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Life Cycle Assessment of Western Red Cedar Decking, Siding, and Competing Products

PROJECT NUMBER: 301015969

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EXECUTIVE SUMMARY

This life cycle assessment (LCA) compares the environmental performance of western red cedar (WRC) siding and decking with competing alternatives, namely, wood-plastic composite decking, vinyl siding, fiber-cement siding, and clay brick siding. LCAs were developed for each of these products and then comparisons were made.

This report was updated by FPInnovations for the Western Red Cedar Lumber Association (WRCLA). The objectives of WRCLA in commissioning this study were to better understand environmental impacts of WRC products, as well as their environmental performance relative to competing products, in order to examine opportunities for improving the environmental footprint of WRC decking and WRC siding.

Study Goals

The goals of the study were to:

- Conduct life cycle assessments of WRC, clay brick, vinyl and FC siding products;
- Conduct life cycle assessments of WRC and composite wood/plastic decking with varying levels of recycled content.
- Evaluate the environmental impact of transporting WRC products to various market regions in the U.S.; and
- Compare and contrast the environmental profile of these WRC products to that of alternative competing construction products
- Update WRC lumber, WRC decking and WRC siding environmental product declarations.

The main changes of this updated report include:

- Modular approach to present LCI flows and LCIA results per North American Structural and Architectural Wood Products PCR
- New cradle-to-gate WRC resource extraction and product manufacturing life cycle inventory (LCI) data gathered for calendar year 2022.
- Recent (2022) vinyl siding industry average manufacturing data
- Recent brick manufacturing energy consumption data
- End-of-life disposal practices adjusted to represent US construction product disposal
- TRACI method was supplemented with CML-baseline, v4.7 August 2016 to calculate ADP fossil impacts. Cumulative Energy Demand (CED v1.11) was used to estimate primary energy consumption by energy sources.

Methods

This study was conducted according to the international life cycle inventory (LCI) and life cycle impact assessment (LCIA) standards defined by the International Organization for Standardization (ISO) in its life cycle assessment standards ISO 14040/44:2006 series and the PCR for Building-Related Products and Services (Part A) and North American Structural and Architectural Wood Products PCR (Part B) published by UL Environment, in 2022 and 2019, respectively. The geographic boundary for the study is North America. The study includes both geographically and technologically representative “cradle-to-grave” life cycle assessments of selected siding and decking products.

Both primary and secondary data sources were used to develop cradle-to-grave inventories of siding and decking. Primary data included data gathered by FPInnovations for WRC resource extraction and WRC products manufacturing. Secondary data was used to develop life cycle inventories (LCIs) for vinyl, clay brick and fiber-cement sidings. Cradle-to-grave LCIs for wood-plastic composite decking made with both virgin and reprocessed plastic were also developed using secondary data sources as well as information collected from experts in the petrochemical and wood-plastic composite fields.

LCIs and LCIA results are presented using the information modules defined in the wood products PCR: A1 – extraction (removal) of raw materials and processing, A2 – transportation of raw materials from an extraction site to a manufacturing site, A3 – manufacturing of the wood construction product, including packaging, building product transport to construction site (A4) and installation (A5), the use-phase (B2 maintenance, B4 replacement and B5 refurbishment) and end-of-life processes (C1, deconstruction, dismantling/demolition, C2, transport from building site to waste processing, and C4, disposal). Such a breakdown helps identify where the environmental contributions occur within the life cycle of each product system.

The LCI results were classified and characterized into impact assessment indicator categories using a combination of both Cumulative Energy Demand (CED) and the US Environmental Protection Agency’s (EPA) TRACI (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) (Bare, et.al, 2003) version 2.1 life cycle impact assessment (LCIA) methods. The functional unit considered is 100 ft^2 of installed products of siding and decking in a residential building over a 75 years period. The default service lives considered for WRC decking is 25 years while 50 years was assumed for siding. The environmental impact indicators included in this comparative assertion are global warming, ozone depletion, acidification, eutrophication, and smog effects, and abiotic resource depletion potential of non-renewable (fossil) energy resources (ADPfossil).

Considerable attention was given to data quality issues including ensuring that the data were representative of the North American context, e.g. energy sources. A sensitivity analysis was performed to check data consistency and precision as well as to verify the findings and test the key assumptions.

Key Findings

Environmental profile of WRC decking and siding

For WRC decking, resource extraction, transportation to consumer, maintenance and end-of-life are the most critical life cycle stages contributing to its environmental impacts. Among the energy flows used in resource extraction, diesel and gasoline use significantly contribute to the environmental impacts.

The same life cycle inventory flows identified for decking are also important in the life cycle of WRC siding. In addition, natural gas use and propane are the most critical energy inputs, as WRC siding manufacturing includes kiln drying. Currently, no wood waste generated from manufacturing is internally recycled to produce heat for kiln drying. The use phase of WRC siding is important as well because painting during installation and periodically during use significantly contributes to the life cycle impacts. Reducing frequency of painting during the 50-year service life cycle would significantly reduce the potential environmental burden of WRC siding.

For both WRC siding and decking, landfilling at end-of-life is a key global warming (GWP100 biogenic) contributor due to potential methane emissions from decaying wood in the landfill. The carbon content of western red WRC decking is greater than life cycle carbon emissions. In other words, sequestered carbon in WRC decking and siding is still available to mitigate the carbon footprint of buildings.

The life cycle environmental performance of siding and decking products were compared using the following base-case conditions:

- Decking products have a 25-year service life with no coatings and no board replacements.
- Siding products have a 50-year service life except for clay brick which has a 100-year service life.
- Minneapolis was chosen as the default location for describing the LCIA results as it is a central location in the US. All conclusions that are described for Minneapolis are also applicable to the other locations. The LCIA results are provided for all three locations in the appendix.
- The WRC and FC siding products are painted at installation and thereafter every 15 years.
- 69% of WRC is disposed in a landfill.
- Environmental flows are attributed to the decking or siding products based on the mass allocation (i.e. mass of the main products and co-products).
- All activities or building elements common to all products are ignored.
- All unique elements are included: nails, brick ties, cement mortar and paint.
- The manufacturing location of the WRC products is assumed to be the US Pacific Northwest.
- The manufacturing location of wood-plastic products is assumed as eastern US.
- The manufacturing location of brick products is assumed as eastern US.
- The manufacturing location of the vinyl products is assumed as eastern US.
- Vinyl siding comes with a polyvinyl chloride (PVC) capstock.

The rationale for these base case assumptions are provided in the body of the text.

In the base-case comparison, WRC decking performs substantially better than wood-plastic composites (See Figure A) in all impact categories except biogenic carbon emissions.

