased acidity of water and soil systems. The acidification potential of an air emission is calculated on the basis of the number of H+ ions that can be produced and, therefore is expressed as potential H+ equivalents on a mass basis.
5. *Eutrophication* (kg N eq) – Eutrophication is the fertilization of surface waters by nutrients that were previously scarce. When a previously scarce or limiting nutrient is added to a water body, it leads to the proliferation of aquatic photosynthetic plant life. This may lead to the water body becoming hypoxic, eventually causing the death of fish and other aquatic life. This impact is expressed on an equivalent mass of nitrogen (N) basis.

6. *Human Health: Carcinogens & Non-carcinogens* (CTU_h) – This impact assesses the potential health impacts of more than 200 chemicals. These health impacts are general, based on emissions from the various life cycle stages, and do not take into account increased exposure that may take place in manufacturing facilities. These impacts are expressed in terms of Comparative Toxic Units (CTU_h). For human health this represents the estimated increase in morbidity in the total human population per kg of chemical emitted.
7. *Respiratory effects* (kg PM 2.5 eq) – This impact methodology assess the impact of increasing concentrations of particulates on human health. Most industrial and transportation processes create emissions of very small particles which can damage lungs and lead to disease and shortened lifespans. This impact is expressed in terms of PM 2.5 (particulates that are 2.5 microns or less in diameter).
8. *Ecotoxicity* (CTU_e) – Many chemicals, when released into the environment, can cause damage individual species and to the overall health of an ecosystem. Ecotoxicity measures the potential damage to the ecosystem that would result from releasing that chemical into the environment. This impact is measured in terms of Comparative Toxic Units (CTUe) and provides an estimate of the potentially affected fraction of species (PAF) integrated over time and volume per unit mass of chemical emitted.

The TRACI impact assessment methodology is intended to be used to assist companies, federal facilities, and industrial organizations in performing broad-based impact assessments of a product's human health, environmental, and resource depletion impacts. The above categories were chosen based on their perceived societal value in the United States; however, significant uncertainty exists surrounding some impact categories, specifically those related to health impacts such as both carcinogen categories, respiration effects, and ecotoxicity. While the results in every category are presented throughout this report, the Environmental Product Declarations will not publish these categories due to the high uncertainty, as based on the Product Category Rule. TRACI does not apply a weighting factor to impact categories, therefore no weighting factors were added in this study.

While the TRACI methodology supports fossil fuel depletion (on a global scale), it does not readily report primary energy use as an impact category. Primary energy use on a cumulative energy demand basis is tabulated and summarized as an impact category directly from the LCI flow results. Energy use is a key impact indicator over which siding manufacturers are likely to assert a considerable level of control and, therefore, is a good internal target for resource conservation. Cumulative energy demand is the sum of all energy sources drawn directly from the earth, such as natural gas, oil, coal, biomass, or hydropower energy. The total primary energy contains further categories, namely non-renewable and renewable energy, and feedstock energy.

5.3 Manufacturing Process Allocation and Assumptions

Life cycle analysis requires that assumptions are made to constrain the project boundary or model processes when little to no data is available. In this industry average study of siding, the following assumptions were made:

- Off-spec and other trimmed materials are recycled back into the extrusion process, unless otherwise noted.

- There are no tracked or monitored emissions produced by any participating facility that are mandated to be reported to the US TRI or Canadian NPRI.
- Manufacturing process allocation was conducted based on production quantities measured by mass produced during the 2015 calendar year.
- A weighted average from the data provided by each participating member company was calculated based on each facility's ratio to the total vinyl siding produced (or polypropylene siding, respectively) by all participating facilities over the reference year. The weighted average vinyl siding was used as an input for the insulated vinyl siding product, utilizing data provided since Progressive Foams is the only contracted company to laminate the insulation onto the vinyl shell.
- Although all use phase stages are considered within the system boundary of this study, the only use phase inputs associated with siding of all varieties is periodic cleaning with soap and water.
- When a material is not available in the available LCI databases, another chemical which has similar manufacturing and environmental impacts may be used as a proxy, representing the actual chemical. The Proxy Chemical List used in this analysis includes:
    - Calcium stearate was modeled as 91% quicklime and 9% fatty acids; process energy excluded (not found)
    - Impact modifier (chlorinated polyethylene) was modeled as 61% high density PE resin, and 39% chlorine; process energy excluded (not found)
    - Pigments were modeled as 50% chromium, 25% antimony, and 25% titanium dioxide; process energy excluded (not found)
    - Tin stabilizer was modeled as 9.5% tin, 11.3% chlorine, 7.7% magnesium, 68.5% fatty acids, 1.3% hydrogen sulfide, and 1.7% ethylene oxide; process energy excluded (not found)
    - Process aid was modeled as 50% methyl methacrylate, 50% methyl acrylate; process energy excluded (not found)

5.4 Initial Service and End-of-Life Assumptions

The study assumes the service life is 50 years and the end-of-life disposition is modeled as 80% to landfill and 20% to incineration, as cited above in section 2.3.1. The selected service life used in the project reflects the expert opinions of the product manufacturers. Disposal in a municipal landfill or in commercial incineration facilities is permissible and should be done in accordance with local, state, and federal regulations.

Additionally, this study assumes a scrap rate of 5% during the siding installation, based on input from VSI member companies.

6.0 Vinyl Siding LCA Results

This section presents the results of the LCA study. It includes quantified impacts for each of the TRACI impact categories.

6.1 Overall Environmental Impact

6.1.1 Overall Environmental Impact Analysis

The graphs in this section are designed to communicate the overall environmental impacts of vinyl siding. This is done using the TRACI methodology as described in Section 5.2 above. While the results in every category are presented throughout this report, the Environmental Product Declaration will omit the results in health categories due to the high uncertainty of those impacts, per the Product Category Rule.

The tables and figures below demonstrate the overall environmental impact (using the TRACI methodology) of manufacturing 100 square feet of vinyl siding. Figure 6.1 illustrates the relative impact contribution from each of the eight life cycle stages (raw materials, raw material transportation, siding manufacturing, final product distribution, installation, use phase (cleaning), end of life transportation, and waste treatment) to each of the environmental impacts.

Table 6.1 – Vinyl Siding TRACI Impacts by Life Cycle Stage

Impact Category	Unit	Raw Materials	Raw Materials Transport	Siding Manufacturing	Final Product Distribution	Installation	Use Phase (Cleaning)	Replacement	EOL Transport	Waste Treatment	Total
Global Warming	kg CO_2 eq	4.5E+01	4.8E-01	4.5E+00	9.6E-01	1.7E+00	4.8E-01	3.1E+01	1.4E-01	8.1E+00	**9.2E+01**
Fossil Fuel Depletion	MJ surplus	1.4E+02	8.5E-01	5.2E+00	1.7E+00	1.3E+00	3.6E-01	7.5E+01	2.6E-01	1.6E+00	**2.3E+02**
Eutrophication	kg N eq	4.3E-02	3.8E-04	4.4E-03	3.2E-04	5.8E-03	2.1E-03	3.0E-02	4.8E-05	3.7E-03	**9.0E-02**
Smog	kg O_3 eq	1.8E+00	1.0E-01	2.8E-01	1.6E-01	9.8E-02	2.9E-02	1.3E+00	2.3E-02	9.4E-02	**3.8E+00**
Acidification	kg SO_2 eq	1.9E-01	3.6E-03	3.4E-02	5.7E-03	9.5E-03	2.5E-03	1.3E-01	8.5E-04	6.6E-03	**3.8E-01**
Ozone Depletion	kg CFC_{11} eq	2.7E-06	2.3E-08	1.2E-07	3.6E-11	1.2E-07	2.9E-08	1.6E-06	5.5E-12	3.2E-07	**4.9E-06**
Carcinogenics	CTU_H	2.7E-06	2.0E-08	6.4E-08	1.3E-08	7.8E-07	2.0E-08	1.9E-06	2.0E-09	2.2E-07	**5.8E-06**
Non-carcinogenics	CTU_H	7.3E-06	6.4E-08	6.1E-07	1.3E-07	8.1E-07	9.9E-08	5.0E-06	1.9E-08	9.2E-07	**1.5E-05**
Respiratory Effects	kg $PM_{2.5}$ eq	1.7E-02	1.4E-04	2.1E-03	9.9E-05	4.0E-03	7.9E-04	1.3E-02	1.5E-05	1.1E-03	**3.8E-02**
Ecotoxicity	CTUe	2.0E+02	1.3E+00	1.1E+01	2.4E+00	3.1E+01	2.2E+00	1.7E+02	3.7E-01	8.6E+01	**5.0E+02**
CED	MJ	1.0E+03	6.7E+00	8.4E+01	1.3E+01	2.5E+01	1.6E+01	5.9E+02	2.0E+00	1.7E+01	**1.8E+03**

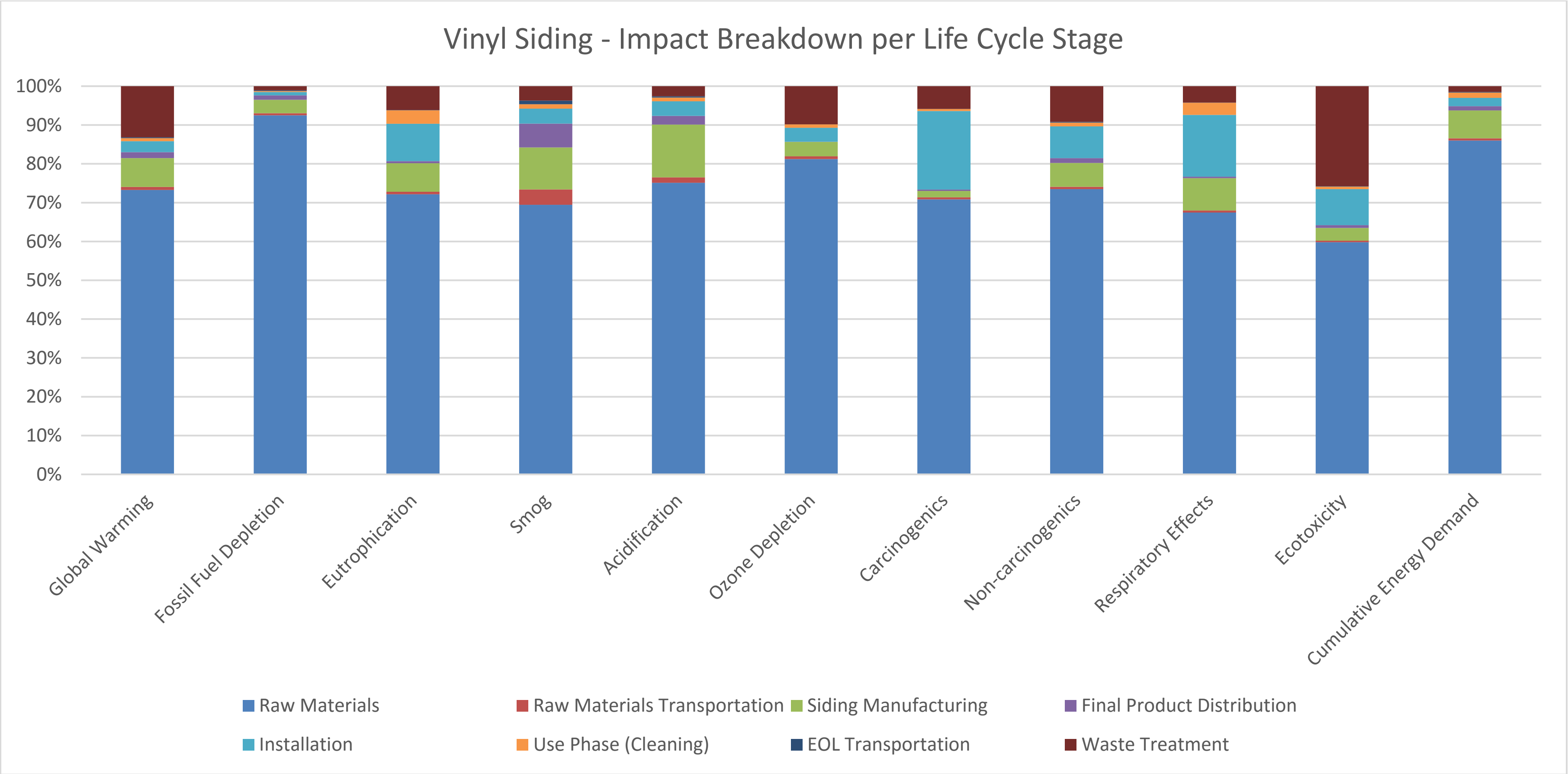


Figure 6.1 – Vinyl Siding TRACI Impacts by Life Cycle Stage

Figure 6.1 shows that for vinyl siding, shows that for vinyl siding, the replacement stage is roughly one third of the impacts of the life cycle. This is due to the declared unit lifetime being 75 years and the product declared lifetime being 50 years, requiring a replacement factor of 0.5 of the life cycle impacts. Outside of the replacement stage, raw materials contribute a majority of the impact in every category. The raw material phase contributes significantly to the overall impacts because vinyl siding is produced through an efficient extrusion process, and because there are virtually non-existent use phase inputs for this product. The following sections will more closely examine the impact breakdown within the manufacturing and raw material phases.

6.1.2 EPD Data

Along with the TRACI impact data shown above in Section 6.1.1, the publication of an EPD requires the inclusion of additional data describing the life cycle of vinyl siding. These additional data include:

- CML impact assessment methodology (an environmental impact assessment methodology similar to the TRACI 2.1 methodology but developed by the Institute of Environmental Sciences at the University of Leiden, and used often in European LCAs.
- Resource use data, as defined by EN15804.
- Output flows and waste data, as defined by EN 15804.

These data are presented below in Tables 6.2 through Tables 6.4.

Table 6.2 – Vinyl Siding System Boundary

Product			Construction Installation		Use							End-of-Life				Benefits of Loads Beyond the System Boundary		
Raw Material Extraction and Processing	Transport	Manufacturing	Transport	Construction/ Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Operational Energy Use	Operational Water Use	De-Construction/ Demolition	Transport	Waste Processing	Disposal	Reuse	Recovery	Recycling
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	D	D
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	MND	MND	MND

Table 6.3 – Vinyl Siding CML Impacts by Life Cycle Stage

CML	A1	A2	A3	A4	A5	B2	B4	C1	C2	C3	C4	Units
Global warming potential	4.5E+01	4.8E-01	4.5E+00	9.6E-01	1.7E+00	4.8E-01	3.1E+01	0.0E+00	1.4E-01	0.0E+00	8.1E+00	kg CO_2 Eq.
Depletion potential of stratospheric ozone layer	2.5E-06	1.7E-08	9.7E-08	3.6E-11	9.3E-08	2.2E-08	1.5E-06	0.0E+00	5.4E-12	0.0E+00	2.8E-07	kg CFC_{-11} Eq.
Acidification potential	1.9E-01	3.6E-03	3.4E-02	5.7E-03	9.5E-03	2.5E-03	1.3E-01	0.0E+00	8.5E-04	0.0E+00	6.6E-03	kg SO_2 Eq.
Eutrophication potential	2.6E-02	6.0E-04	3.1E-03	8.3E-04	2.8E-03	1.1E-03	1.8E-02	0.0E+00	1.2E-04	0.0E+00	1.9E-03	kg $(PO4)_{3-}$ Eq.
Photochemical ozone creation potential	1.2E-02	1.1E-04	1.6E-03	2.2E-04	6.1E-04	7.6E-04	8.0E-03	0.0E+00	3.3E-05	0.0E+00	3.6E-04	kg ethane Eq.

The CML results reflect the TRACI impact assessment results in Section 6.1.1 above. The environmental impacts associated with vinyl siding are driven by the raw materials life cycle stage, with manufacturing being the second largest contributor. Global warming potential and ozone depletion results are within the same magnitude in results between the two methodologies, although a few elemental flows to nature could differ between the categories.

Table 6.4 – Vinyl Siding Resource Use by Life Cycle Stage

Resource Use	A1	A2	A3	A4	A5	B2	B4	C1	C2	C3	C4	Units
Use of RENEWABLE primary energy excluding the RENEWABLE primary energy used as raw materials	7.0E+02	6.7E+00	6.8E+01	1.3E+01	2.1E+01	5.4E+00	4.2E+02	0.0E+00	2.0E+00	0.0E+00	1.6E+01	MJ (LHV)
Use of RENEWABLE primary energy resources used as raw materials	2.9E+02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.4E+02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	MJ
Use of NON-RENEWABLE primary energy excluding the NON-RENEWABLE primary energy resources used as raw materials	9.9E+02	6.7E+00	6.8E+01	1.3E+01	2.1E+01	5.4E+00	5.6E+02	0.0E+00	2.0E+00	0.0E+00	1.6E+01	MJ
Use of NON-RENEWABLE primary energy excluding the NON-RENEWABLE primary energy resources used as raw materials	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	MJ
Use of NON-RENEWABLE primary energy as raw materials	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	MJ
Total use of NON-RENEWABLE primary energy	2.1E+01	2.4E-02	1.6E+01	0.0E+00	3.3E+00	1.1E+01	2.6E+01	0.0E+00	0.0E+00	0.0E+00	1.2E+00	MJ
Use of secondary materials	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	kg
Renewable secondary fuels	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	MJ
Use of NON-RENEWABLE secondary fuels	2.0E-01	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.9E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	MJ
Use of fresh water resources	7.4E+00	1.6E-01	1.8E+00	0.0E+00	1.7E+00	6.6E-01	6.0E+00	0.0E+00	0.0E+00	0.0E+00	2.2E-01	m^3

These resource use data show the flow of energy and materials across the life cycle stages of the product. Important to note is that a significant portion of the renewable energy is embodied in the raw materials, reinforcing the fact that environmental impacts are driven by the raw materials life cycle stage.

Table 6.5 – Vinyl Siding Output Flows and Waste by Life Cycle Stage

Output Flows and Waste	A1	A2	A3	A4	A5	B2	B4	C1	C2	C3	C4	Total	Units
Disposed-of-hazardous WASTE	6.1E-02	3.2E-06	1.0E-02	0.0E+00	4.7E-05	9.2E-06	3.5E-02	0.0E+00	0.0E+00	0.0E+00	4.3E-05	1.1E-01	kg
Disposed-of non-hazardous WASTE	8.0E-01	1.6E-02	6.6E-01	0.0E+00	3.7E+00	6.1E-02	1.1E+01	0.0E+00	0.0E+00	0.0E+00	1.7E+01	3.3E+01	kg
Disposed-of Radioactive WASTE	1.2E-04	8.7E-07	1.6E-05	0.0E+00	3.9E-05	4.9E-06	1.3E-04	0.0E+00	0.0E+00	0.0E+00	8.3E-05	4.0E-04	kg
Components for reuse	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	kg
Materials for recycling	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	kg
Materials for energy recovery	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	kg
Exported electrical energy (waste to energy)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	MJ
Exported thermal energy (waste to energy)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	MJ

These data show the flows of wastes and outputs from the system across the life cycle stages. The waste processing stage is where the majority of non-hazardous waste is disposed of, whereas the majority of hazardous waste is generated during the upstream processing of raw materials.

6.2 Manufacturing Impacts

6.2.1 Manufacturing Impact Analysis

Energy is required to extract, process, and ship raw materials to the plant, manufacture the vinyl siding, and ship the final product to the customer.

Table 6.3 and Figure 6.3 below list the TRACI life cycle impacts for the manufacturing of vinyl siding, and how those impacts are distributed across the ten manufacturing inputs (electricity, natural gas, propane, water, gasoline, packaging materials, water treatment, transportation, wastewater treatment, and waste disposal.

Table 6.6 – Vinyl Siding TRACI Impacts by Manufacturing Input per 100 Square Feet

Impact Category	Unit	Electricity	Natural Gas	Propane	Water	Gasoline	Packaging Materials	Water Treatment	Transportation	Wastewater Treatment	Waste Disposal	Total
Ozone Depletion	kg CFC_{-11} eq	4.8E-11	1.1E-13	3.9E-12	3.6E-10	1.7E-12	1.2E-07	4.3E-10	9.0E-14	4.2E-10	1.6E-09	**1.2E-07**
Global Warming	kg CO_2 eq	2.9E+00	1.5E-01	9.8E-02	7.3E-03	7.9E-05	1.3E+00	3.4E-03	2.4E-03	4.2E-03	7.1E-03	**4.5E+00**
Smog	kg O_3 eq	1.6E-01	3.3E-03	5.2E-03	3.8E-04	2.8E-05	1.0E-01	2.1E-04	3.8E-04	4.0E-04	8.7E-04	**2.8E-01**
Acidification	kg SO_2 eq	2.5E-02	1.3E-03	2.7E-04	4.6E-05	9.0E-07	7.8E-03	2.9E-05	1.4E-05	3.6E-05	3.3E-05	**3.5E-02**
Eutrophication	kg N eq	3.4E-04	1.3E-05	1.4E-05	2.5E-05	6.1E-08	3.7E-03	1.4E-05	7.8E-07	3.3E-04	1.0E-05	**4.4E-03**
Carcinogenics	CTU_h	6.8E-09	6.4E-10	1.4E-09	8.3E-10	1.4E-12	5.2E-08	2.2E-10	3.2E-11	1.8E-09	2.0E-10	**6.4E-08**
Non-carcinogenics	CTU_h	1.1E-07	8.0E-09	1.3E-08	2.3E-09	1.4E-11	4.5E-07	1.8E-09	3.1E-10	2.3E-08	5.2E-10	**6.1E-07**
Respiratory Effects	kg $PM_{2.5}$ eq	1.3E-03	7.7E-05	5.8E-06	3.5E-06	1.5E-08	7.5E-04	2.4E-06	2.4E-07	3.4E-06	3.4E-06	**2.1E-03**
Ecotoxicity	CTU_E	1.7E+00	2.0E-01	2.6E-01	5.1E-02	3.5E-04	8.6E+00	5.1E-02	6.0E-03	1.0E-01	1.1E-02	**1.1E+01**
Fossil Fuel Depletion	MJ surplus	2.8E+00	4.0E-01	2.0E-01	4.8E-03	1.8E-04	2.4E+00	4.5E-03	4.5E-03	3.5E-03	1.5E-02	**5.8E+00**

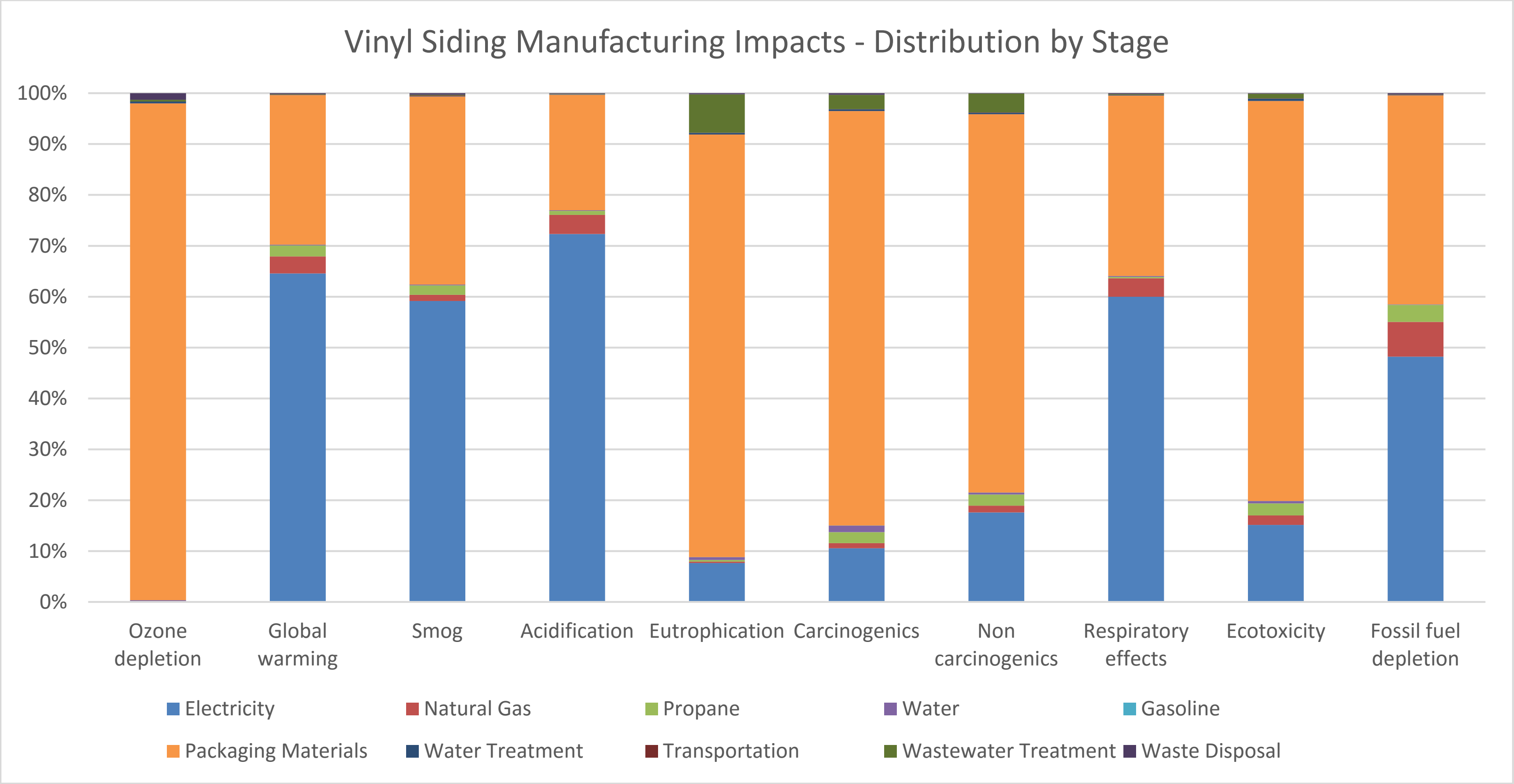


Figure 6.2 – Vinyl Siding TRACI Impacts by Manufacturing Input

As shown in the table and figure above, the manufacturing impacts are primarily driven by two main inputs: electricity and packaging materials. Electricity consumption is the primary contributor to the global warming, smog, acidification, and respiratory effects categories, while packaging inputs drive the results in the ozone depletion, eutrophication, carcinogenics, non-carcinogenics, and ecotoxicity categories. The impacts associated with electricity consumption are driven largely by the burning of coal, while the impacts associated with packaging are driven by the upstream production of cardboard and wood pallets, which are the primary two materials used in the packaging of vinyl siding.

6.3 Raw Material Impacts

In addition to the impacts associated with the manufacturing stage of the product life cycle, examining the raw materials is important to understanding the life cycle of the products, especially since raw materials are by far the most impactful segment of the vinyl siding life cycle. This process includes quantifying all the material inputs including scrap rates. Each raw material has an associated environmental impact. Table 6.4 shows the industry average formulation data of vinyl siding, both with an ASA and PVC capstock. The vinyl siding product is modeled as a 50/50 blend of PVC and ASA capstock versions.

Table 6.7 – Vinyl Siding Formulation

Constituent	% in Siding with PVC Capstock	% in Siding with ASA Capstock
PVC	80.4%	69%
ASA	--	12%
Calcium Carbonate	11.1%	10%
Impact Modifier	1.9%	1.1%
Titanium Dioxide	1.4%	0.9%
Tin Stabilizer	0.6%	0.7%
Process Aid	0.5%	0.0%
Lubricant	1.7%	1.7%
Chlorinated Polyethylene	0.7%	2.4%
Sealant	0.8%	0%
Calcium Stearate	0.6%	0.0%
Pigments	.1%	0.2%

6.3.1 Raw Material Impact Analysis

To investigate these raw material impacts further, Table 6.8 and Figure 6.4 illustrate the environmental impact of each of the major raw materials used in the production of the vinyl siding product, in the proportions found in the industry average vinyl siding product with PVC capstock. Table 6.9 and Figure 6.5 show the same analysis for the ASA capstock variety. In order to illustrate these impacts, the TRACI impact methodology was used to assess the impacts of the raw materials in the proportions according to the industry average recipe for both varieties.

Table 6.8 – PVC Capstock Vinyl Siding TRACI Impacts by Raw Material

Impact Category	Unit	PVC Resin	Tin Stabilizer	Titanium Dioxide	Impact Modifier (Chlorinated Polyethylene)	Process Aid	Calcium Stearate	Paraffin Wax	Calcium Carbonate	Pigments	Total
Global Warming	kg CO_2 eq	3.3E+01	6.8E-01	1.9E+00	7.0E-01	1.0E+00	2.7E-01	2.7E-01	9.8E-03	2.2E+00	**4.0E+01**
Fossil Fuel Depletion	MJ surplus	1.1E+02	7.5E-01	3.6E+00	3.1E+00	2.6E+00	1.2E-01	2.4E+00	1.1E-02	1.9E+00	**1.2E+02**
Eutrophication	kg N eq	2.3E-03	2.6E-03	7.4E-03	1.1E-04	9.2E-04	1.2E-03	5.0E-04	1.3E-06	4.0E-02	**5.5E-02**
Smog	kg O_3 eq	1.1E+00	6.4E-02	1.3E-01	2.5E-02	4.4E-02	1.5E-02	2.1E-02	6.2E-04	1.5E-01	**1.6E+00**
Acidification	kg SO_2 eq	1.1E-01	7.7E-03	1.4E-02	4.5E-03	4.1E-03	1.3E-03	1.9E-03	6.7E-05	1.4E-02	**1.6E-01**
Ozone Depletion	kg CFC_{-11} eq	1.8E-06	5.6E-08	3.7E-07	3.6E-08	2.3E-08	1.0E-08	9.4E-09	6.1E-12	1.5E-07	**2.5E-06**
Carcinogenics	CTU_h	6.2E-08	4.1E-08	8.3E-08	3.9E-09	2.8E-08	7.3E-09	9.4E-09	6.4E-11	3.5E-06	**3.8E-06**
Non-carcinogenics	CTU_h	7.7E-07	1.1E-07	4.2E-07	4.9E-08	6.1E-08	3.2E-08	6.4E-08	7.9E-10	8.0E-06	**9.5E-06**
Respiratory Effects	kg $PM_{2.5}$ eq	6.8E-03	1.8E-03	1.3E-03	2.6E-04	2.8E-04	2.9E-04	1.9E-04	3.0E-06	5.3E-03	**1.6E-02**
Ecotoxicity	CTU_e	8.5E+00	3.1E+00	1.2E+01	1.2E+00	1.9E+00	8.3E-01	2.1E+00	1.2E-02	2.3E+02	**2.6E+02**
Cumulative Energy Demand	MJ	7.1E+02	1.4E+01	3.6E+01	2.3E+01	2.2E+01	6.3E+00	1.8E+01	1.4E-01	3.5E+01	**8.7E+02**

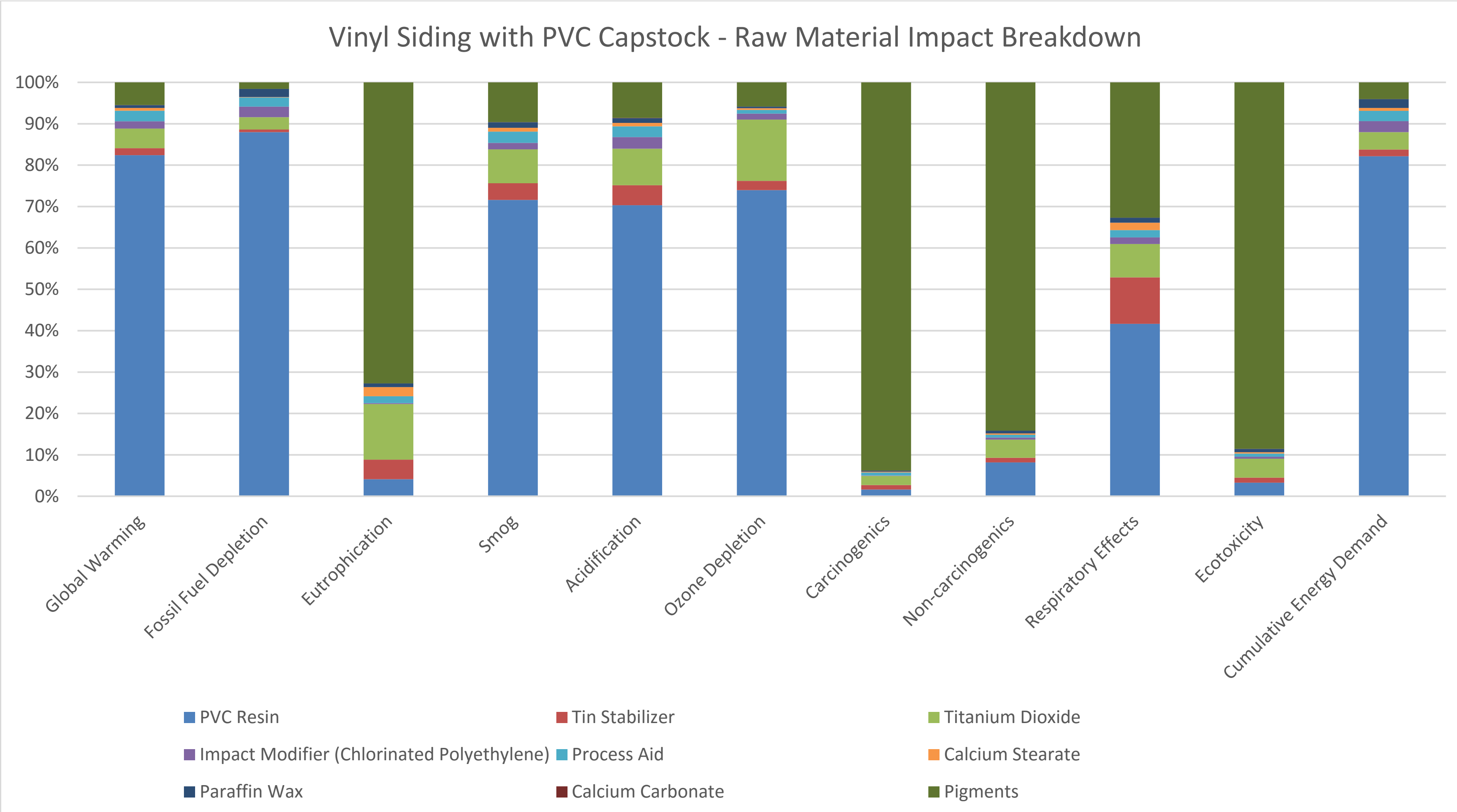


Figure 6.3 – PVC Capstock Vinyl Siding TRACI Impacts by Raw Material

For the PVC capstock formulation, the PVC resin contributes the majority of the raw material impacts in most impact categories. This is consistent with the fact that PVC is the primary component of the vinyl siding products. The eutrophication, carcinogens, non-carcinogens, and ecotoxicity categories do not follow this trend; instead, pigments have the largest contribution to the impacts for these categories.