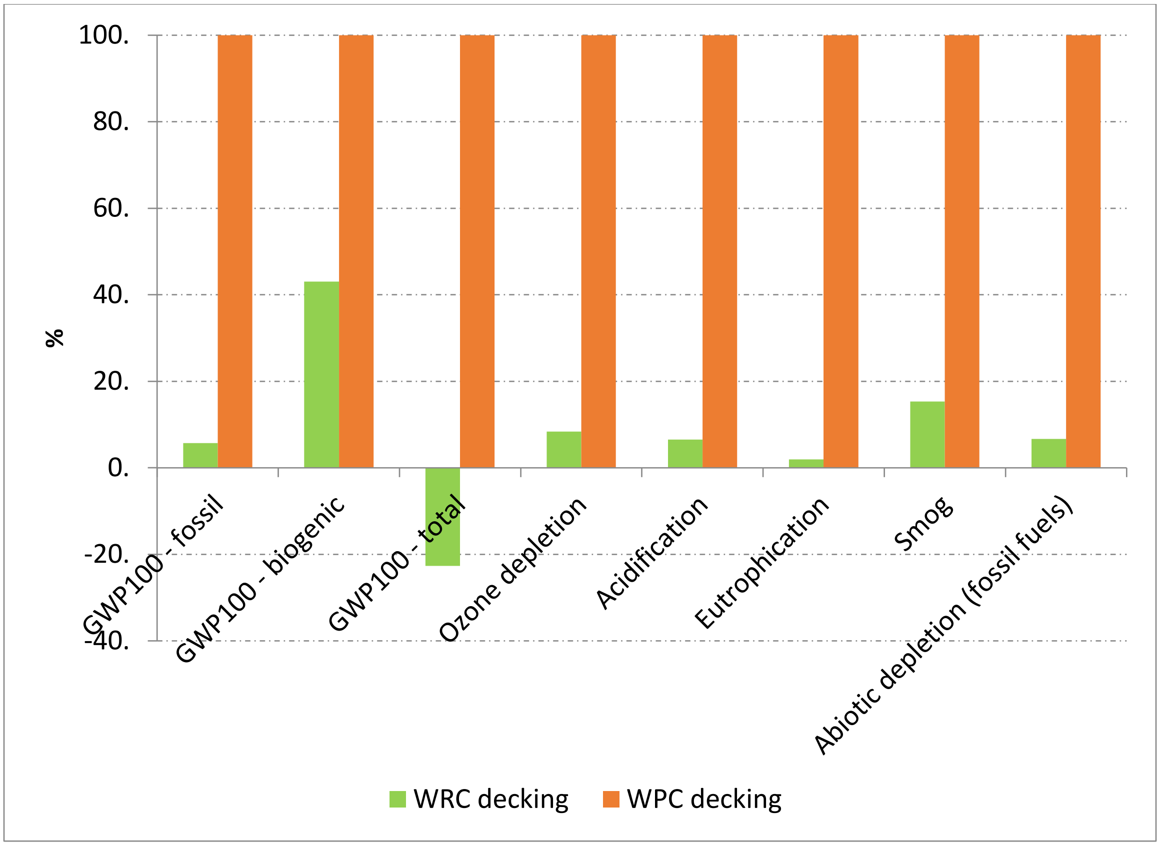

Figure A LCIA Result Comparison for WRC and WPC decking –percentage basis, base case
Note: In each set of bars, the product with the highest impact in that category is the benchmark (100%) and the other products are shown as a percentage relative to the benchmark.

WRC siding performs better than the siding alternatives on the global warming potential (GWP100 fossil) and abiotic depletion of fossil fuel metrics (See Figure B). For siding products, the differences in environmental performance with competing products are smaller than decking because WRC siding carries two additional burdens over decking: it is kiln-dried (a more energy-intensive process) and it is painted. Paint is responsible for a large share of environmental burdens in two impact categories: smog and eutrophication.

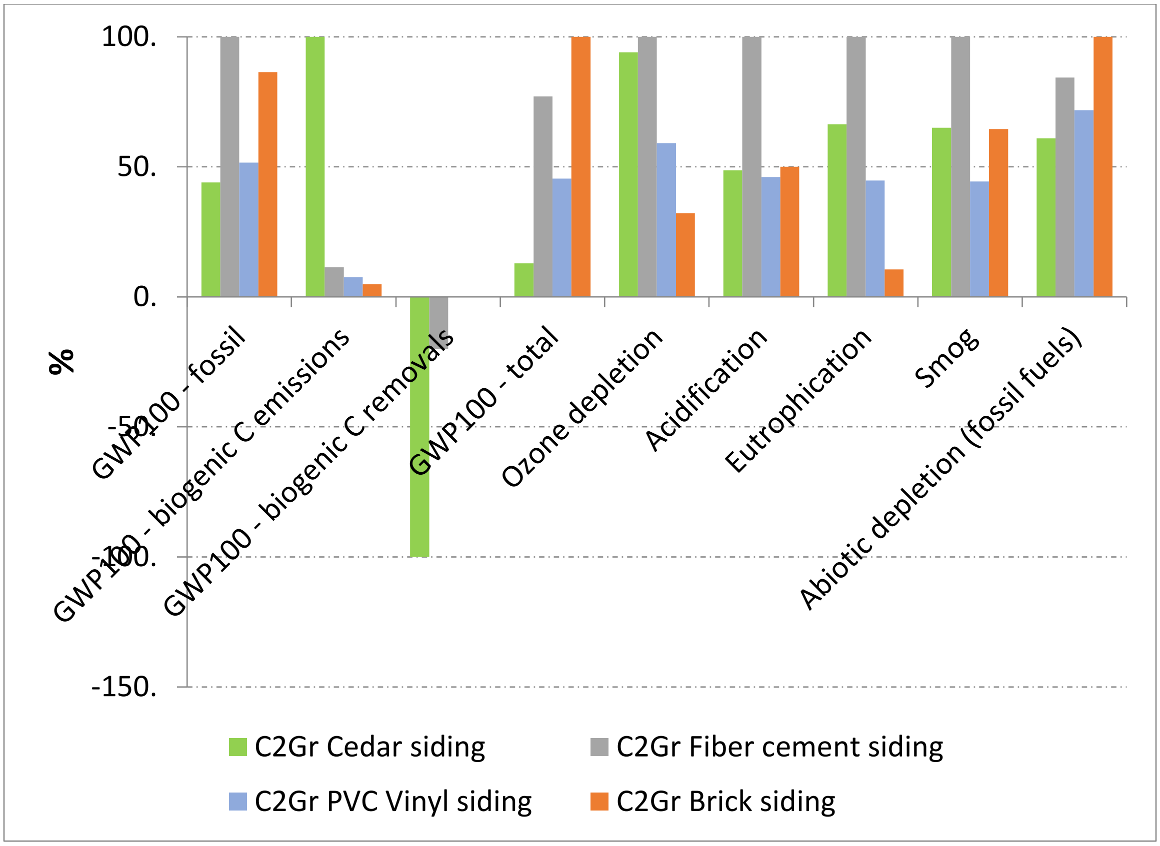

Figure B LCIA results of siding products – percentage basis, base case

Interpretation

Uncertainties surrounding the base case conditions were tested using sensitivity analyses. Sensitivity analyses serve the purpose of exploring how key assumptions affect the results. The following scenarios were analyzed:

Decking

- Replacing 100% of WRC boards due to degradation during use.
- Periodically staining WRC decking.
- Replacing Missouri electricity grid used for WPC decking with less carbon intensive electricity grid (i.e. BC electricity grid which is mostly hydro and less carbon intensive)

Siding

- Increasing the frequency of repainting WRC to every 10 years.
- Vinyl siding comes with acrylonitrile styrene acrylate (ASA) capstock.
- Brick is manufactured using 20% renewable energy.

Results of the sensitivity analysis indicate that the decking and siding findings are generally consistent. For decking, WRC has the lowest impact even in a worst-case scenario for WRC and a base-case scenario for wood-plastic. For siding, paint regimes and end-of-life scenarios are most important since reducing the frequency of painting improves the environmental footprint of WRC siding. WRC siding has the lowest impacts in global warming (GWP100 fossil), and energy use (particularly in abiotic depletion of fossil fuel) in a worst-case scenario for WRC and best-case scenarios for the alternative siding types (brick, FC and vinyl sidings).

Comparative graphs

The figures below show the performance of various products relative to each other across five environmental impact measures as well as energy use (abiotic depletion of fossil fuel). In each set of bars, the product with the highest impact in that category is the benchmark (100%) and the other products are shown as a percentage relative to the benchmark. These are percentage values against a benchmark and not absolute values. In other words, the heights of the bars do not indicate the absolute value and do not indicate relative importance or impact of each measure.

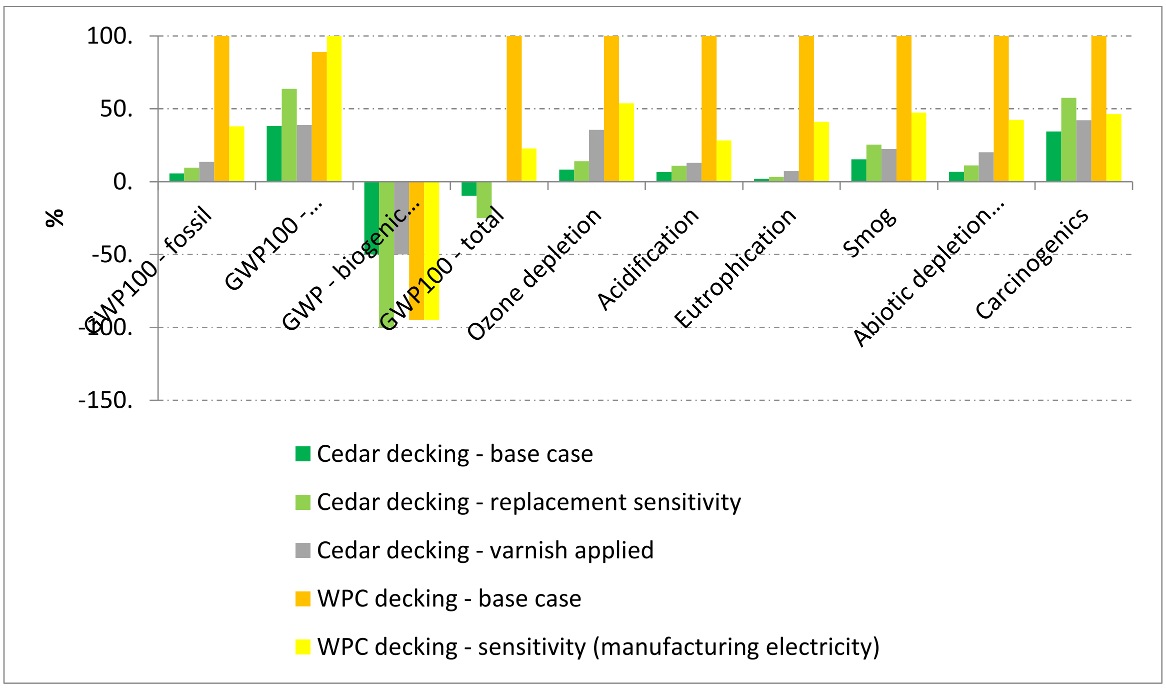

Figure C Summary results of sensitivity analysis conducted for WRC and WPC decking systems on a percentage basis

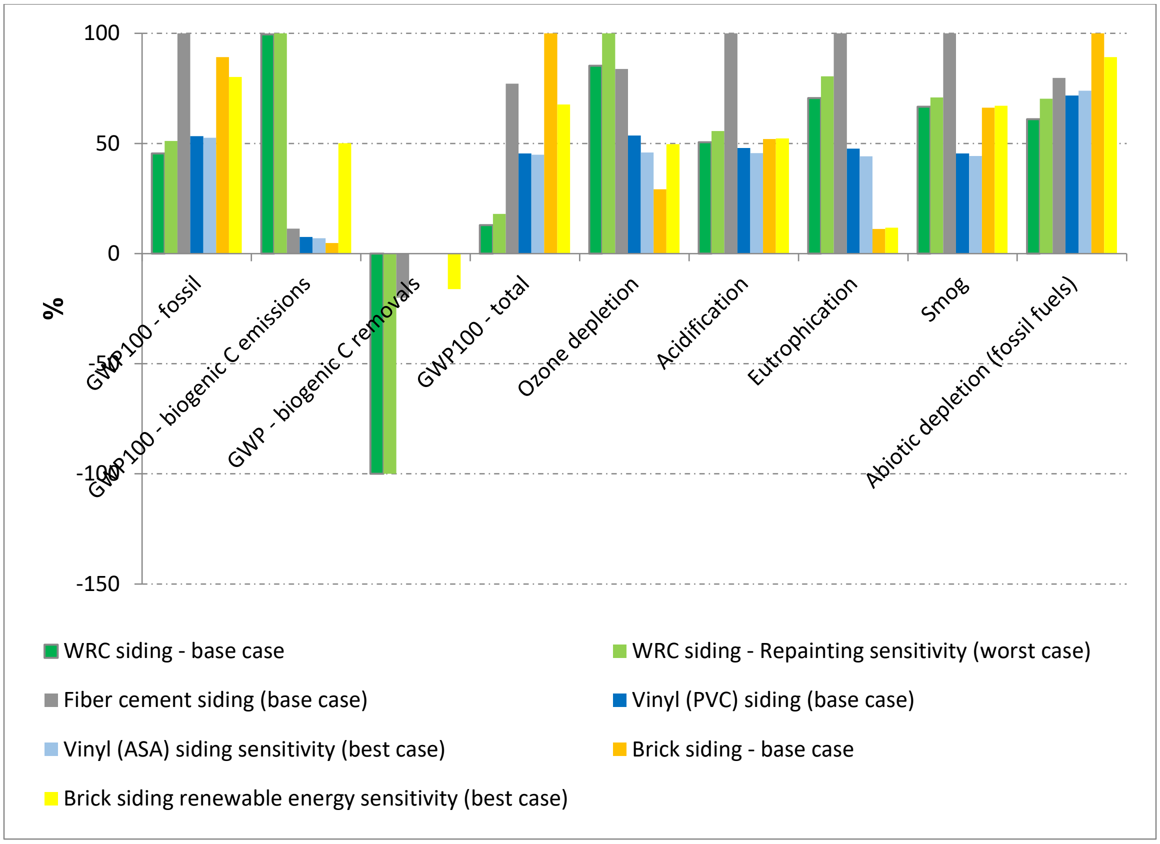

Figure D Sensitivity analysis summary results – WRC siding base case and worst case vs base case of brick siding, FC siding, and vinyl siding base case and best case of brick and vinyl sidings on percentage basis (FU: 100 ft² over 75 years)

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LIST OF ACRONYMS

ADPfossil	Abiotic Resource Depletion Potential of Non-renewable (fossil) energy resources
ASTM	American Society for Testing and Materials
BCEK	Biogenic carbon emissions from packaging
BCEP	Biogenic carbon emissions from the product
BCEW	Biogenic carbon emissions from combustion of waste from renewable sources used in production
BCRK	Biogenic carbon removal from packaging
BCRP	Biogenic carbon removal from the product
CU	Components for reuse
CWNR	Carbon emissions from combustion of waste from non-renewable sources used in production processes
EE	Recovered energy exported from the product system
EPD	Environmental product declaration
EoL	End-of-life
ESL	Estimated service life
FC	Fiber cement
FU	Functional unit
FW	Consumption of freshwater
GWP	Global Warming Potential
HLRW	High level radioactive waste
HWD	Hazardous waste disposed
ILLRW	Intermediate and low-level radioactive waste
ISO	International organization for standardization
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LCA	Life cycle assessment
LHV	Lower heating value

MER	Materials for energy recovery
MJ	Mega joule
MR	Materials for recycling
NHWD	Non- hazardous waste disposed
NPRI	National Pollutant Release Inventory
$NRPR_E$	Non-renewable primary energy carrier used as energy
$NRPR_M$	Non-renewable primary energy carrier used as material
NRSF	Non-renewable secondary fuel
PCR	Product Category Rules
RE	Recovered energy
RSF	Renewable secondary fuel
RPR_E	Renewable primary energy carrier used as energy
RPR_M	Renewable primary energy carrier used as material
SM	Secondary material
TRACI	Tool for the Reduction and Assessment of Chemical and other environmental Impacts
UNEP	United Nations's Environmental Program
UNSPSC	United Nations Standard Products and Services Code
wbLCA	Whole building life cycle assessment
WRCLA	Western red cedar

1 INTRODUCTION

The application and use of life cycle assessment (LCA) is increasing in the field of environmental assessment in many sectors including the construction sector. The US Green Building Council included LCA and environmental product declarations (EPD) in version (v4) of the LEED rating system in 2015. Since then, there is increasing demand from manufacturers to communicate the potential environmental impacts of their products using environmental declarations (EPDs). The Government of Canada under its greening strategy[1], for example, has developed a whole building LCA (wbLCA) for incorporating LCA and EPDs into government procurement[2]. The City of Vancouver is using wbLCA to reduce embodied carbon from the construction sector[3]. In the US, the federal and state governments are using LCAs and EPDs for design and procurement[4][5][6].

Consequently, many manufacturers are now adopting life cycle assessment to help identify and reduce the environmental burdens of their products by considering their product's life cycle environmental footprint. The Western Red WRC Lumber Association (WRCLA) is continuing to apply LCA to benchmark and improve the manufacturing of western red WRC siding and WRC decking products with a view to understand the environmental performance of these products relative to alternative building materials. FPInnovations was commissioned to undertake this LCA study to update the comparative LCA report complied in 2017 and renew the WRC lumber, decking, and siding EPDs. This study follows International Organization for Standardization (ISO) guidelines provided in ISO 14040 and ISO 14044 series[7] and the PCR for Building-Related Products and Services (Part A) published by UL Environment (2022).

This LCA assesses environmental impacts of WRC green lumber (UNSPSC 3110), decking (UNSPSC 31211), and siding (UNSPSC 31211) and compares the life cycle impacts of western red WRC decking to composite wood-plastic decking, and western red WRC siding to vinyl, clay brick (UNSPSC 37117), and fiber cement siding (FC) (UNSPSC 37570)products.

The major changes captured in this updated report include:

- LCI flows, LCIA results, and resource use are calculated and presented in accordance with the Product Category Rules (PCR) Guidance for Building-Related Products Part B Structural and Architectural Wood Products EPD Requirements
- New cradle-to-gate WRC resource extraction and product manufacturing life cycle inventory (LCI) data gathered for 2022 calendar year.

[1] https://nrc.canada.ca/en/research-development/research-collaboration/programs/low-carbon-assets-through-life-cycle-assessment-initiative

[2] https://nrc-publications.canada.ca/eng/view/object/?id=f7bd265d-cc3d-4848-a666-8eeb1fbde910

[3] https://vancouver.ca/files/cov/embodied-carbon-guidelines.pdf

[4] https://www.govinfo.gov/content/pkg/FR-2021-12-13/pdf/2021-27114.pdf

[5] https://www.dgs.ca.gov/PD/Resources/Page-Content/Procurement-Division-Resources-List-Folder/Buy-Clean-California-Act#:~:text=The%20Buy%20Clean%20California%20Act,limit%20for%20four%20eligible%20materials.