Table 6.9 – ASA Capstock Vinyl Siding TRACI Impacts by Raw Material

Impact Category	Unit	PVC Resin	Tin Stabilizer	Titanium Dioxide	Impact Modifier (Chlorinated Polyethylene)	Paraffin Wax	Calcium Carbonate	Pigments	Acyrlic Impact Modifier	Lubricant	ASA	Total
Global Warming	kg CO_2 eq	3.3E+01	1.2E+00	7.2E-01	8.3E-01	2.6E-01	1.3E-02	4.7E-01	1.7E-01	1.2E-01	9.5E+00	**4.6E+01**
Fossil Fuel Depletion	MJ surplus	1.1E+02	1.3E+00	1.4E+00	3.6E+00	2.3E+00	1.4E-02	4.1E-01	4.6E-01	3.0E-01	3.2E+01	**1.5E+02**
Eutrophication	kg N eq	2.3E-03	4.6E-03	2.8E-03	1.3E-04	4.8E-04	1.7E-06	8.7E-03	4.4E-04	5.3E-04	5.5E-03	**2.5E-02**
Smog	kg O_3 eq	1.1E+00	1.1E-01	4.9E-02	3.0E-02	2.1E-02	8.0E-04	3.3E-02	9.0E-03	7.7E-03	4.0E-01	**1.8E+00**
Acidification	kg SO_2 eq	1.1E-01	1.4E-02	5.3E-03	5.3E-03	1.8E-03	8.5E-05	3.0E-03	8.6E-04	8.1E-04	6.5E-02	**2.1E-01**
Ozone Depletion	kg CFC_{-11} eq	1.9E-06	1.0E-07	1.4E-07	4.2E-08	9.1E-09	7.8E-12	3.2E-08	2.1E-08	7.8E-09	4.0E-07	**2.6E-06**
Carcinogenics	CTU_h	6.2E-08	7.2E-08	3.2E-08	4.6E-09	9.2E-09	8.2E-11	7.7E-07	1.3E-08	3.9E-09	2.9E-07	**1.2E-06**
Non-carcinogenics	CTU_h	7.8E-07	1.9E-07	1.6E-07	5.9E-08	6.2E-08	1.0E-09	1.7E-06	3.6E-08	1.8E-08	1.1E-06	**4.1E-06**
Respiratory Effects	kg $PM_{2.5}$ eq	6.8E-03	3.2E-03	5.0E-04	3.1E-04	1.9E-04	3.8E-06	1.2E-03	7.2E-05	1.4E-04	3.9E-03	**1.6E-02**
Ecotoxicity	CTU_e	8.5E+00	5.5E+00	4.5E+00	1.5E+00	2.1E+00	1.6E-02	4.9E+01	9.2E-01	5.1E-01	4.0E+01	**1.1E+02**
Cumulative Energy Demand	MJ	7.2E+02	2.5E+01	1.4E+01	2.7E+01	1.8E+01	1.8E-01	7.6E+00	4.3E+00	4.4E+00	2.6E+02	**1.1E+03**

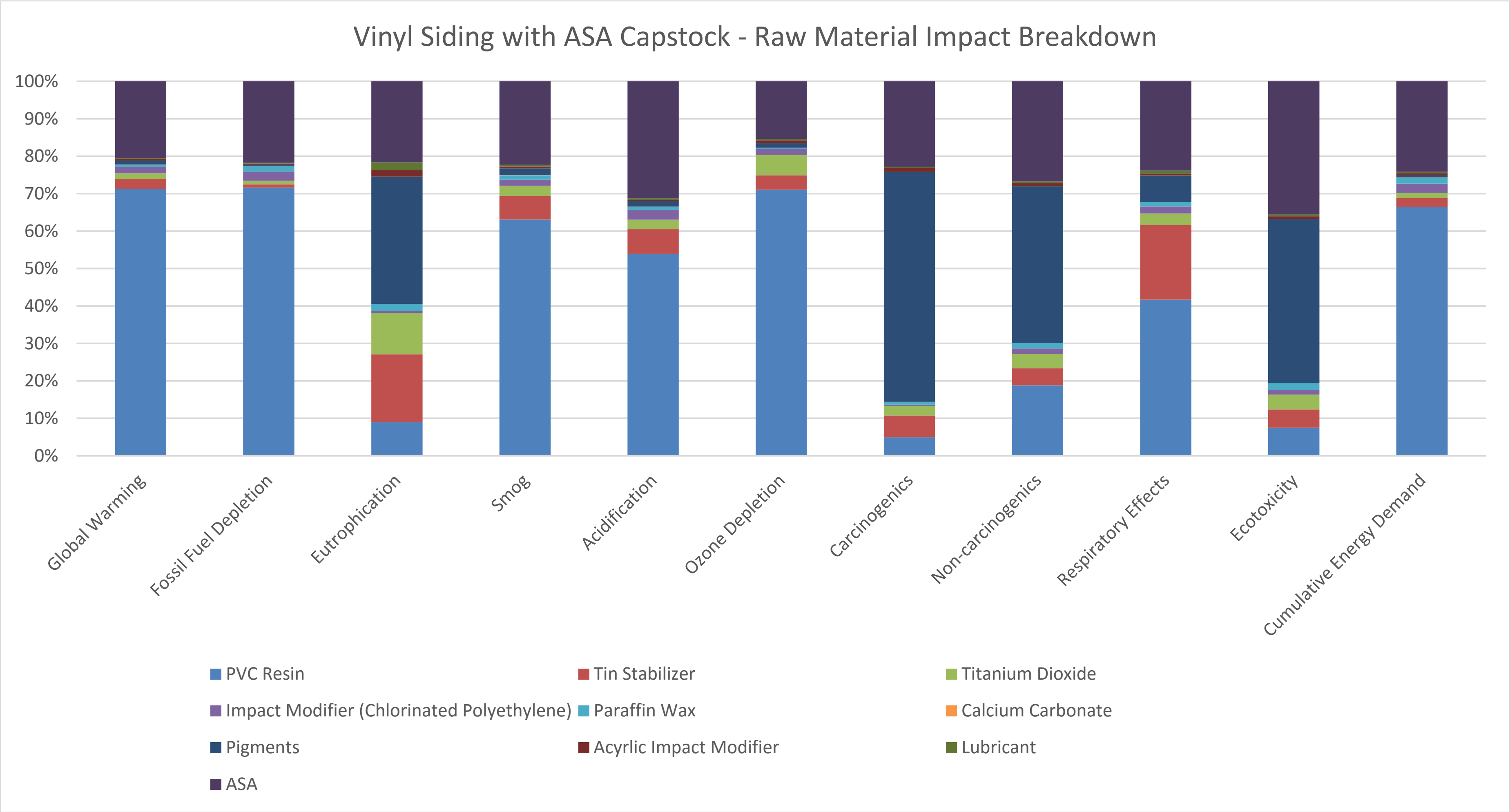


Figure 6.4 – ASA Capstock Vinyl Siding TRACI Impacts by Raw Material

The ASA capstock formulation follows a similar trend to the PVC capstock formulation. The PVC and ASA resins drive the impacts in most impact categories, with the PVC resin contributing more heavily since it is still the primary component in this material. The percent contribution of ASA resin mirrors the percent composition in the product recipe. The eutrophication, carcinogens, non-carcinogens, and ecotoxicity categories are the only impact categories which are most heavily influenced by the pigments, as opposed to the plastic resins.

7.0 Insulated Vinyl Siding LCA Results

This section presents the results of the LCA study for insulated vinyl siding. It includes quantified impacts for each of the TRACI impact categories of 100 square feet of insulated vinyl siding with a 0.040” D4.5” profile.

7.1 Overall Environmental Impact

7.1.1 Overall Environmental Impact Analysis

The graphs in this section are designed to communicate the overall environmental impacts of insulated vinyl siding. This is done using the TRACI methodology as described in Section 5.2 above. While the results in every category are presented throughout this report, the Environmental Product Declaration will omit the results in health categories due to the high uncertainty of those impacts, per the Product Category Rule.

The tables and figures below demonstrate the overall environmental impact (using the TRACI methodology) of manufacturing 100 square feet of insulated vinyl siding. The figure illustrates the relative impact contribution from each of the eight life cycle stages (raw materials, raw material transportation, siding manufacturing, final product distribution, installation, use phase (cleaning), end of life transportation, and waste treatment) to each of the environmental impacts.

Table 7.1 – Insulated Vinyl Siding TRACI Impacts by Life Cycle Stage per 100 Square Feet

Impact Category	Unit	Raw Materials	Raw Materials Transportation	Siding Manufacturing	Final Product Distribution	Installation	Use Phase (Cleaning)	Replacement	EOL Transportation	Waste Treatment	Total
Global Warming	kg CO_2 eq	5.7E+01	8.8E-01	4.6E+00	1.1E+00	1.7E+00	4.8E-01	3.7E+01	1.7E-01	8.1E+00	**1.1E+02**
Fossil Fuel Depletion	MJ surplus	1.8E+02	1.6E+00	5.2E+00	2.0E+00	1.3E+00	3.6E-01	9.7E+01	3.0E-01	1.6E+00	**2.9E+02**
Eutrophication	kg N eq	4.9E-02	6.3E-04	4.4E-03	3.7E-04	8.3E-03	2.1E-03	3.4E-02	5.5E-05	3.7E-03	**1.0E-01**
Smog	kg O_3 eq	2.6E+00	2.3E-01	2.8E-01	1.8E-01	1.0E-01	2.9E-02	1.8E+00	2.7E-02	9.4E-02	**5.3E+00**
Acidification	kg SO_2 eq	3.1E-01	8.1E-03	3.5E-02	6.6E-03	1.0E-02	2.5E-03	1.9E-01	9.9E-04	6.6E-03	**5.7E-01**
Ozone Depletion	kg CFC_{-11} eq	3.4E-06	2.4E-08	1.2E-07	4.2E-11	1.2E-07	2.9E-08	2.0E-06	6.3E-12	3.2E-07	**6.0E-06**
Carcinogenics	CTU_h	3.0E-06	2.5E-08	6.5E-08	1.5E-08	7.9E-07	2.0E-08	2.1E-06	2.3E-09	2.2E-07	**6.3E-06**
Non-carcinogenics	CTU_h	9.8E-06	1.2E-07	6.2E-07	1.5E-07	1.5E-06	9.9E-08	6.6E-06	2.2E-08	9.2E-07	**2.0E-05**
Respiratory Effects	kg $PM_{2.5}$ eq	2.4E-02	2.1E-04	2.1E-03	1.2E-04	4.1E-03	7.9E-04	1.6E-02	1.7E-05	1.1E-03	**4.9E-02**
Ecotoxicity	CTU_e	2.7E+02	2.3E+00	1.1E+01	2.8E+00	4.5E+01	2.2E+00	2.1E+02	4.2E-01	8.6E+01	**6.3E+02**
Cumulative Energy Demand	MJ	1.4E+03	1.2E+01	8.5E+01	1.5E+01	2.5E+01	1.6E+01	7.7E+02	2.3E+00	1.7E+01	**2.3E+03**

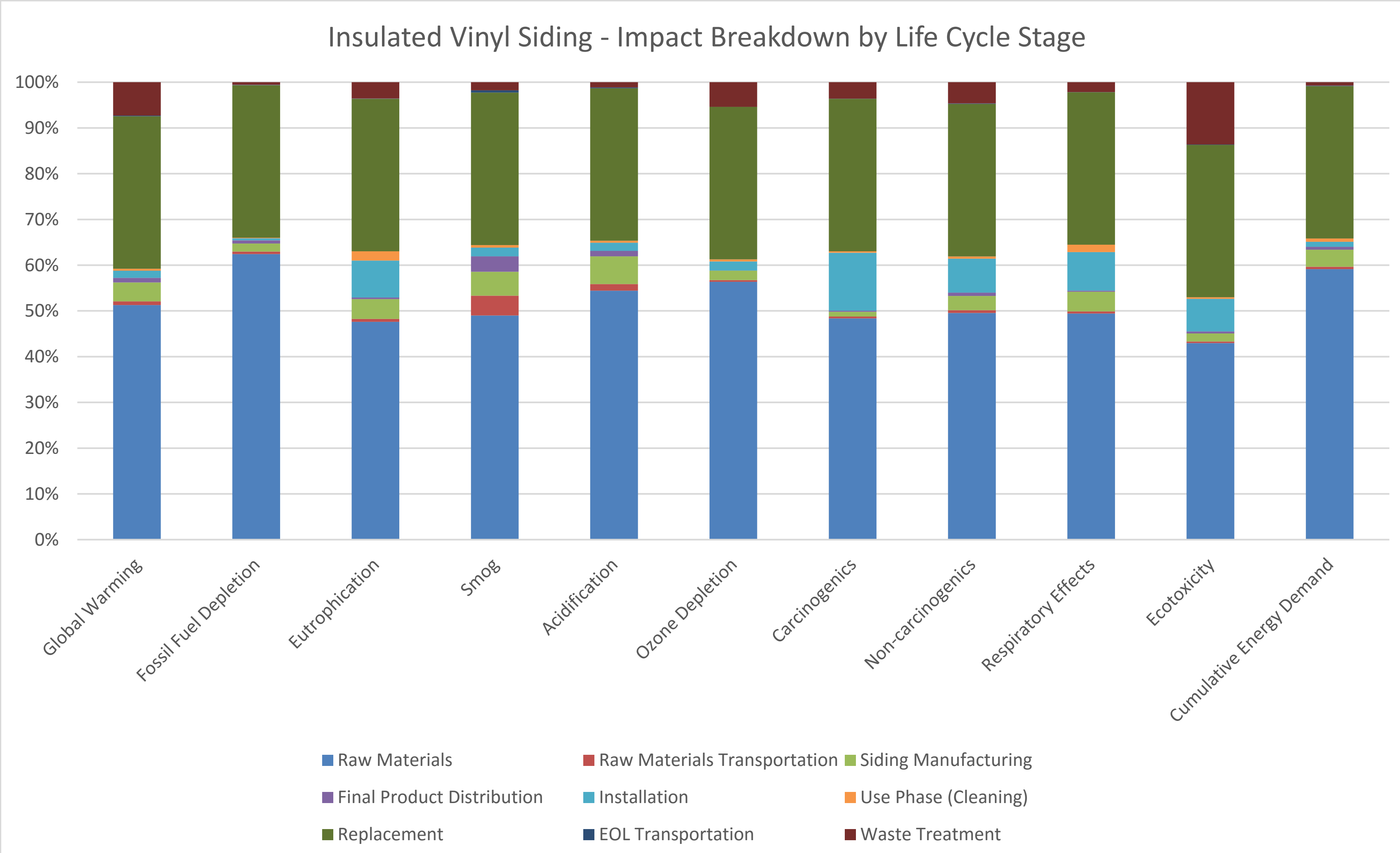


Figure 7.1 – Insulated Vinyl Siding TRACI Impacts by Life Cycle Stage

Figure 7.1 shows that for insulated vinyl siding, the replacement stage is roughly one third of the impacts of the life cycle. This is due to the declared unit lifetime being 75 years and the product declared lifetime being 50 years, requiring a replacement factor of 0.5 of the life cycle impacts. Outside of the replacement stage, raw materials contribute a majority of the impact in every category. The raw material phase contributes significantly to the overall impacts because siding is produced through an efficient extrusion process, and because there are minimal use phase inputs for this product. The production of the insulating EPS foam layer at Progressive Foam Technologies is also included in the raw material phase, further contributing to the large relative impacts of this life cycle stage. The following sections, Section 7.2 and Section 7.3, will more closely examine the impact breakdown within the Manufacturing and Raw Material phases, respectively.

7.1.2 EPD Data

Along with the TRACI impact data shown above, the publication of an EPD requires the inclusion of additional data describing insulated vinyl siding's life cycle. These additional data include:

- CML impact assessment methodology (an environmental impact assessment methodology similar to the TRACI 2.1 methodology but developed by the Institute of Environmental Sciences at the University of Leiden, and used often in European LCAs.
- Resource use data, as defined by EN15804.
- Output flows and waste data, as defined by EN 15804.

These data are presented below, in Table 7.2 through Table 7.4:

Table 7.2 – Insulated Vinyl Siding System Boundary

Product			Construction Installation		Use							End-of-Life				Benefits of Loads Beyond the System Boundary		
Raw Material Extraction and Processing	Transport	Manufacturing	Transport	Construction/ Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Operational Energy Use	Operational Water Use	De-Construction/ Demolition	Transport	Waste Processing	Disposal	Reuse	Recovery	Recycling
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	D	D
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	MND	MND	MND

Table 7.3 – Insulated Vinyl Siding CML Impacts by Life Cycle Stage

CML	A1	A2	A3	A4	A5	B2	B4	C1	C2	C3	C4	Total	Units
Global warming potential	5.7E+01	8.8E-01	4.6E+00	1.1E+00	1.7E+00	4.8E-01	3.7E+01	0.0E+00	1.7E-01	0.0E+00	8.1E+00	1.1E+02	kg CO_2 Eq.
Depletion potential of stratospheric ozone layer	3.1E-06	1.8E-08	9.8E-08	4.2E-11	9.2E-08	2.2E-08	1.8E-06	0.0E+00	6.3E-12	0.0E+00	2.8E-07	5.4E-06	kg CFC_{-11} Eq.
Acidification potential	3.4E-01	6.6E-03	3.7E-02	5.5E-03	1.1E-02	2.3E-03	2.0E-01	0.0E+00	8.2E-04	0.0E+00	5.4E-03	6.1E-01	kg SO_2 Eq.
Eutrophication potential	3.1E-02	1.3E-03	3.2E-03	9.7E-04	3.9E-03	1.1E-03	2.2E-02	0.0E+00	1.4E-04	0.0E+00	1.9E-03	6.6E-02	kg $(PO4)_3$- Eq.
Photochemical ozone creation potential	5.7E-02	2.2E-04	1.6E-03	2.5E-04	6.4E-04	7.6E-04	3.0E-02	0.0E+00	3.8E-05	0.0E+00	3.6E-04	9.1E-02	kg ethane Eq.