[6] https://osa.colorado.gov/energy-environment/buy-clean-colorado-act#:~:text=The%20Buy%20Clean%20Colorado%20(BCCO,or%20after%20January%201%2C%202024.

[7] ISO 14040:2006, *Environmental Management - Life Cycle Assessment - Principles and Framework* and ISO 14044:2006, *Environmental Management - Life Cycle Assessment – Requirements and Guidelines*.

- Newer LCI data based on published in recent EPDs and other literature for wood plastic composite (WPC) decking, FC siding, brick siding, and vinyl siding.
- Global warming impacts are calculated according to IPCC 2021 method (Arias, et. al., 2021).

The four-phased methodology provided in ISO 14040 and ISO 14044 series was applied in conducting this LCA study (see Appendix A for more details).

2 GOAL AND SCOPE DEFINITION

2.1 Goals

The following goals were established for the study considering the WRCLA's intention to apply LCA to understand and improve environmental performance of WRC siding and decking products relative to alternative building materials:

- Conduct environmental life cycle assessments of WRC, clay brick, vinyl and FC siding products and their use in typical residential applications in three US market locations;
- Conduct environmental life cycle assessments of WRC and composite wood-plastic decking with varying levels of recycled content and their use in typical residential applications in three US market locations, and,
- Compare and contrast the life cycle environmental impact of WRC decking and siding with alternative decking and siding products such as composite wood-plastic decking and vinyl, clay brick, and FC siding products used in residential applications.
- Report the LCA results as per the CML life cycle impact assessment method (CML, 2016) to maintain or expand export market of Canadian WRC products to Netherlands

These comparative assertions rely on primary data gathered in for WRC resource extraction and product manufacturing operations, and secondary data available in the literature for alternative decking and siding types. Data quality criteria discussed in Section 2.4.2 applied in drawing secondary data in modeling the competing alternative products, and wherever applicable the data quality issues including missing data are discussed and limitations are provided in the report.

2.2 Intended Uses

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

- *Process Improvements* – WRCLA participating plants can use the LCA to evaluate possible process improvements in the manufacture of WRC lumber and siding.
- Communicate with consumers – WRCLA intends to use the results to develop and publish cradle-to-grave environmental product declarations (EPD) for WRC siding and WRC decking.

In addition, the results of the study may be used by WRCLA for the following purposes:

- The results of the study are useful as a benchmark in tracking significant aspects and environmental impacts in devising an ISO compliant environmental management program for the industry.
- *Sustainable Development Reporting and Indicators* – the plant LCI data may be used in part for sustainability reporting by the participating facilities.

Findings from this study may be useful for waste management companies and municipalities to better understand potential environmental impacts from end-of-life disposal practices of siding and decking products.

ISO 14044 (2006) requires that LCA studies making *comparative assertions* need to be critically reviewed by a third-party panel in order to reduce possible misunderstanding or negative effects on external interested parties when disclosing the results to the public. As WRCLA intends to disclose the findings from this study to the public, this study was critically reviewed by a three-member third party panel comprised of Dr. Tom Gloria at Industrial Ecology Consultants (chair), Dr. Charles Thibodeau, an independent contractor at CT Consultant and James Salazar at WAP Sustainability (see final critical review report in Appendix O).

2.3 Functional Unit

The functional unit (FU) is quantified performance of a product system for use as a reference unit in LCA. Siding, for example, protects a given wall area (ft^2 or m^2) against weather including rain, snow or ice while decking extends living space (ft^2 or m^2) of a building. Besides these primary functions, siding provides aesthetically pleasing look and decking enhances the visual appeal of a building. Inclusion of such secondary utility functions in the assessment of the product systems is beyond the scope of the study. Further, sidings have different thermal properties (i.e. different R-values) depending on the siding products and types. Sidings' contribution to overall thermal performance of an exterior wall is minor given that their R-values with respect to the overall R-values of an exterior wall are very small[8].

In defining a functional unit, the study looked into the units of measurements that are used in the construction products market in the US. In the US, construction products are sold in imperial sizes. For this reason, the FU used in this assessment is 100 square feet of installed cladding or decking products including any ancillary materials (e.g., fasteners, mortar, paint, etc.) for 75 years building life including end-of-life disposition of the unique product systems. The assumed service life, i.e. the key performance characteristic for the residential decking and siding product systems are 25 and 50 years, respectively. The study assumes that with proper maintenance and replacement regimes that the service life performance of the alternative siding and decking systems are or can be made effectively equivalent. Reference flows quantify the amounts of products required to deliver the functional unit (e.g. 100 ft^2 of siding for 75 years) over the life cycle of a residential building. A default 75-year building estimated service life (ESL)" shall be used for construction products systems per the building related products and services product category rules (PCR)

[8] Typical recommendations by US Department of Energy for exterior walls range from R-13 to R-23 (see https://www.jm.com). Sidings' contribution to overall R-value exterior walls are small as R-value of WRC, FC, brick and vinyl siding are 0.81, 0.37, 0.44 (see http://www.sidingpriceguides.com) and 0.62 (see https://www.archtoolbox.com) respectively.

published by UL Environment (2022) for construction products. Figure 1 depicts decking and siding products included in this study. The calculated reference flows for each of the product systems installed in residential building with 75-year service life are provided in Table 1 and Table 2.

Default end-of-life solid waste management practices for each of the decking and siding products were defined based on the recyclability, current North American waste management drivers and common disposal practices. The product service life and end-of-life disposal scenarios are investigated with a sensitivity analysis to explore the implications of these default assumptions on the study conclusions.