These results reflect the TRACI impact results in Section 7.1.1 above. The environmental impacts associated with insulated vinyl siding are driven by the raw materials life cycle stage, with manufacturing being the second largest contributor. Global warming potential and ozone depletion results are within the same magnitude in results between the two methodologies, although a few elemental flows to nature could differ between the categories.

Table 7.4 – Insulated Vinyl Siding Resource Use by Life Cycle Stage

Resource Use	A1	A2	A3	A4	A5	B2	B4	C1	C2	C3	C4	Total	Units
Use of RENEWABLE primary energy excluding the RENEWABLE primary energy used as raw materials	1.0E+03	1.2E+01	6.9E+01	1.5E+01	2.1E+01	5.4E+00	5.9E+02	0.0E+00	2.3E+00	0.0E+00	1.6E+01	1.8E+03	MJ (LHV)
Use of RENEWABLE primary energy resources used as raw materials	2.9E+02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.5E+02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.4E+02	MJ
Use of NON-RENEWABLE primary energy excluding the NON-RENEWABLE primary energy resources used as raw materials	1.3E+03	1.2E+01	6.9E+01	1.5E+01	2.1E+01	5.4E+00	7.4E+02	0.0E+00	2.3E+00	0.0E+00	1.6E+01	2.2E+03	MJ
Use of NON-RENEWABLE primary energy excluding the NON-RENEWABLE primary energy resources used as raw materials	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	MJ
Use of NON-RENEWABLE primary energy as raw materials	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	MJ
Total use of NON-RENEWABLE primary energy	2.2E+01	2.5E-02	1.6E+01	0.0E+00	3.4E+00	1.1E+01	2.7E+01	0.0E+00	0.0E+00	0.0E+00	1.2E+00	8.0E+01	MJ
Use of secondary materials	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	kg
RENEWABLE secondary fuels	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	MJ
Use of NON-RENEWABLE secondary fuels	2.0E-01	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.0E-01	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.0E-01	MJ
Use of fresh water resources	1.2E+01	1.6E-01	1.8E+00	0.0E+00	2.4E+00	6.6E-01	8.7E+00	0.0E+00	0.0E+00	0.0E+00	2.2E-01	2.6E+01	m^3

These resource use data show the flow of energy and materials through across the life cycle stages of the product. One important resource use to note is that a significant portion of the renewable energy is embodied in the raw materials, reinforcing the fact that environmental impacts are driven by the raw materials life cycle stage.

Table 7.5 – Insulated Vinyl Siding Output Flows and Waste by Life Cycle Stage

Output Flows and Waste	A1	A2	A3	A4	A5	B2	B4	C1	C2	C3	C4	Total	Units
Disposed-of-hazardous WASTE	1.5E-01	3.3E-06	1.0E-02	0.0E+00	6.0E-05	9.2E-06	8.0E-02	0.0E+00	0.0E+00	0.0E+00	4.3E-05	2.4E-01	kg
Disposed-of non-hazardous WASTE	1.1E+00	1.7E-02	6.7E-01	0.0E+00	2.7E+00	6.1E-02	1.1E+01	0.0E+00	0.0E+00	0.0E+00	1.7E+01	3.2E+01	kg
Disposed-of Radioactive WASTE	1.3E-04	8.8E-07	1.6E-05	0.0E+00	3.9E-05	4.9E-06	1.4E-04	0.0E+00	0.0E+00	0.0E+00	8.3E-05	4.1E-04	kg
Components for reuse	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	kg
Materials for recycling	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	kg
Materials for energy recovery	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	kg
Exported electrical energy (waste to energy)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	MJ
Exported thermal energy (waste to energy)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	MJ

These data show the flows of wastes and outputs from the system across the life cycle stages. The waste processing stage is where the majority of non-hazardous waste is disposed of, whereas the majority of hazardous waste is generated during the upstream processing of raw materials.

7.2 Manufacturing Impacts

7.2.1 Manufacturing Impact Analysis

Energy is required to extract, process, and ship raw materials to the plant, manufacture the insulated vinyl siding, and ship the final product to the customer.

Table 7.6 and Figure 7.3 below list the TRACI life cycle impacts for the manufacturing of insulated vinyl siding and how those impacts are distributed across the ten manufacturing inputs (electricity, natural gas, propane, water, gasoline, packaging materials, water treatment, transportation, wastewater treatment, and waste disposal).

Table 7.6 – Insulated Vinyl Siding TRACI Impacts by Manufacturing Input

Impact Category	Unit	Electricity	Natural Gas	Propane	Water	Gasoline	Packaging Materials	Water Treatment	Transportation	Wastewater Treatment	Waste Disposal	Total
Ozone Depletion	kg CFC_{-11} eq	4.9E-11	1.1E-13	3.9E-12	3.7E-10	1.7E-12	1.2E-07	4.4E-10	9.1E-14	4.2E-10	1.6E-09	**1.2E-07**
Global Warming	kg CO_2 eq	3.0E+00	1.5E-01	9.9E-02	7.4E-03	8.0E-05	1.4E+00	3.5E-03	2.4E-03	4.3E-03	7.3E-03	**4.6E+00**
Smog	kg O_3 eq	1.7E-01	3.4E-03	5.2E-03	3.8E-04	2.8E-05	1.0E-01	2.2E-04	3.9E-04	4.1E-04	8.9E-04	**2.8E-01**
Acidification	kg SO_2 eq	2.5E-02	1.3E-03	2.7E-04	4.7E-05	9.2E-07	7.9E-03	2.9E-05	1.4E-05	3.6E-05	3.4E-05	**3.5E-02**
Eutrophication	kg N eq	3.4E-04	1.3E-05	1.4E-05	2.5E-05	6.2E-08	3.7E-03	1.5E-05	7.9E-07	3.4E-04	1.0E-05	**4.5E-03**
Carcinogenics	CTU_h	6.9E-09	6.5E-10	1.4E-09	8.4E-10	1.4E-12	5.3E-08	2.2E-10	3.3E-11	1.8E-09	2.0E-10	**6.5E-08**
Non-carcinogenics	CTU_h	1.1E-07	8.1E-09	1.4E-08	2.3E-09	1.4E-11	4.6E-07	1.9E-09	3.1E-10	2.3E-08	5.3E-10	**6.2E-07**
Respiratory Effects	kg $PM_{2.5}$ eq	1.3E-03	7.8E-05	5.9E-06	3.5E-06	1.5E-08	7.6E-04	2.4E-06	2.5E-07	3.5E-06	3.4E-06	**2.1E-03**
Ecotoxicity	CTU_E	1.7E+00	2.1E-01	2.6E-01	5.2E-02	3.6E-04	8.8E+00	5.1E-02	6.1E-03	1.0E-01	1.1E-02	**1.1E+01**
Fossil Fuel Depletion	MJ surplus	2.9E+00	4.0E-01	2.0E-01	4.8E-03	1.8E-04	2.4E+00	4.6E-03	4.6E-03	3.5E-03	1.6E-02	**5.9E+00**

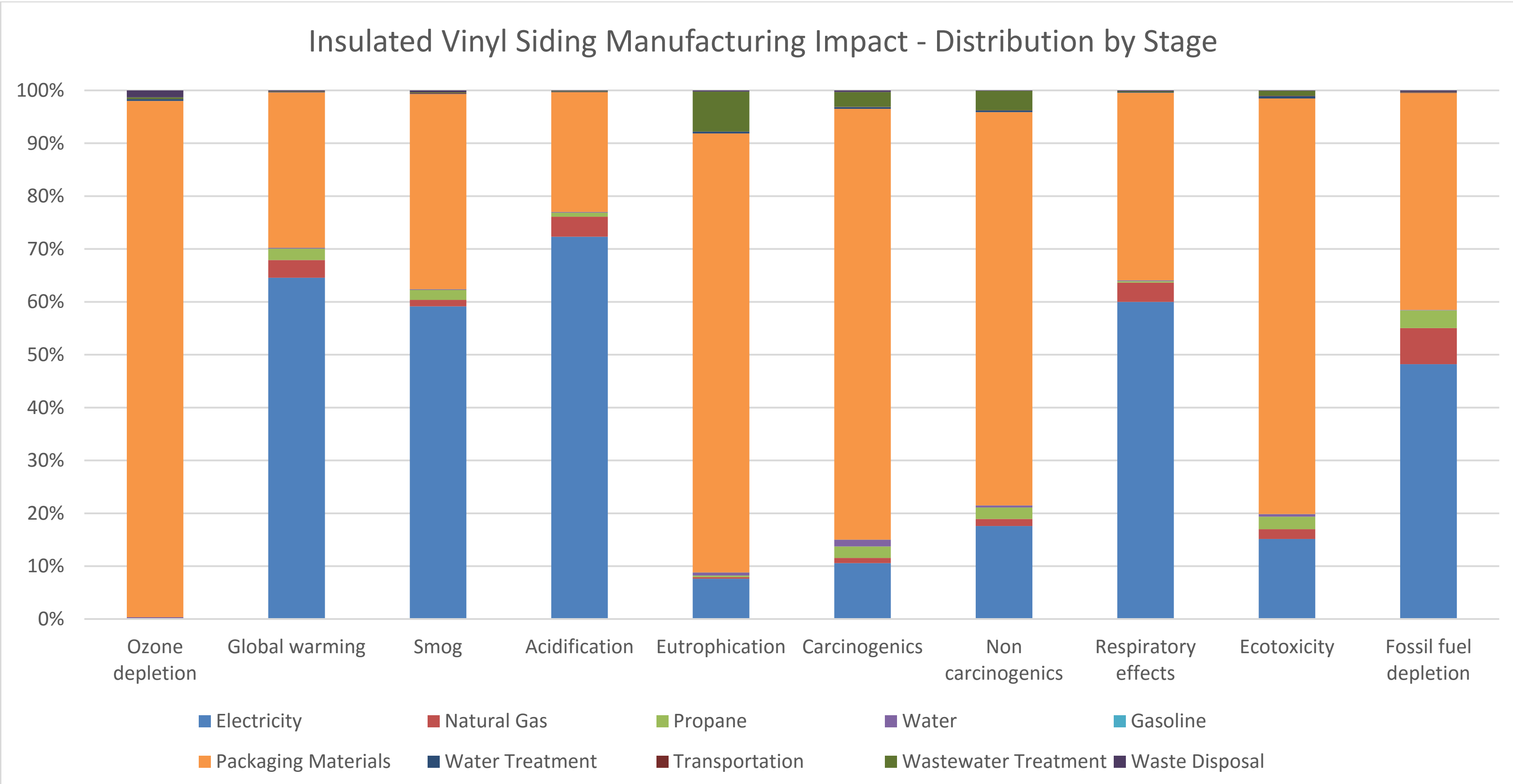


Figure 7.2 – Insulated Vinyl Siding TRACI Impacts by Manufacturing Input

As shown in the table and figure above, the manufacturing impacts are primarily driven by two main inputs: Electricity and Packaging Materials. Electricity consumption is the primary contributor to the global warming, smog, acidification, and respiratory effects categories, while packaging inputs drive the results in the ozone depletion, eutrophication, carcinogenics, non-carcinogenics, and ecotoxicity categories. The impacts associated with electricity consumption are driven largely by the burning of coal, while the impacts associated with packaging are driven by the upstream production of cardboard and wood pallets, which are the primary two materials used in the packaging of vinyl siding.

7.3 Raw Material Impacts

In addition to the impacts associated with the manufacturing stage of the product life cycle, examining the raw materials is important to understanding the life cycle of the products, especially since raw materials are by far the most impactful segment of the insulated vinyl siding life cycle. This process includes quantifying all the material inputs including scrap rates. Each raw material has an associated environmental impact. Table 7.7 shows the industry average formulation data of insulated vinyl siding. The formulation of the vinyl portion is identical to the non-insulated vinyl siding, so this analysis will show the impact breakdown across the vinyl, foam insulation, and glue components of the insulated siding. For a detailed raw material impact analysis of the individual constituents of the vinyl component itself, see section 6.3.1.

Table 7.7 – Insulated Vinyl Siding Formulation

Component	Weight (lb/100sf)	% of Product
Vinyl Siding	42.4	86%
Foam Insulation	6.2	13%
Glue	0.73	1%
Constituent	**% in Siding with PVC Capstock**	**% in Siding with ASA Capstock**
PVC	80.4%	69%
ASA	--	12%
Calcium Carbonate	11.1%	10%
Impact Modifier	1.9%	1.1%
Titanium Dioxide	1.4%	0.9%
Tin Stabilizer	0.6%	0.7%
Process Aid	0.5%	0.0%
Lubricant	1.7%	1.7%
Chlorinated Polyethylene	0.7%	2.4%
Sealant	0.8%	0%
Calcium Stearate	0.6%	0.0%
Pigments	.1%	0.2%

7.3.1 Raw Materials Impact Analysis

To investigate these raw material impacts further, Table 7.8 and Figure 7.3 illustrate the environmental impact of each of the major components used in the production of the insulated vinyl siding product, in the proportions found in the industry average insulated vinyl siding product, using the vinyl siding formulation data presented in Section 4.1, as an input for the siding component of the insulated product. In order to illustrate these impacts, the TRACI impact methodology was used to assess the impacts of the components in the proportions according to the recipe for insulated vinyl siding.

Table 7.8 – Insulated Vinyl Siding TRACI Impacts by Component

Impact Category	Unit	Vinyl	Foam	Glue	Total
Global Warming	kg CO_2 eq	4.0E+01	8.6E+00	1.3E+00	**5.0E+01**
Fossil Fuel Depletion	MJ surplus	1.2E+02	3.3E+01	2.7E+00	**1.6E+02**
Eutrophication	kg N eq	3.8E-02	3.2E-03	1.4E-03	**4.3E-02**
Smog	kg O_3 eq	1.6E+00	5.7E-01	1.5E-01	**2.3E+00**
Acidification	kg SO_2 eq	1.7E-01	9.6E-02	7.9E-03	**2.7E-01**
Ozone Depletion	kg CFC_{-11} eq	2.4E-06	5.8E-07	1.0E-08	**3.0E-06**
Carcinogenics	CTU_h	2.4E-06	1.6E-07	7.1E-08	**2.7E-06**
Non-carcinogenics	CTU_h	6.5E-06	1.9E-06	2.2E-07	**8.6E-06**
Respiratory Effects	kg $PM_{2.5}$ eq	1.5E-02	5.0E-03	1.2E-03	**2.1E-02**
Ecotoxicity	CTU_e	1.8E+02	5.5E+01	5.2E+00	**2.4E+02**
Cumulative Energy Demand	MJ	9.0E+02	2.7E+02	2.5E+01	**1.2E+03**

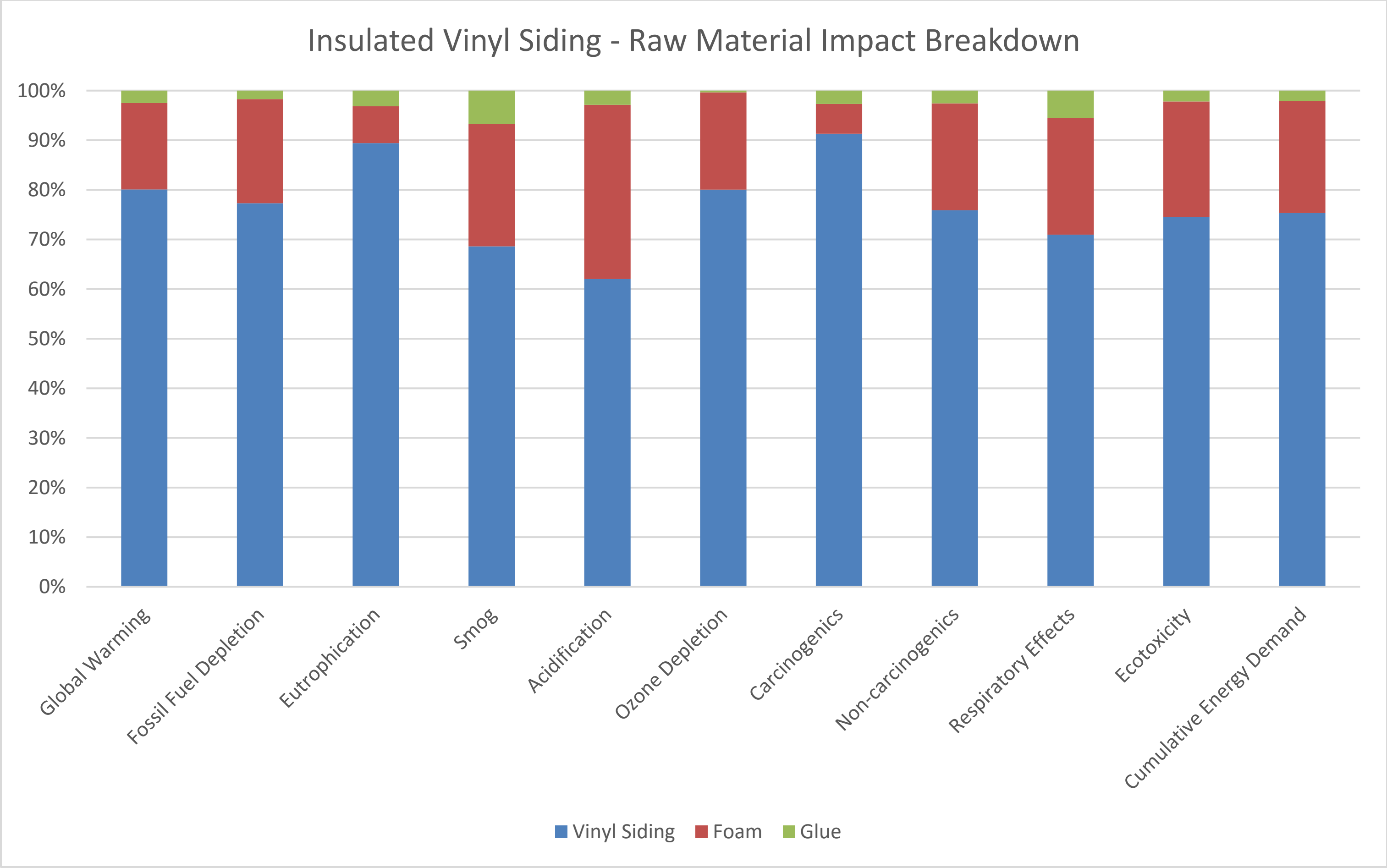


Figure 7.3 – Insulated Vinyl Siding TRACI Impacts by Component

For the insulated vinyl siding product, the vinyl component contributes the majority of the raw material impacts in most impact categories. This is consistent with the fact that the vinyl layer is the primary component of the insulated vinyl siding product.

8.0 Polypropylene Siding LCA Results

This section presents the results of the LCA study. It includes quantified impacts for each of the TRACI impact categories.

8.1 Overall Environmental Impact

8.1.1 Overall Environmental Impact Analysis

The graphs in this section are designed to communicate the overall environmental impacts of polypropylene siding. This is done using the TRACI methodology as described in Section 5.2 above. While the results in every category are presented throughout this report, the Environmental Product Declaration will omit the results in health categories due to the high uncertainty of those impacts, per the Product Category Rule.

The tables and figures below demonstrate the overall environmental impact (using the TRACI methodology) of manufacturing 100 square feet of polypropylene siding of a 0.085" S7" cedar shake profile. The figure illustrates the relative impact contribution from each of the eight life cycle stages (raw materials, raw material transportation, siding manufacturing, final product distribution, installation, use phase (cleaning), end of Life transportation, and waste treatment) to each of the environmental impacts.

Table 8.1 – Polypropylene Siding TRACI Impacts by Life Cycle Stage per 100 Square Feet

Impact Category	Unit	Raw Materials	Raw Materials Transportation	Siding Manufacturing	Final Product Distribution	Installation	Use Phase (Cleaning)	Replacement	EOL Transportation	Waste Treatment	Total
Global Warming	kg CO_2 eq	4.6E+01	2.3E+00	4.1E+01	3.5E+00	1.7E+00	4.8E-01	5.5E+01	2.4E-01	1.6E+01	**1.7E+02**
Fossil Fuel Depletion	MJ surplus	3.1E+02	3.9E+00	4.3E+01	6.3E+00	1.4E+00	3.6E-01	1.8E+02	4.3E-01	4.5E+00	**5.5E+02**
Eutrophication	kg N eq	2.8E-02	3.8E-03	2.1E-02	1.2E-03	5.8E-03	2.1E-03	4.4E-02	8.0E-05	2.6E-02	**1.3E-01**
Smog	kg O_3 eq	2.4E+00	6.7E-01	2.2E+00	5.7E-01	1.0E-01	2.9E-02	3.2E+00	3.9E-02	4.0E-01	**9.6E+00**
Acidification	kg SO_2 eq	8.8E-01	2.3E-02	3.3E-01	2.1E-02	9.6E-03	2.5E-03	6.5E-01	1.4E-03	3.9E-02	**2.0E+00**
Ozone Depletion	kg CFC_{-11} eq	7.9E-06	3.2E-07	5.3E-07	1.3E-10	1.3E-07	2.9E-08	4.7E-06	9.2E-12	4.5E-07	**1.4E-05**
Carcinogenics	CTU_h	2.4E-05	2.1E-07	3.2E-07	4.8E-08	7.8E-07	2.0E-08	1.3E-05	3.3E-09	8.3E-07	**4.0E-05**
Non-carcinogenics	CTU_h	1.3E-05	3.1E-07	3.1E-06	4.6E-07	8.2E-07	9.9E-08	1.1E-05	3.2E-08	3.6E-06	**3.3E-05**
Respiratory Effects	kg $PM_{2.5}$ eq	5.0E-02	1.4E-03	1.8E-02	3.6E-04	4.0E-03	7.9E-04	3.9E-02	2.5E-05	2.6E-03	**1.2E-01**
Ecotoxicity	CTU_e	6.7E+02	6.4E+00	6.0E+01	8.9E+00	3.1E+01	2.2E+00	4.6E+02	6.1E-01	1.5E+02	**1.4E+03**
Cumulative Energy Demand	MJ	2.4E+03	3.4E+01	6.9E+02	4.8E+01	2.5E+01	1.6E+01	1.6E+03	3.3E+00	9.3E+01	**4.9E+03**

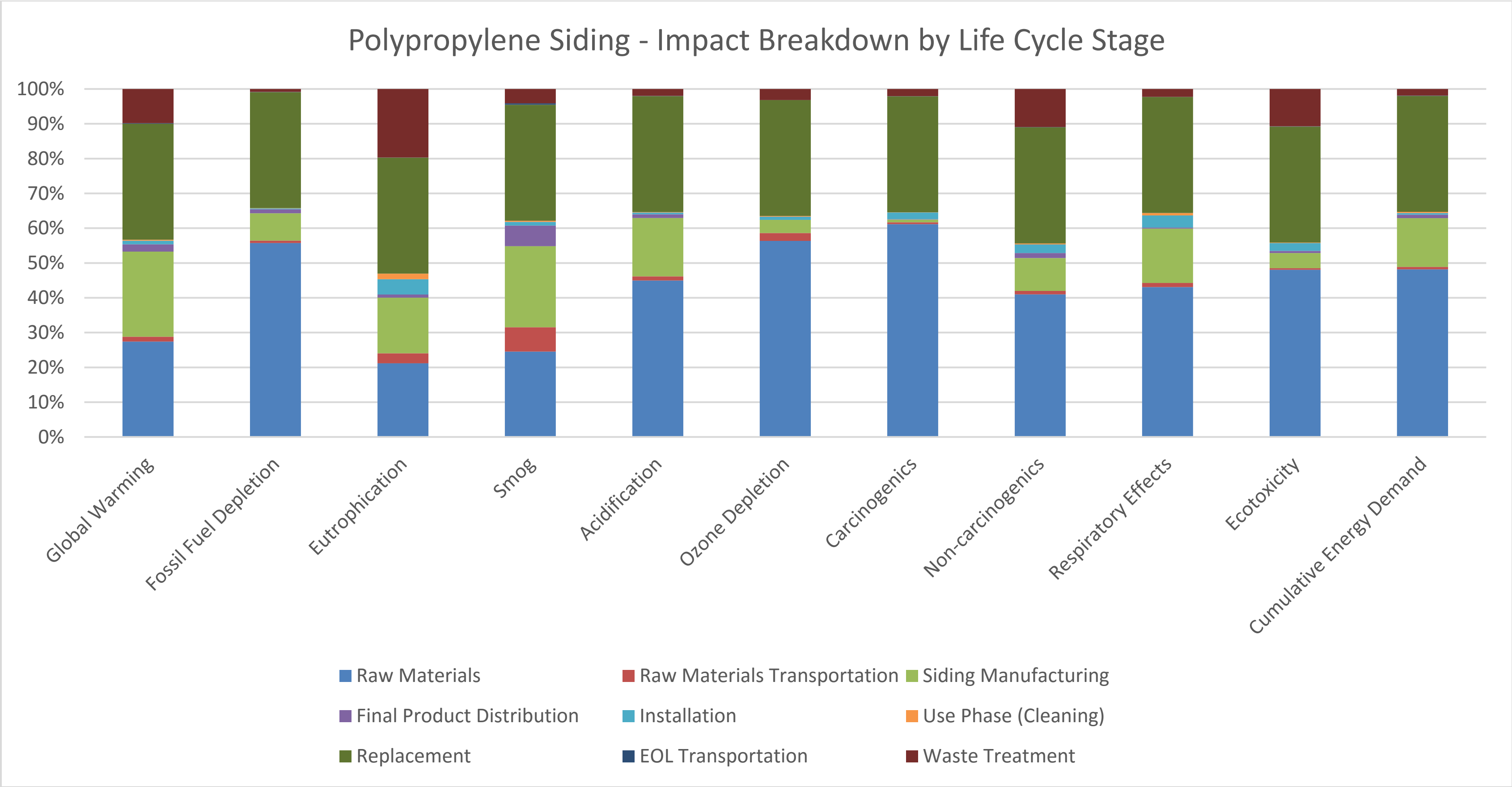


Figure 8.1 – Polypropylene Siding TRACI Impacts by Life Cycle Stage

Figure 8.1 shows that for polypropylene siding, the replacement stage is roughly one third of the impacts of the life cycle. This is due to the declared unit lifetime of 75 years and the product declared lifetime being 50 years, requiring a replacement factor of 0.5 of the life cycle impacts. Outside of the replacement stage, raw materials contribute a majority of the impact in every category, except for global warming and smog. The raw material phase contributes significantly to the overall impacts because siding is produced through an efficient extrusion process, and because there are nearly non-existent use phase inputs for this product. The manufacturing component is also a significant contributor to the life cycle impacts, although these impacts are not as large as those from the raw material stage, with the exception of smog and global warming. The following sections will more closely examine the impact breakdown within the raw material and manufacturing phases.

8.1.2 EPD Data

Along with the TRACI impact data shown above, the publication of an EPD requires the inclusion of additional data describing polypropylene siding's life cycle. These additional data include:

- CML impact assessment methodology (an environmental impact assessment methodology similar to the TRACI 2.1 methodology but developed by the Institute of Environmental Sciences at the University of Leiden, and used often in European LCAs.
- Resource use data, as defined by EN15804.
- Output flows and waste data, as defined by EN 15804.

These data are presented below in Tables 8.2 through 8.5:

Table 8.2 – Polypropylene Siding System Boundary

Product			Construction Installation		Use							End-of-Life				Benefits of Loads Beyond the System Boundary		
Raw Material Extraction and Processing	Transport	Manufacturing	Transport	Construction/ Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Operational Energy Use	Operational Water Use	De-Construction/ Demolition	Transport	Waste Processing	Disposal	Reuse	Recovery	Recycling
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	D	D
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	MND	MND	MND

Table 8.3 – Polypropylene Siding CML Impacts by Life Cycle Stage

CML	A1	A2	A3	A4	A5	B2	B4	C1	C2	C3	C4	Total	Units
Global warming potential	4.6E+01	2.3E+00	4.1E+01	3.5E+00	1.7E+00	4.8E-01	5.5E+01	0.0E+00	2.4E-01	0.0E+00	1.6E+01	1.7E+02	kg CO_2 Eq.
Depletion potential of stratospheric ozone layer	6.7E-06	2.4E-07	4.2E-07	1.3E-10	9.9E-08	2.2E-08	3.9E-06	0.0E+00	9.1E-12	0.0E+00	3.2E-07	1.2E-05	kg CFC_{-11} Eq.
Acidification potential	1.0E+00	1.9E-02	3.6E-01	1.7E-02	9.8E-03	2.3E-03	7.3E-01	0.0E+00	1.2E-03	0.0E+00	4.0E-02	2.2E+00	kg SO_2 Eq.
Eutrophication potential	2.1E-02	4.5E-03	1.9E-02	3.0E-03	2.9E-03	1.1E-03	3.2E-02	0.0E+00	2.1E-04	0.0E+00	1.2E-02	9.6E-02	kg $(PO4)_3$- Eq.
Photochemical ozone creation potential	5.2E-02	5.8E-04	1.4E-02	7.9E-04	6.1E-04	7.6E-04	3.6E-02	0.0E+00	5.5E-05	0.0E+00	1.7E-03	1.1E-01	kg ethane Eq.

These results reflect the TRACI impact results in Section 8.1.1 above. The environmental impacts associated with polypropylene siding are driven by the raw materials life cycle stage, with manufacturing being the second largest contributor.

Table 8.4 – Polypropylene Siding Resource Use by Life Cycle Stage

Resource Use	A1	A2	A3	A4	A5	B2	B4	C1	C2	C3	C4	Total	Units
Use of RENEWABLE primary energy excluding the RENEWABLE primary energy used as raw materials	1.1E+03	3.3E+01	6.0E+02	4.8E+01	2.2E+01	5.4E+00	9.3E+02	0.0E+00	3.3E+00	0.0E+00	9.0E+01	2.8E+03	MJ (LHV)
Use of RENEWABLE primary energy resources used as raw materials	1.3E+03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	6.6E+02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.0E+03	MJ
Use of NON-RENEWABLE primary energy excluding the NON-RENEWABLE primary energy resources used as raw materials	2.4E+03	3.3E+01	6.0E+02	4.8E+01	2.2E+01	5.4E+00	1.6E+03	0.0E+00	3.3E+00	0.0E+00	9.0E+01	4.8E+03	MJ
Use of NON-RENEWABLE primary energy excluding the NON-RENEWABLE primary energy resources used as raw materials	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	MJ
Use of NON-RENEWABLE primary energy as raw materials	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	MJ
Total use of NON-RENEWABLE primary energy	4.6E+00	3.3E-01	8.8E+01	0.0E+00	3.3E+00	1.1E+01	5.5E+01	0.0E+00	0.0E+00	0.0E+00	3.3E+00	1.7E+02	MJ
Use of secondary materials	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	kg
RENEWABLE secondary fuels	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	MJ
Use of NON-RENEWABLE secondary fuels	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	MJ
Use of fresh water resources	3.7E+01	2.2E+00	3.5E+02	0.0E+00	1.7E+00	6.6E-01	2.0E+02	0.0E+00	0.0E+00	0.0E+00	2.1E+01	6.1E+02	m^3

These resource use data show the flow of energy and materials across the life cycle stages of the product. One important resource use to note is that a significant portion of the renewable energy is embodied in the raw materials, reinforcing the fact that environmental impacts are driven by the raw materials life cycle stage.

Table 8.5 – Polypropylene Siding Output Flows and Waste by Life Cycle Stage

Output Flows and Waste	A1	A2	A3	A4	A5	B2	B4	C1	C2	C3	C4	Total	Units
Disposed-of-hazardous WASTE	6.8E-01	4.4E-05	1.9E-02	0.0E+00	4.8E-05	9.2E-06	1.4E+01	0.0E+00	0.0E+00	0.0E+00	2.7E+01	4.1E+01	kg
Disposed-of non-hazardous WASTE	2.3E+00	2.2E-01	7.8E-01	0.0E+00	6.5E+00	6.1E-02	4.9E+00	0.0E+00	0.0E+00	0.0E+00	1.9E-04	1.5E+01	kg
Disposed-of Radioactive WASTE	5.3E-05	1.2E-05	6.2E-05	0.0E+00	3.9E-05	4.9E-06	8.5E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.6E-04	kg
Components for reuse	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	kg
Materials for recycling	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	kg
Materials for energy recovery	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	kg
Exported electrical energy (waste to energy)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	MJ
Exported thermal energy (waste to energy)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	MJ

These data show the flows of wastes and outputs from the system across the life cycle stages. The waste processing stage is where the majority of non-hazardous waste is disposed of, whereas the majority of hazardous waste is generated during the upstream processing of raw materials.

8.2 Manufacturing Impacts

8.2.1 Manufacturing Impact Analysis

Energy is required to extract, process, and ship raw materials to the plant, manufacture the polypropylene siding, and ship the final product to the customer.

Table 8.6 and Figure 8.2 below list the TRACI life cycle impacts for the manufacturing of polypropylene siding, and how those impacts are distributed across the nine manufacturing inputs (electricity, natural gas, propane, water, packaging materials, water treatment, transportation, wastewater treatment, and waste disposal).