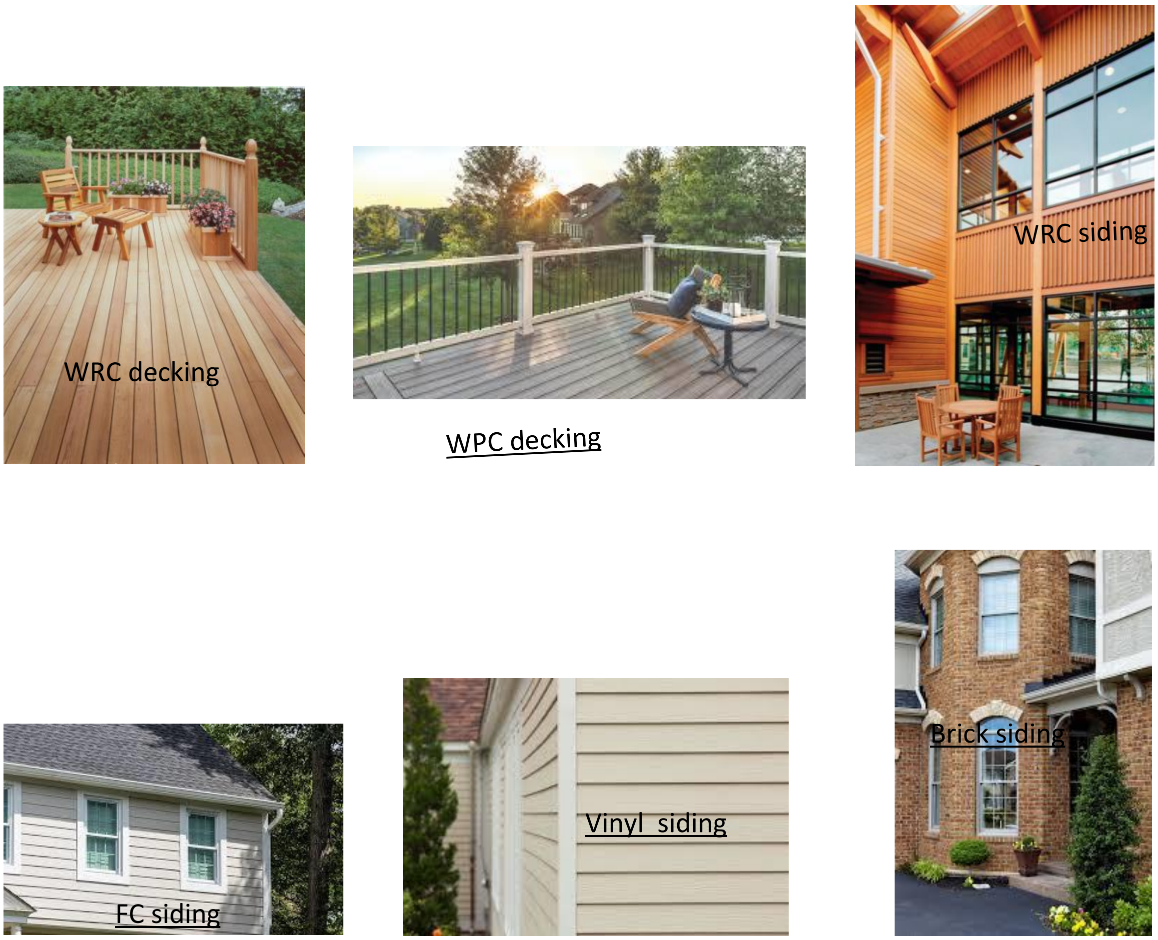


Figure 1 **Images of decking and siding products included in this study**

Table 1 Product specifics, functions, functional unit and reference flows of decking product systems

Product		WRC decking	WPC decking
Product specifics	Size of boards (Nominal)	5/4" x 6"	1" x 6"
	Density	329 kg (oven dry)/m3	Density of WPC is 1,180 kg/m^3
	Service life	25 years	25 years
Functions		(a) Extends living space of a building. (b) Enhances the visual appeal of a building (c) Meets WRCLA specifications*	(a) Extends living space of a building. (b) Enhances the visual appeal of a building (c) Meets ASTM D7032 – 15 performance rating (equivalent to WRCLA specifications)
Relevant functions for this particular LCA		Extension of living space of a building.	
Functional unit		100 square feet of installed decking over 75-year building life	100 square feet of installed decking over 75-year building life
Performance of the product		238 linear feets of 5/4 WRC boards/100 sq.ft deck and a life span of 25 years	240 linear feets of 5/4 WPC boards/100 sq.ft deck and a life span of 25 years;
Reference flows		3 cradle-to-grave life cycle = 75/25 of 100 sq. ft of WRC decking with a life span of 25 years (3 replacements over 75-year building life); decking material amount: 306.9 kg for 75 years building life	3 cradle-to-grave life cycle = 75/25 of 100 sq. ft of WPC decking with a life span of 25 years (3 replacements over 75-year building life); decking material amount: 1354.05 kg for 75 years building life;

Table 2 Product specifics, functions, functional unit and reference flows of siding product systems

Product	WRC siding	FC	Vinyl siding	Brick siding
Product specifics	Type – Generic Density- 329 kg (oven dry)/m^3 Generic dimensions: 1/2” x 6” Service life=50 years (1.5 replacements over 75 years)	Type – Generic Specific density- 12.45 kg/m^2 Generic dimensions: 5/16”x6-1/4” Service life=50 years (1.5 replacements over 75 years) Meets Type A sheet requirements of ASTM C1186 - 08(2016)	Type- Generic Specific density- 1430 kg/m^3 Generic dimensions: One square (100 ft^2) Service life=50 years (1.5 replacements over 75 years) Made according to ASTM D3679 - 13	Type- Generic Specific density- 2120 kg/m^3 Generic dimensions: - Service life=100 years[9] No replacements over 75 years). Made according to ASTM C1088 - 14 Type TBS (Standard)
Functions	(a) Primary function: provide an external cover to protect the internal wall structure against rain, snow or ice; (b) Other functions: aesthetic function			
Relevant functions for this particular LCA	Primary function: provide an external cover to protect the internal wall structure			
Functional unit	100 square feet of installed siding over 75-year building life			
Performance of the product*	110 sq.ft of WRC siding product with generic product dimensions (1/2”x6”) and a life span of 50 years. Installed per WRCLA specifications**	110 sq.ft of FC siding product with generic product dimensions (5/16”x6-1/4”) and a life span of 50 years	110 sq.ft of vinyl siding product with generic product dimensions (one square) and a life span of 50 years. Installed per ASTM D4756.	105 sq. ft of brick siding with generic product and a life span of 50 years
Reference flows for 75 years building life	1.5 cradle-to-grave life cycle = 75/50 of 100 sq. ft. of WRC siding with a life span of 50 years; siding material amount: 64.80 kg	1.5 cradle-to-grave life cycle = 75/50 of 100 sq. ft of FC siding with a life span of 50 years; siding material amount: 228.75 kg	1.5 cradle-to-grave life cycle = 75/50 of 100 sq. ft. of vinyl siding with a life span of 50 years; siding material amount: 28.95 kg	1 cradle-to-grave life cycle = 75/75 of 100 sq. ft. of brick siding with a life span of 50 years; siding material amount: 1543.50 kg

[9] See https://www.nachi.org/inspecting-brick-veneer-residential-construction.htm

2.1 System Boundary

Figure 2 defines the decking and siding system boundaries. The study considers all the life cycle stages (i.e., production, construction, operation, and end-of life (EoL)), and the activities except repairs (B3), refurbishment (B5), and energy consumption (B6) information modules in the operation stage. Repairs and refurbishment are excluded considering both decking and siding come with product warranties. Energy consumption (B6) is excluded because decking and siding are exterior parts of buildings that do not require operational energy during their use. More importantly, the contribution of siding to overall thermal performance of an exterior wall is minor. The score of B1 is set to zero since emissions associated with detergent and water use during periodic maintenance are accounted in module B2.