Table 8.6 – Polypropylene Siding TRACI Impacts by Manufacturing Input

Impact Category	Unit	Electricity	Natural Gas	Propane	Water	Packaging Materials	Water Treatment	Transportation	Wastewater Treatment	Waste Disposal	Total
Ozone Depletion	kg CFC_{-11} eq	5.7E-09	3.4E-12	3.6E-13	1.1E-09	5.2E-07	5.1E-10	2.1E-12	6.1E-10	8.5E-10	**5.3E-07**
Global Warming	kg CO_2 eq	3.0E+01	4.8E+00	9.1E-03	2.2E-02	5.3E+00	2.0E-03	5.4E-02	6.2E-03	1.7E-01	**4.1E+01**
Smog	kg O_3 eq	1.7E+00	1.0E-01	4.8E-04	1.1E-03	3.9E-01	1.2E-04	8.8E-03	5.9E-04	1.4E-03	**2.2E+00**
Acidification	kg SO_2 eq	2.6E-01	4.1E-02	2.5E-05	1.4E-04	2.7E-02	1.8E-05	3.2E-04	5.3E-05	5.6E-05	**3.3E-01**
Eutrophication	kg N eq	3.8E-03	4.0E-04	1.3E-06	7.5E-05	1.6E-02	7.1E-06	1.8E-05	4.9E-04	9.2E-05	**2.1E-02**
Carcinogenics	CTU_h	7.4E-08	2.0E-08	1.3E-10	2.5E-09	2.1E-07	1.5E-10	7.4E-10	2.7E-09	4.5E-09	**3.2E-07**
Non-carcinogenics	CTU_h	1.0E-06	2.5E-07	1.3E-09	6.8E-09	1.8E-06	1.5E-09	7.1E-09	3.3E-08	8.9E-09	**3.1E-06**
Respiratory Effects	kg $PM_{2.5}$ eq	1.3E-02	2.4E-03	5.4E-07	1.0E-05	2.5E-03	2.0E-06	5.6E-06	5.1E-06	3.3E-06	**1.8E-02**
Ecotoxicity	CTU_E	1.5E+01	6.4E+00	2.4E-02	1.5E-01	3.6E+01	3.7E-02	1.4E-01	1.5E-01	2.0E+00	**6.0E+01**
Fossil Fuel Depletion	MJ surplus	2.6E+01	1.2E+01	1.8E-02	1.4E-02	8.7E+00	2.4E-03	1.0E-01	5.1E-03	8.9E-03	**4.8E+01**

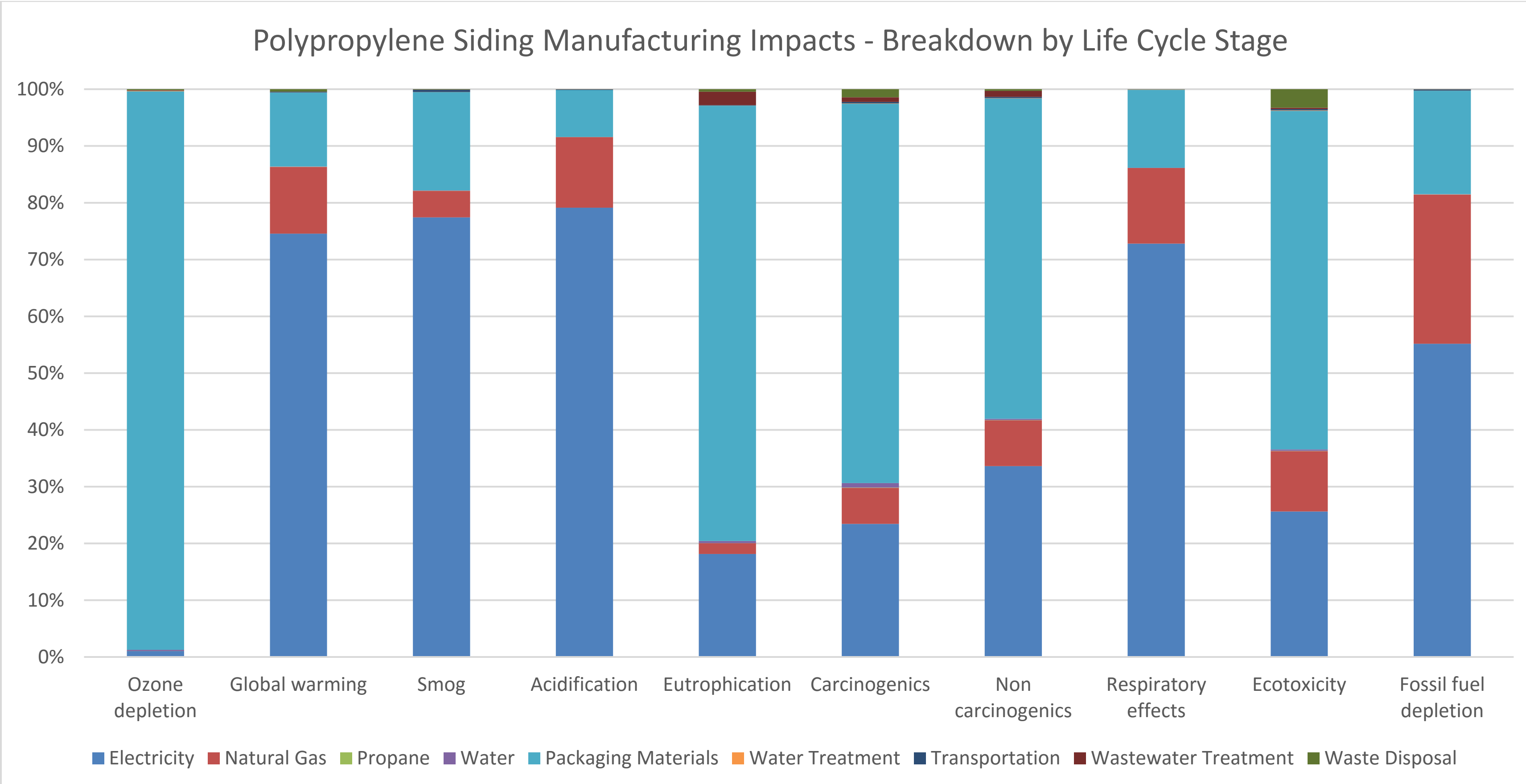


Figure 8.2 – Polypropylene Siding TRACI Impacts by Manufacturing Input

As shown in the table and figure above, the manufacturing impacts are primarily driven by two main inputs: Electricity and Packaging Materials. Electricity consumption is the primary contributor to the global warming, smog, acidification, and respiratory effects categories, while packaging inputs drive the results in the ozone depletion, eutrophication, carcinogenics, non-carcinogenics, and ecotoxicity categories. The impacts associated with electricity consumption are driven largely by the burning of coal, while the impacts associated with packaging are driven by the upstream production of cardboard and wood pallets, which are the primary two materials used in the packaging of vinyl siding.

8.3 Raw Material Impacts

In addition to the impacts associated with the manufacturing stage of the product life cycle, examining the raw materials is important to understanding the life cycle of the products, especially since raw materials are the most impactful segment of the polypropylene siding life cycle. This process includes quantifying all the material inputs including scrap rates. Each raw material has an associated environmental impact. Table 8.7 shows the industry average formulation data of polypropylene siding.

Table 8.7 – Polypropylene Siding Formulation

Constituent	% in Siding
Polypropylene	85%
Calcium Carbonate	12%
Pigments and Additives	3%

8.3.1 Raw Material Impact Analysis

To investigate these raw material impacts further, Table 8.8 and Figure 8.3 illustrate the environmental impact of each of the major raw materials used in the production of the polypropylene siding product, in the proportions found in the industry average polypropylene siding product. In order to illustrate these impacts, the TRACI impact methodology was used to assess the impacts of the raw materials in the proportions according to the recipe shown above.

Table 8.8 – Polypropylene Siding TRACI Impacts by Raw Material

Impact Category	Unit	Polypropylene	Polypropylene Pigments	Calcium Carbonate	Total
Global Warming	kg CO_2 eq	4.1E+01	2.7E+00	2.1E-02	**4.3E+01**
Fossil Fuel Depletion	MJ surplus	2.8E+02	9.2E+00	2.5E-02	**2.9E+02**
Eutrophication	kg N eq	2.1E-02	5.5E-03	2.8E-06	**2.6E-02**
Smog	kg O_3 eq	2.1E+00	1.4E-01	1.4E-03	**2.2E+00**
Acidification	kg SO_2 eq	8.1E-01	3.0E-02	1.4E-04	**8.4E-01**
Ozone Depletion	kg CFC_{-11} eq	7.2E-06	3.6E-07	1.3E-11	**7.6E-06**
Carcinogenics	CTU_h	1.2E-06	2.2E-05	1.4E-10	**2.3E-05**
Non-carcinogenics	CTU_h	1.2E-05	7.0E-07	1.7E-09	**1.3E-05**
Respiratory Effects	kg $PM_{2.5}$ eq	4.5E-02	2.0E-03	6.5E-06	**4.7E-02**
Ecotoxicity	CTU_e	3.9E+02	2.4E+02	2.7E-02	**6.4E+02**
Cumulative Energy Demand	MJ	2.2E+03	7.8E+01	3.1E-01	**2.3E+03**

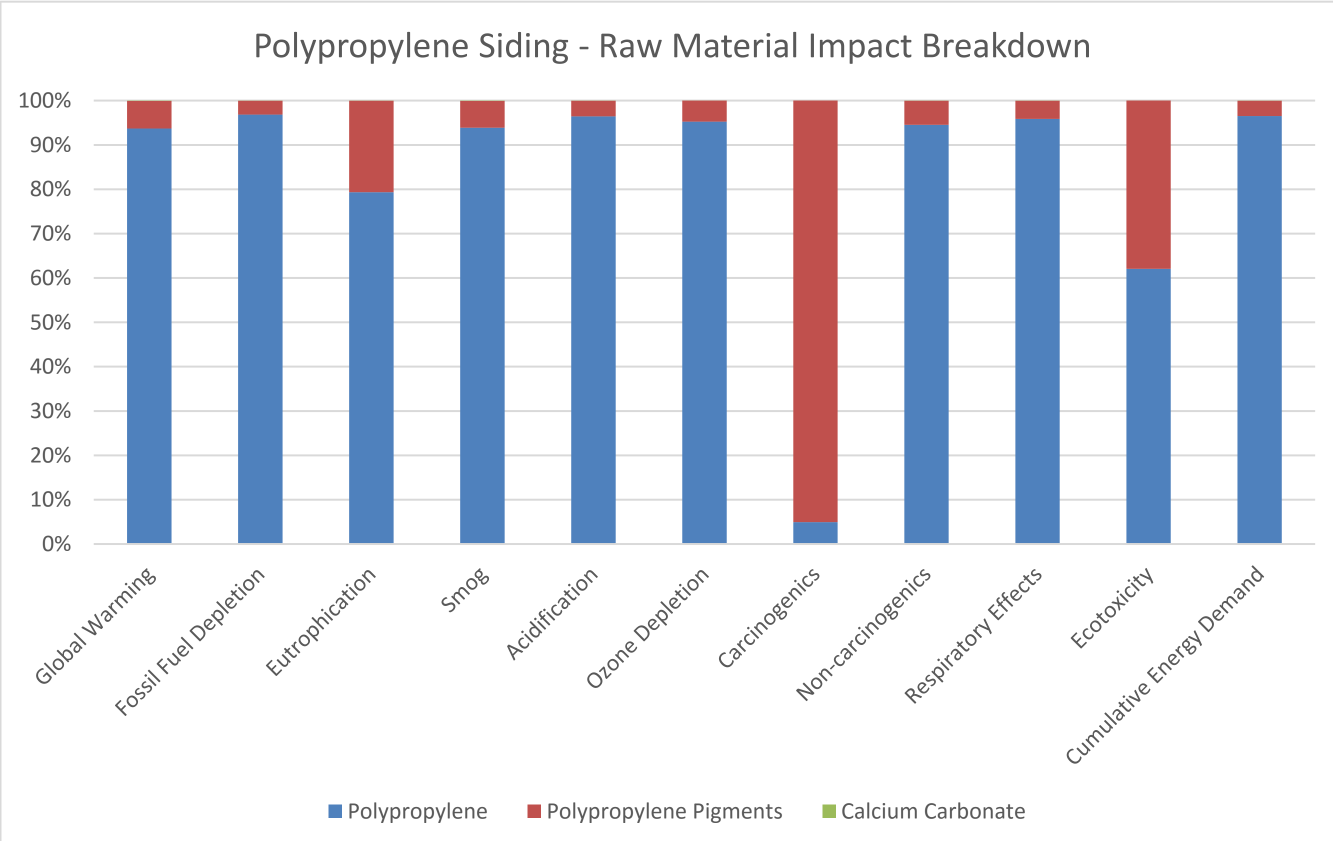


Figure 8.3 – Polypropylene Siding TRACI Impacts by Raw Material

The polypropylene resin contributes the majority of the raw material impacts in most impact categories. This is consistent with the fact that polypropylene is the primary component of the polypropylene siding products. The one impact category that does not follow this trend is carcinogens, where the impacts are driven by the pigments.

Since the upstream production of polypropylene is driving the impacts for this cladding product, obtaining updated production data from suppliers would benefit this study to more accurately represent this product. In this analysis, the production process is modeled as a combination of liquid monomer and gas phase polypropylene production processes, with energy inputs of electricity, natural gas, and propane. Specific data would allow more accurate modeling of this process and accounting of the energy inputs involved.

9.0 Limitations

All data for the operations at each participating VSI manufacturing member facility, as well as transportation distances and modes, was collected directly from each VSI member company participating in this study. Efforts were made to check the data for internal consistency and to verify data with plant personnel.

The findings in this research are limited by the inherent uncertainty of creating a representative model through LCA. Many assumptions were made in modeling the product system with representative processes and datasets. While quality control was undertaken at each step in building the LCI and conducting the LCIA, uncertainty is still present in the results since the data evaluated represents only one year of manufacturing information. Some level of uncertainty is inherent in conducting LCA and decision making must reflect this fact.

10.0 Conclusions

Based on the results from the life cycle assessment, the life cycle impacts for each product are driven primarily by the raw material stage in the life cycle or the replacement stage. The manufacturing process is the second largest contributor after raw materials for each product, although for polypropylene the manufacturing impacts are relatively larger than for vinyl and insulated vinyl siding, due to the higher melting point of polypropylene. For this reason, any efforts to decrease the material requirements of the various siding products will serve to reduce the potential environmental impacts. For vinyl and insulated vinyl siding specifically, the pigments and titanium dioxide are particularly impactful, especially in the eutrophication, carcinogens, non-carcinogens, and ecotoxicity categories. For polypropylene siding, the polypropylene resin is the driver of most environmental impacts for the product's life cycle.

Further, increasing energy efficiency, decreasing process losses, and implementing supplier sustainability requirements would be the best way to reduce overall environmental impacts. Extending the service life of siding and identifying alternate uses or recycling options of the siding will reduce the end-of-life impacts.

Further data and research on the longevity of vinyl and polypropylene siding to confirm the lifespan of the products may decrease the environmental impact assumptions in the replacement stage of the life cycle.

11.0 Recommendations

This information can prepare VSI and its member companies for future sustainable supply chain requirements and can form the basis of marketing literature focused on environmental benefits. This LCA will also assist with modeling and evaluating any green product claims by competitors.

VSI and its member companies should use the siding life cycle assessment for evaluating alternate raw materials and source locations, recycled content, and alternate transportation modes as part of a sustainable product development process. The information compiled from developing this LCA should assist VSI in taking a leadership position in sustainable product development, and its member companies can use this LCA as a basis to meet future requirements for customer sustainable purchasing programs and government requirements.

Sub-metering of energy use would be helpful for better allocation of energy use within the facility, as well as to measure and benchmark energy use for energy efficiency opportunity analysis. VSI member companies should also evaluate opportunities for energy conservation including waste heat recovery from air compressors, free cooling, and process optimization to reduce energy consumption and related impacts in the manufacturing process.

Working with raw materials suppliers, specifically those who supply PVC resin, polypropylene resin, titanium dioxide, and pigments to develop more specific life cycle models is also recommended. Supplier-specific LCA model data can feed into the siding LCA model, producing a more accurate demonstration of the value and impacts of this product to customers and governments. For vinyl and insulated vinyl siding specifically, reducing the proportion of pigments and titanium dioxide in the vinyl siding formulation will reduce the overall impact. For the polypropylene siding, increasing the amount of calcium carbonate filler will also reduce the environmental impact, as this material has a low environmental impact compared to the other constituents.

Each member company has direct control over the modes of transportation for raw materials and final products, as well as the manufacturing process. Any opportunities to reduce energy consumption in these areas will have a direct reduction in environmental impacts. It will also provide cost savings and potential competitive advantage to any company implementing these reductions.

When possible, integrating recycled content from pre- and post-consumer sources into the product formulations may reduce the raw material potential environmental impacts of the product.

Life extension techniques for the siding products and alternate uses or recycling options of the various siding types should be investigated to reduce impacts at the end of life. Both vinyl siding and polypropylene siding are recyclable at the end of the product's useful life. By working with recyclers and distributors to take-back installation scrap and products at the end of their useful service life, VSI members can develop an infrastructure to reuse the material into new products. This effort will reduce the impacts of the disposal stage for the first life of the material, and also consequently reduce the raw materials impact of the second generation product. By investigating these possibilities, claims by competing material industries may be mitigated.

Sustainable Solutions Corporation is recommending publication of the three VSI industry-averaged life cycle assessments at this time via Environmental Product Declarations (EPDs). This LCA will be used by VSI as a basis for publication of the three industry average EPDs: one each for vinyl, insulated vinyl, and polypropylene siding.

Appendix A: Process Flow Diagram

A.1 BEES Process Flow Diagram

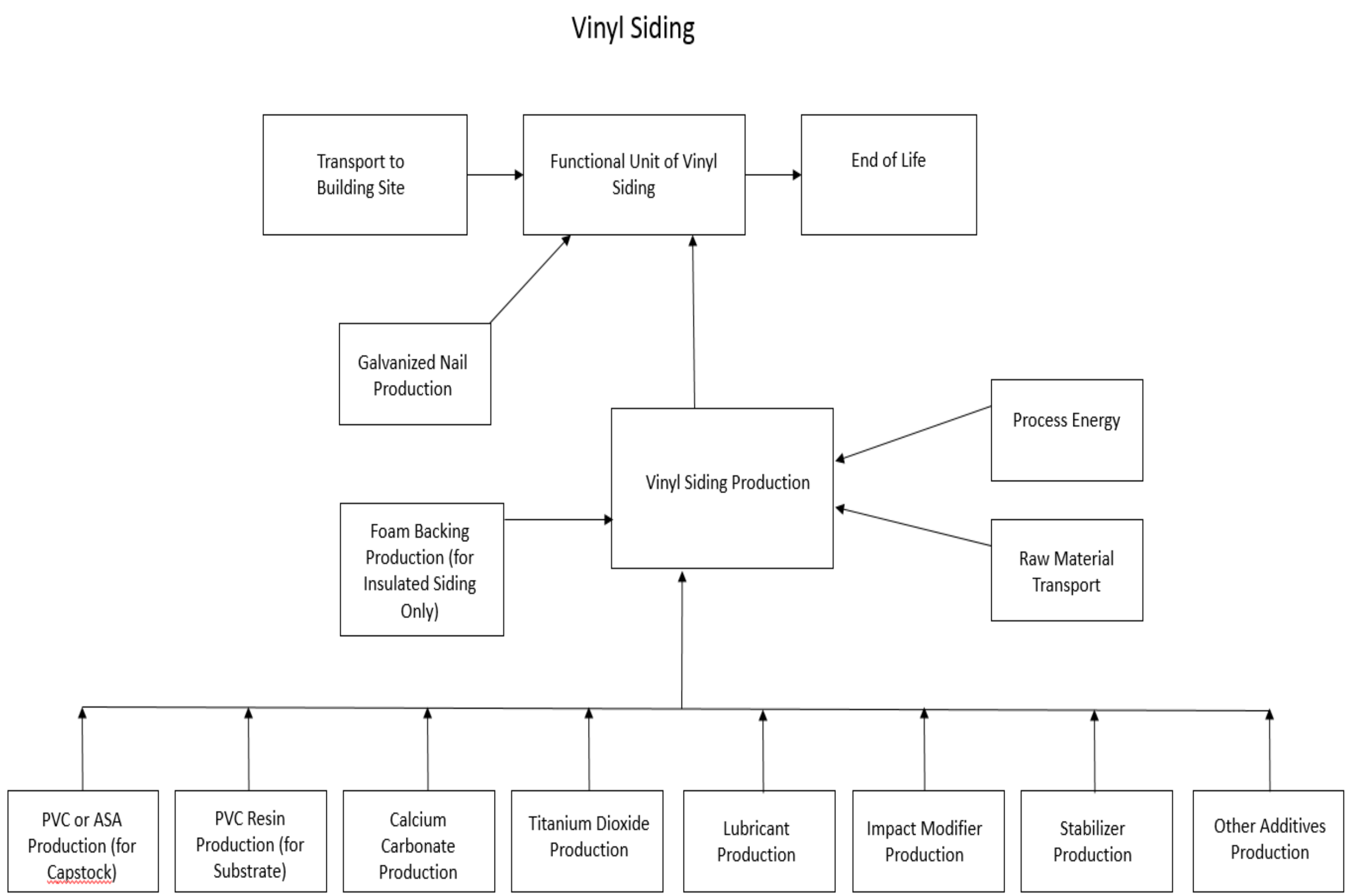


Figure A.1 – Vinyl Siding Process Flow Diagram

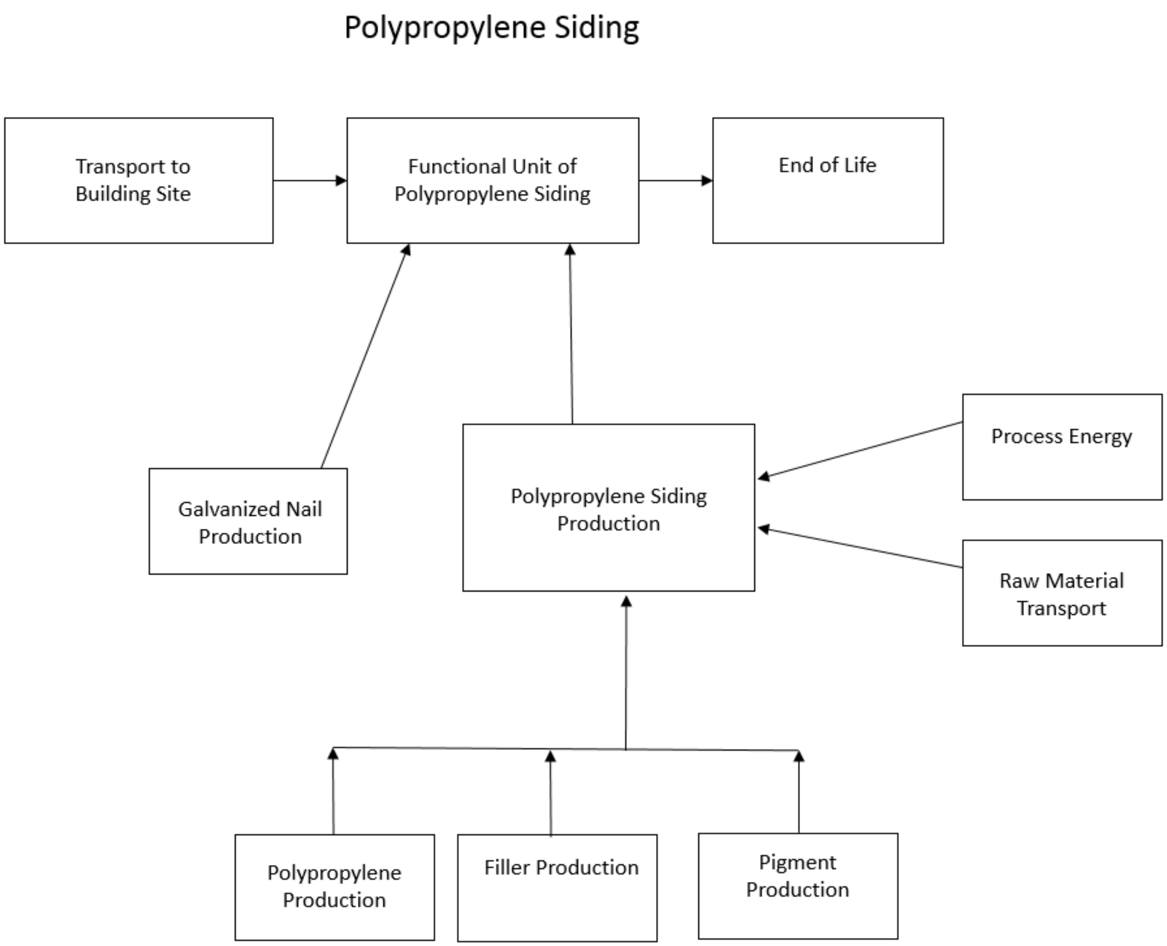
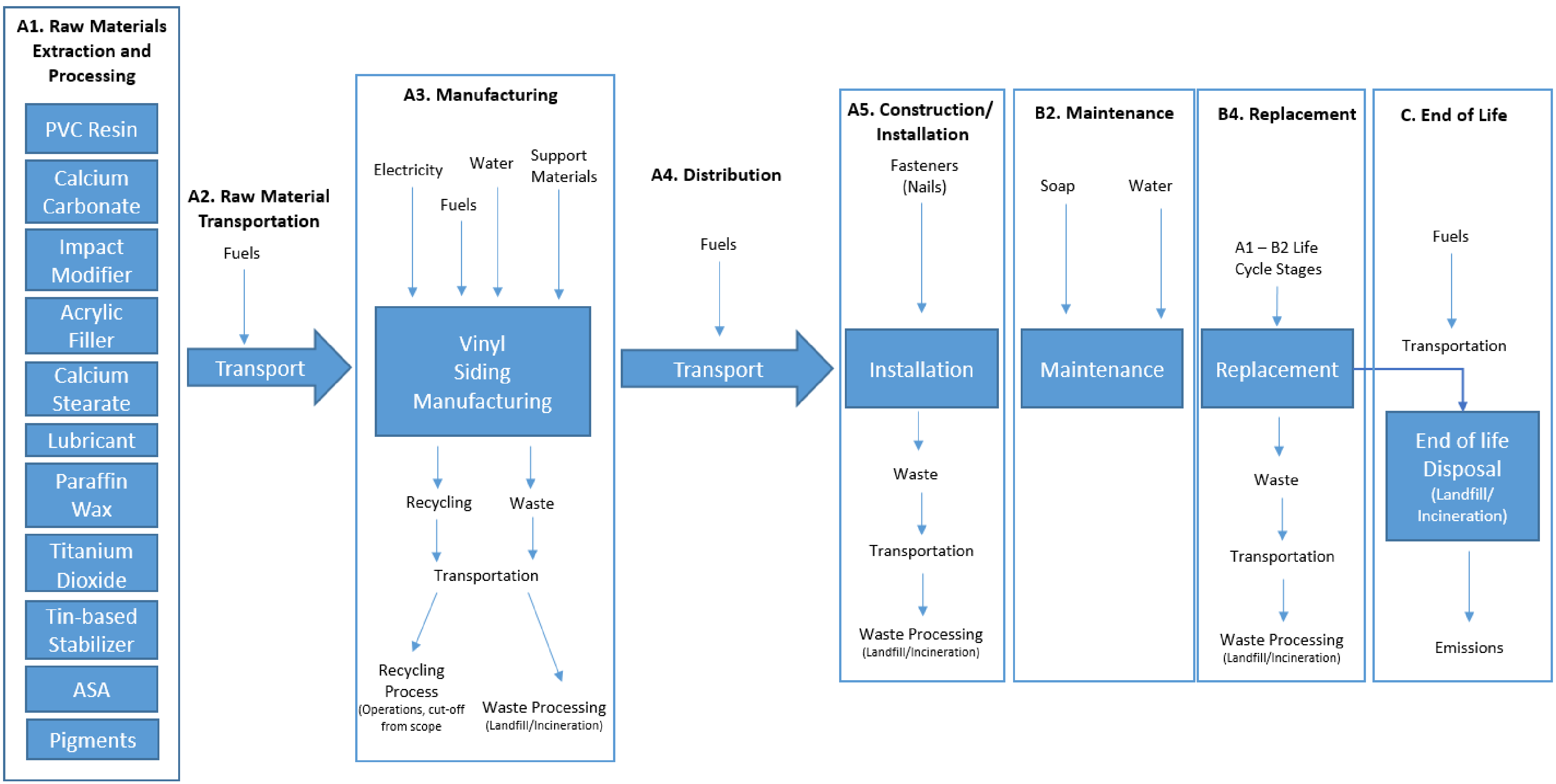
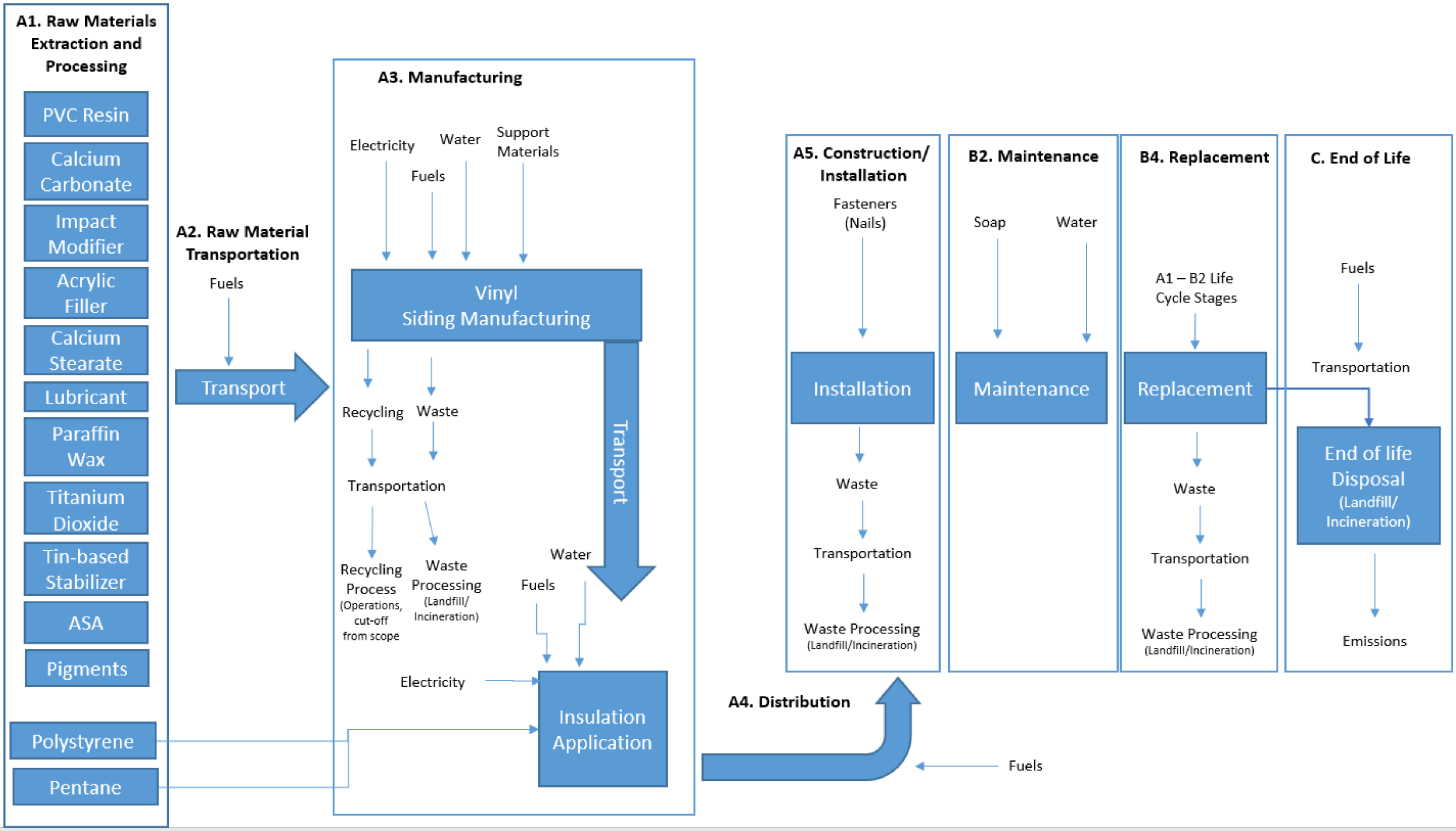


Figure A.2 – Polypropylene Siding Process Flow Diagram

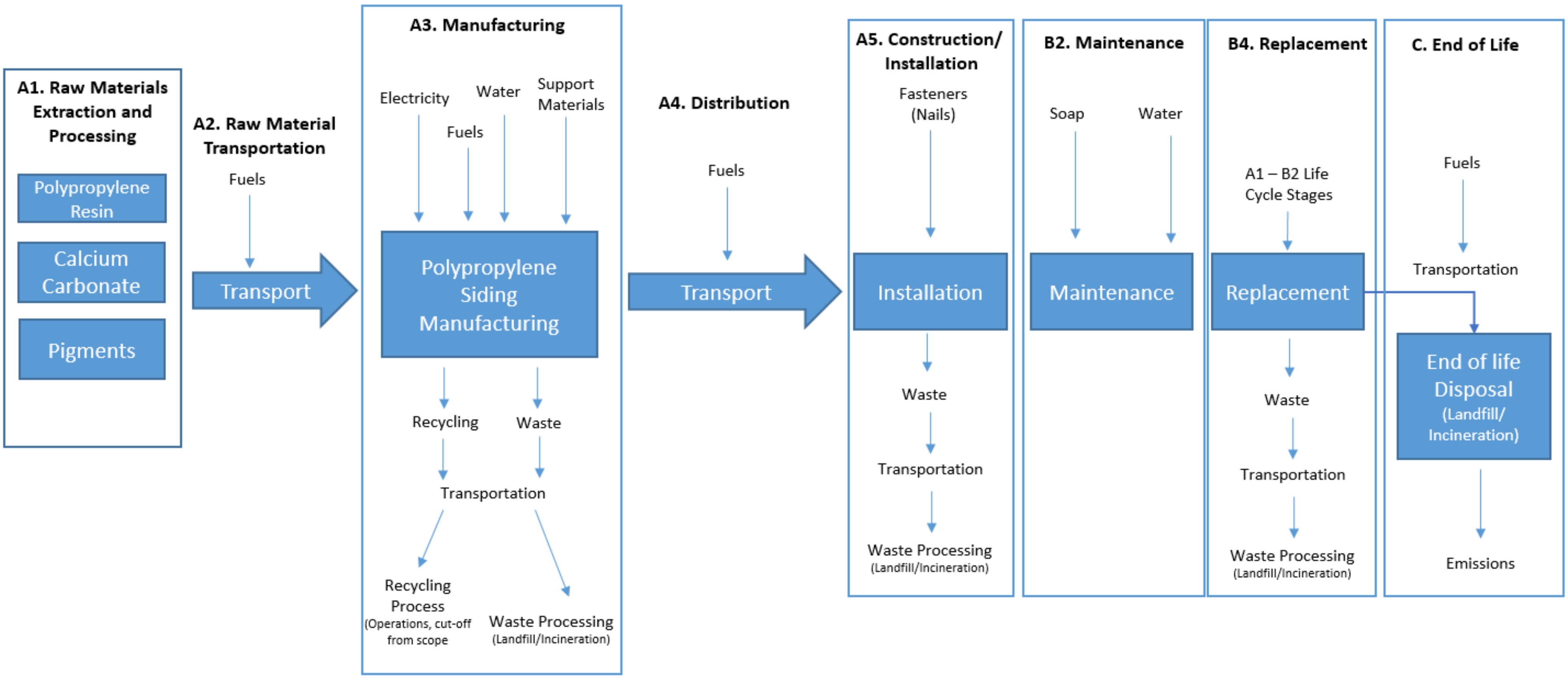
A.2 Vinyl Siding Process Flow Diagram



A.2 Insulated Vinyl Siding Process Flow Diagram



A.3 Polypropylene Siding Process Flow Diagram



Appendix B: Sensitivity Analysis

B.1 Vinyl Siding Thickness Variation Analysis

This study analyzed 0.040-inch thick vinyl siding, with the functional unit of 100 square feet weighing 42.4 lbs. In addition to 0.040-inch thick variety, vinyl siding is also sold in different thicknesses with the most common alternatives being 0.042", 0.044", and 0.046" thicknesses. To assess the range of impacts that may occur based on variable siding thickness, a sensitivity analysis was performed.