This study assumes that the structural requirements for all decking and siding types are identical. As a result, structural elements are excluded from the study's system boundary.

The study system boundary includes the transportation of major inputs to (and within) each activity stage including the shipment of decking and siding products to three hypothetical building site locations in the US (i.e., Seattle, Minneapolis, and New York city) by common transportation modes as well as transportation to a waste transfer station at the end of the service life for each product. Benefits beyond the EoL included in Module D (i.e., reuse and recycling) are excluded from the system boundary.

Any site-generated energy and purchased electricity for manufacturing facilities in the A3 stage is included in the system boundary. The extraction, processing, and delivery of primary fuels, e.g., natural gas and fuels used to generate purchased electricity are also included within the system boundary. Purchased electricity consumed at various site locations is modeled to come from the relevant Canadian and US e-GRID regions.

Ancillary material use (e.g., paints, fasteners, packaging materials, etc.) was also investigated for inclusion within the system boundary (see 2.4.1 below for cut-off criteria levels).

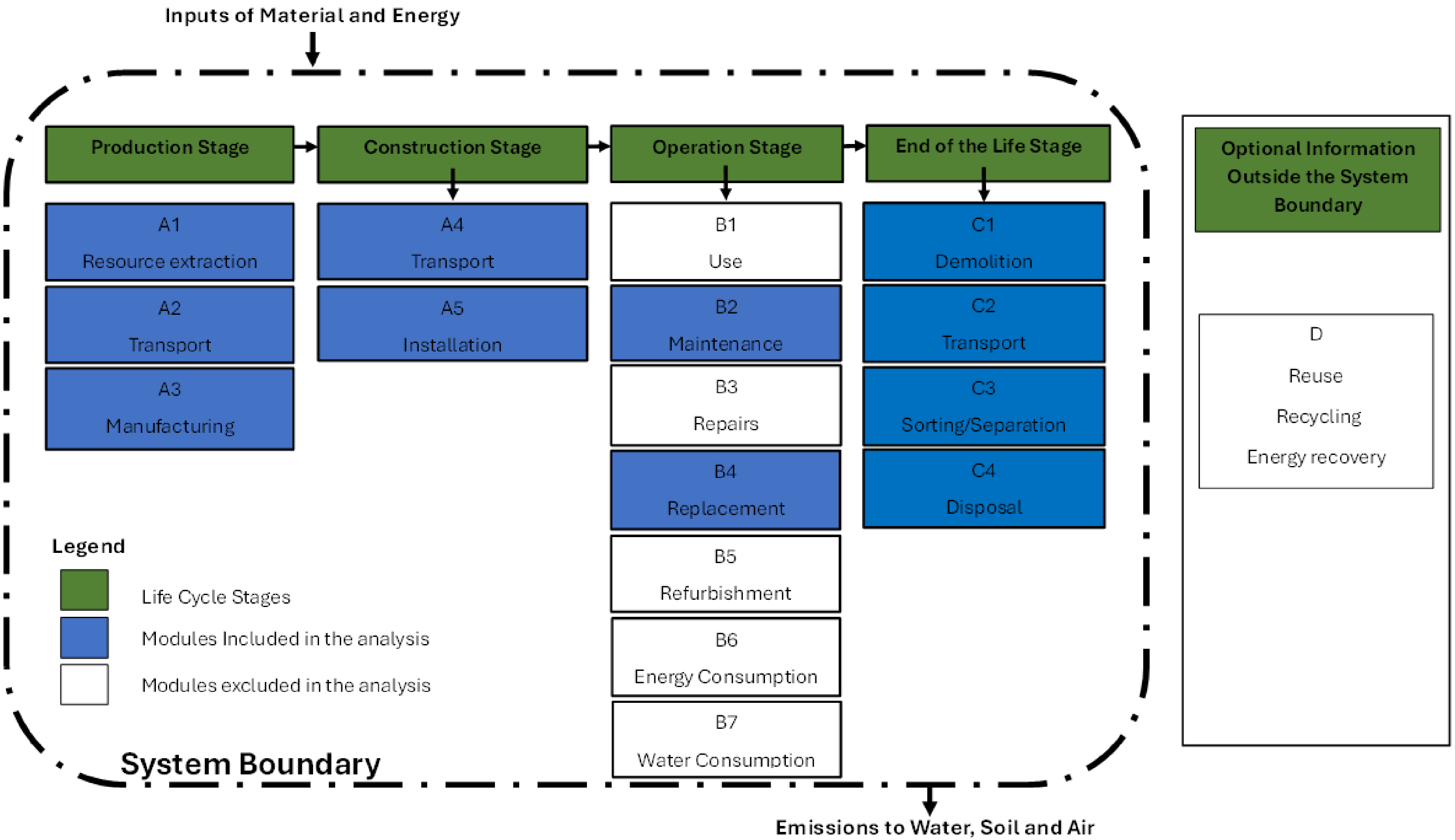


Figure 2 System boundary of decking and siding systems

2.2 Cut-off Criteria

Cut-off was avoided as much as possible by collecting process-specific data. The following cut-off criteria were applied when it is not possible to avoid cut-off:

1. Any flows contributing to more than 1% of the mass or energy inputs to the processes are included. If data is available, these flows are included even if they represent less than 1% of the mass and energy required over the product lifecycle inventory under the FU.
2. Environmental relevance – if a flow meets the above two criteria, but is determined (via secondary data analysis) to contribute 2% or more to any product life cycle impact category (see below), it is included within the system boundary. Flows contributing less than 2% of impacts were excluded.

At least 95% of the total mass and energy flows of all the modules involved in the system boundary of the underlying LCA were included and the life cycle impact data contain at least 95% of all elementary flows that contribute to each of the impact category indicators. All chemical substances listed in the National Pollutant Release Inventory (NPRI) were included in the LCA. Cut-off rules were applied to all other substances except toxic materials and substances.

List of the input flows that deemed to have met these cut-off criteria and were excluded from the decking and selected product system is provided in Table 3 below.