To perform this sensitivity analysis, 0.046" thick siding was analyzed to show the range of impacts that may occur across different sizes. Siding of this thickness is 15% thicker than the 0.040" variety; therefore, the weight was assumed to increase proportionately resulting in the functional unit of 100 square feet of 0.046" vinyl siding weighing 48.8 lbs.

To quantify the increase in environmental impacts resulting from an increase in siding thickness, TRACI results for the 0.040" and 0.046" variety were compared. Table B.1 below shows the overall TRACI impacts for the two vinyl siding thicknesses, and Figure B.1 shows the percentage increase of the total impacts in each category resulting from an increased thickness.

Table B.0.1 – Overall TRACI Impacts for Vinyl Siding of Variable Thickness

Impact Category	0.040"	0.046"
Global Warming (kg CO2 eq)	6.1E+01	6.3E+01
Fossil Fuel Depletion (MJ surplus)	1.5E+02	1.5E+02
Eutrophication (kg N eq)	6.0E-02	6.9E-02
Smog (kg O3 eq)	2.5E+00	2.6E+00
Acidification (kg SO2 eq)	2.5E-01	2.8E-01
Ozone Depletion (kg CFC-11 eq)	3.3E-06	3.2E-06
Carcinogenics (CTUh)	3.9E-06	3.5E-06
Non-carcinogenics (CTUh)	1.0E-05	1.1E-05
Respiratory Effects (kg PM2.5 eq)	2.5E-02	2.1E-02
Ecotoxicity (CTUe)	3.3E+02	3.2E+02
Cumulative Energy Demand (MJ)	1.2E+03	1.2E+03

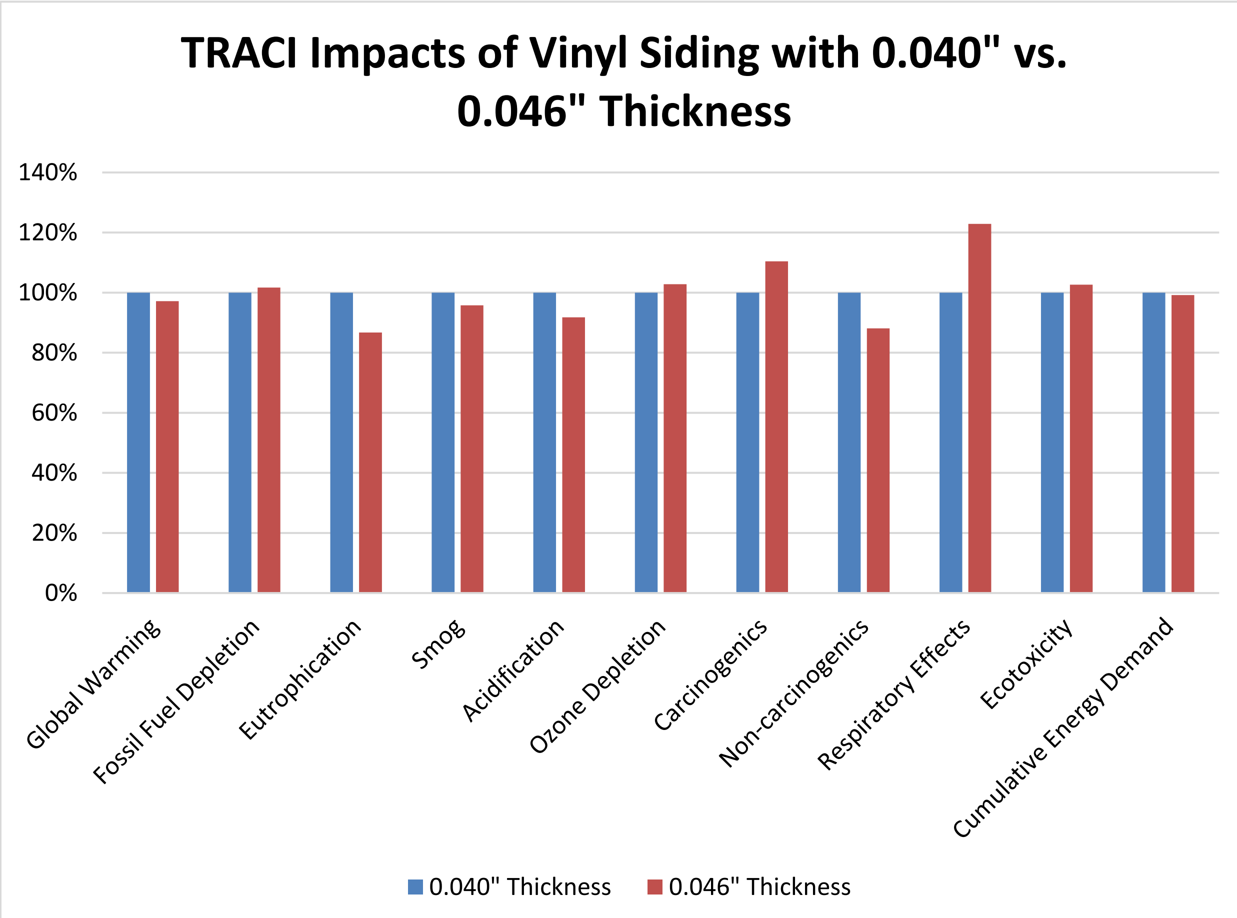


Figure B.1 – TRACI Impacts Comparison of Variable Vinyl Siding Thickness

For each impact category, the 0.046" thick variety of vinyl siding is between 13% and 15% more impactful than the 0.040" thick variety. The increase in the TRACI impacts mirrors the percent increase in weight between the two varieties of siding. This analysis shows that the environmental impacts of vinyl siding are directly related to the amount of material used in the product.

B.2 Insulated Siding Thickness Variation

The insulated vinyl siding analyzed in the study had a functional unit of 100 square feet weighing 49.33 lbs, including an 0.040" vinyl siding layer back with glue and insulating foam. Similar to vinyl siding, insulated vinyl siding comes in variable thickness as well. To assess the range of environmental impacts that may occur from variable insulated vinyl siding thickness, a sensitivity analysis was performed.

The product variation used in this sensitivity analysis was a 0.046" vinyl siding layer, backed with the identical glue and insulating foam as the baseline product and weighing 53.73 lbs per 100 square feet. To quantify the increase in environmental impacts resulting from this thicker product, TRACI results for the two varieties were compared. Table B.2 below shows the overall TRACI impacts for the two vinyl siding thicknesses, and Figure B.2 shows the percentage increase of the total impacts in each category resulting from an increased thickness.

Table B.0.2 – Overall TRACI Impacts for Insulated Vinyl Siding of Variable Thickness

Impact Category	Unit	0.040	0.046
Global Warming	kg CO_2 eq	7.3E+01	7.4E+01
Fossil Fuel Depletion	MJ surplus	1.9E+02	1.9E+02
Eutrophication	kg N eq	6.7E-02	6.9E-02
Smog	kg O_3 eq	3.5E+00	3.5E+00
Acidification	kg SO_2 eq	3.8E-01	3.8E-01
Ozone Depletion	kg CFC_{-11} eq	4.0E-06	4.0E-06
Carcinogenics	CTU_h	4.2E-06	4.2E-06
Non-carcinogenics	CTU_h	1.3E-05	1.3E-05
Respiratory Effects	kg $PM_{2.5}$ eq	3.3E-02	3.3E-02
Ecotoxicity	CTU_e	4.2E+02	4.2E+02
Cumulative Energy Demand	MJ	1.5E+03	1.5E+03

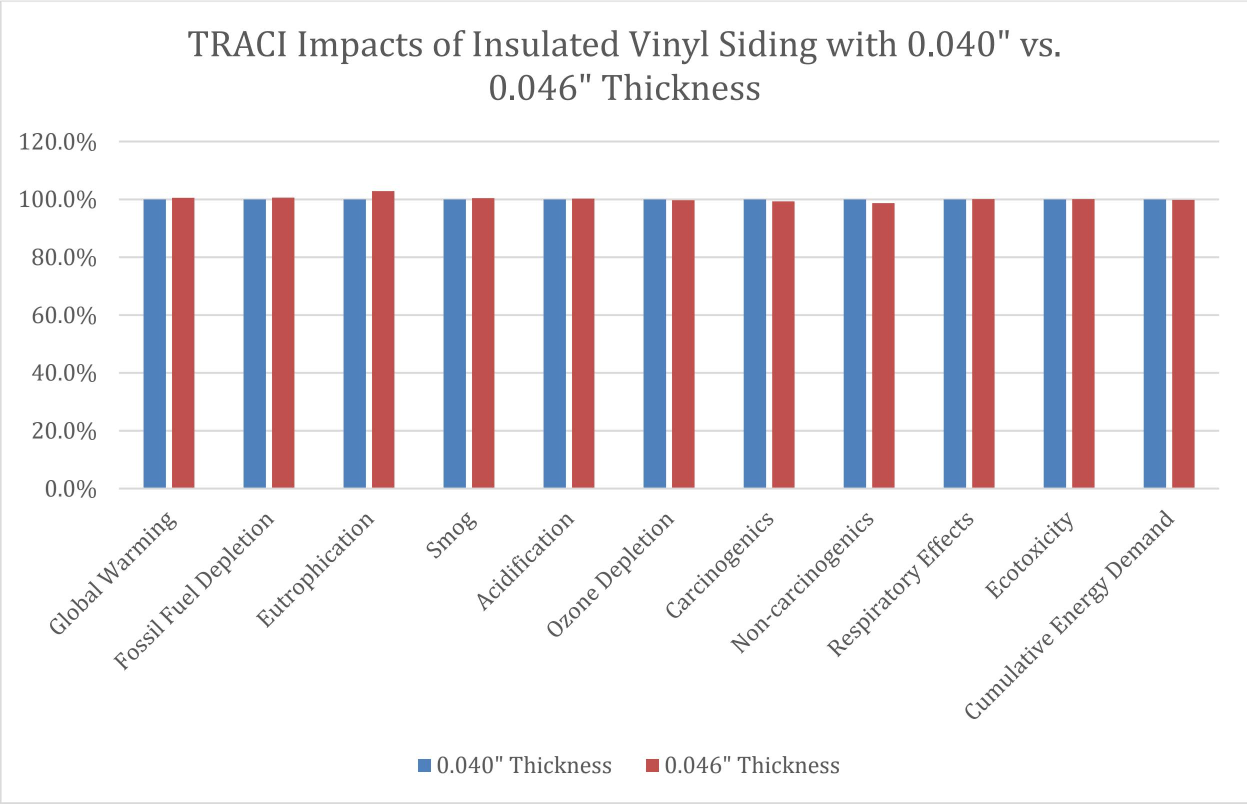


Figure B.2 – TRACI Impact Comparison of Variable Insulated Vinyl Siding Thickness

For each impact category, the 0.046" thick variety of insulated vinyl siding is between 9% and 13% more impactful than the 0.040" thick variety. This analysis shows that using thicker vinyl increases the environmental impacts of insulated vinyl siding, but at a slower rate than for vinyl siding since insulated vinyl siding has other components such as the glue and an insulating foam layer.

B.3 Polypropylene Shape Sensitivity

This study analyzed a traditional 7" polypropylene shake, with a 100 square foot functional unit weight of 71.3 lbs. In addition to the traditional, straight style, polypropylene siding is also produced in a variety of other shapes. Another popular polypropylene siding profile is the scallop shape, which is similar to the traditional shake but with a curved bottom. To assess the range of impacts that may occur based on variable siding shape, a sensitivity analysis was performed.

To perform this analysis, it was assumed that scallop shaped polypropylene siding has a weight of 75 lbs per 100 square feet, based on information from participating companies. This represents a 5% increase in weight from the traditionally shaped polypropylene siding.

To quantify the increase in environmental impacts resulting from a larger, scallop shaped siding profile, TRACI results for the scallop and traditional siding varieties were compared. Table B.3 below shows the overall TRACI impacts for the two vinyl siding thicknesses, and Figure B.3 shows the percentage increase of the total impacts in each category resulting from the scallop shaped polypropylene siding.

Table B.0.3 – Overall TRACI Impacts for Traditional and Scallop Shape Polypropylene Siding

Impact Category	Unit	Traditional	Scallop
Global Warming	kg CO_2 eq	1.1E+02	1.1E+02
Fossil Fuel Depletion	MJ surplus	3.7E+02	3.7E+02
Eutrophication	kg N eq	8.7E-02	8.7E-02
Smog	kg O_3 eq	6.4E+00	6.4E+00
Acidification	kg SO_2 eq	1.3E+00	1.3E+00
Ozone Depletion	kg CFC_{-11} eq	9.3E-06	9.4E-06
Carcinogenics	CTU_h	2.7E-05	2.7E-05
Non-carcinogenics	CTU_h	2.2E-05	2.2E-05
Respiratory Effects	kg $PM_{2.5}$ eq	8.0E-02	7.7E-02
Ecotoxicity	CTU_e	9.3E+02	9.3E+02
Cumulative Energy Demand	MJ	3.3E+03	3.3E+03

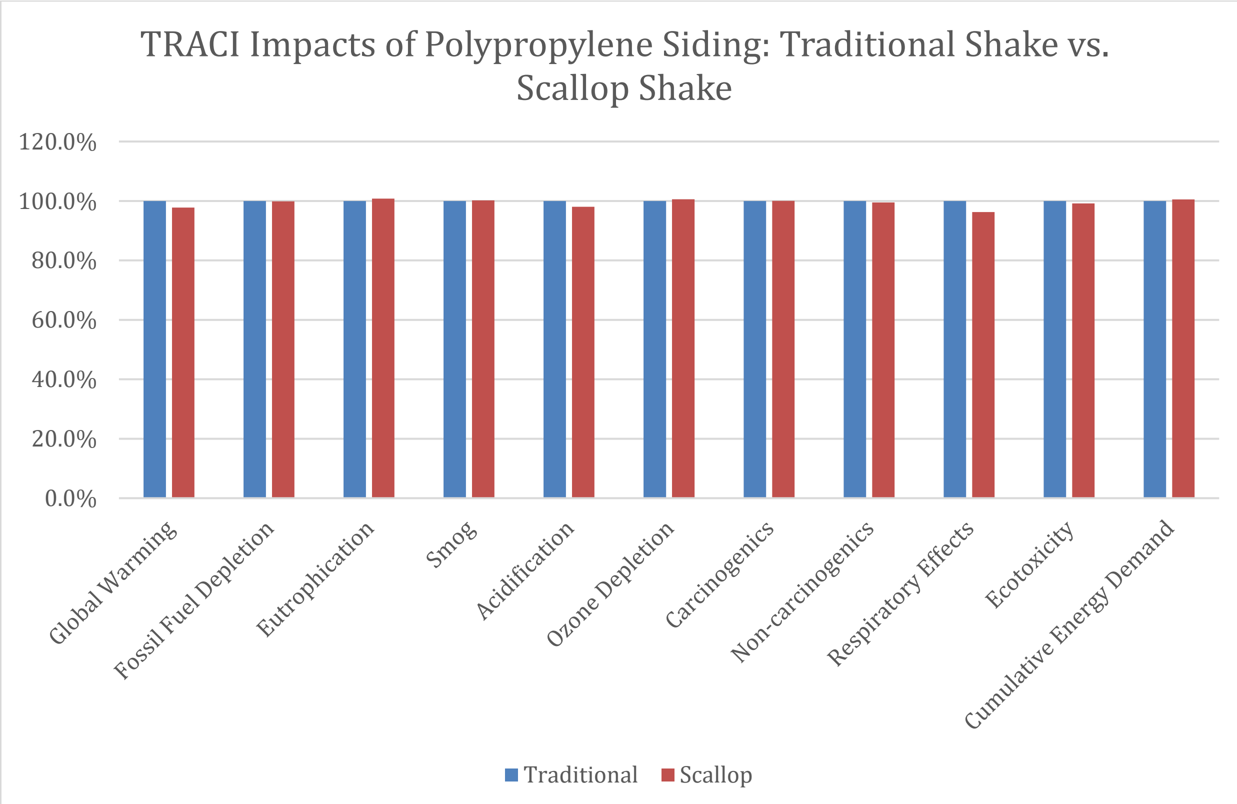


Figure B.3 – TRACI Impact Comparison of Variable Polypropylene Siding Shape

For each impact category, the scallop shaped polypropylene siding is between 4% and 6% more impactful than the traditional shape. The increase in TRACI impacts mirrors the increase in weight between the two products. The increase in the TRACI impacts mirrors the percent increase in weight between the two varieties of siding. This analysis shows that the environmental impacts of polypropylene siding are directly related to amount of material used in the product, and that changes in siding shape can increase environmental impacts by about 5%.