Table 3 Excluded input flows that deemed to have met the cut-off criteria

Product system	Excluded input flows
Decking	
WRC	Electricity consumption for the power guns/drills used for installation, electricity used for power washing decks
WPC	Packaging, Electricity consumption for the power guns/drills used for installation, electricity used for power washing decks
Siding	
WRC	Electricity consumption for the power guns/drills used for installation, and electricity used for power washing exterior cladding
Brick	Packaging, electricity consumption for the power guns/drills used for installation, electricity used for power washing exterior cladding
FC	Packaging, electricity consumption for the power guns/drills used for installation, electricity used for power washing exterior cladding
Vinyl	Packaging, electricity consumption for the power guns/drills used for installation, electricity used for power washing exterior cladding

2.3 Data Quality Requirements

The data source should be complete and representative of North America in terms of the geographic and technological coverage and be of a recent vintage, i.e. less than 10 years old. North America (Canada and USA, not Mexico) is considered as the geographic boundary of this study. Data should be precise, consistent, and reproduceable, and where applicable, missing data are documented. The reference year is considered to be 2022 as the primary data on WRC siding and decking manufacturing were gathered for that calendar year.

2.3.1 Data Sources and Modeling Software

North America is considered as the geographic boundary of this study. The reference year is 2022 as the primary data on WRC siding and decking manufacturing were gathered for that calendar year. All other LCI data is collected from secondary sources including EPDs, literature, previous LCI studies and life cycle databases (e.g. emissions from fuel combustion, fuel production, brick production, etc.).

The study relied on secondary LCI data available in DATASMART LCI Package (LTS, 2021), USLCI (National Renewable Energy Laboratory, 2012) and ecoinvent 3.8. DATASMART Life Cycle Inventory better represents U.S. operations than other LCI data sources and is representative of the North American region[10]. This database contains USLCI data modified with ecoinvent v.2.2 datasets and electricity grid mixes for all states in the US. The dummy processes in the US LCI database are replaced with appropriate data. DATASMART fulfills the requirements of product category rules (PCRs) that require data representative of U.S. and North America (LTS, 2021).

SimaPro software v9.4.0.3 was used for modeling the complete cradle-to-grave LCI for both the decking and siding product systems. Within SimaPro, all process data including inputs (raw materials, energy and ancillary material use) and outputs (emissions and production volumes) are considered and modeled to represent each unit and system process. The analysis includes both measured and calculated data and conducts a mass balance to ensure consistency. The complete LCIs (as well as technosphere flows) for the various process and product systems are provided to aid external reproducibility. The study's geographical and technological coverage is North America as well as average or typical technologies. SimaPro was used for generating life cycle impact assessment (LCIA) results.

2.3.2 Data Exclusions from the System Boundary

Human activity, capital equipment and infrastructure, and land use associated with forestry and WRC product manufacturing operations, and alternative product manufacturing operations were excluded from the system boundary for the following reasons:

- The data collection required to properly quantify human involvement in production is particularly complicated, and allocating such flows to production and use, as opposed to other societal activities, was not feasible for a study of this nature.

[10] https://simapro.com/products/datasmart-lci-package/

- The environmental effects of capital equipment manufacturing and installation 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.
- Currently there is no internationally accepted methodology to address land use impacts on biodiversity and ecosystems services (UNEP, 2016).

2.4 Allocation

2.4.1 Multiple-output Process Allocation

For processes that produce multiple products, input and output flows need to be split among the multiple products coming out from the product system in accordance with the principles of partitioning of the LCI flows among defined in ISO 14040 and ISO 14044 series. Among the decking and siding products included in this comparative assertion, only WRC products generate multiple products. All other products are single output product systems, and hence multiple-output process allocation applies only to WRC decking and siding.

WRC harvesting produces roundwood and harvest residues (waste) and WRC lumber manufacturing produces a main product, lumber, as well as coproducts such as bark, pulp chips, etc. One way of splitting the burden is based on the physical relationships (i.e., mass) between the lumber and co-products. PCR Part B Structural and Architectural Wood Products EPD Requirements (UL Environment, 2019) requires allocating environmental burden based on mass; mass allocation is applied in the base case analysis to split the environmental burden of the main product and co-products comes out from WRC lumber, decking, and siding manufacturing phase (A3). Revenue based allocation was applied in the sensitivity analysis to evaluate the validity of base case findings.

2.4.2 Allocation procedure for recycling

Among the product systems considered, only WPC decking production uses both virgin and recycled PE as material inputs. The cut-off approach was applied to split the initial burden associated with recycled PE. All burdens from virgin PE production are assigned to the first use and the burdens associated with the reprocessing of post-consumer PE were assigned to recycled PE.

2.5 Selected Life Cycle Impact Assessment Indicators

As defined in ISO 14044:2006, “*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, a set of selected environmental issues referred to as impact categories is modeled, and category indicators are used 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. LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

ISO 14044 does not specify impact assessment methods 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. As such, the selected indicators to be supported in the study were selected to cover the breadth of resource and materials inputs and releases to air, water and land without venturing into less established measures, i.e., the selected measures tend towards mid-point potentials as opposed to the less certain end-point valuations based on damage functions.

The LCIA framework includes three steps to convert LCI results to 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.

The environmental impact categories stated in ISO 21930[11] (i.e. global warming, ozone depletion, acidification and smog effects), and Abiotic Resource Depletion Potential of Non-renewable (fossil) energy resources (ADPfossil), are used for the comparative assertion to report environmental impacts (see Table 4) considering the environmental emissions occur during the cradle-to-grave life cycles of the decking and siding products. Impact assessment methods are chosen in accordance with the PCR for Building-Related Products and Services: Part A published by UL Environment (2022).

The U.S. Environmental Protection Agency's TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts) v2.1 was the LCIA tool applied to characterize the inventory flows. The GWP method available in TRACI v2.1 was replaced with IPCC 2021 GWP 100 method to align with ISO 21930. Also, the TRACI method was supplemented with CML-baseline, v4.7 August 2016 to calculate ADP fossil impacts. Cumulative Energy Demand (CED v1.00) was used to estimate primary energy consumption by energy sources.

Material consumption and waste data derived from LCI and not assigned to impact categories were not included in the comparative assertion. However, material consumption, fresh water consumption, waste, and biogenic carbon removals and emissions (see Table 6 for more details) results were calculated in accordance with the UL Environment PCR Part A for WRC rough green lumber, decking and siding, and provided in Appendix B for EPD reporting. In addition, the impacts categories shown in Table 4 were chosen in accordance with the requirements of the Dutch building code for reporting in WRC EPDs. As per the Dutch Building code, the CML 2 baseline 2016 LCIA method (v3.01) was applied to calculate environmental impacts since Europe is one of the main export markets of WRC products. The Dutch Building regulation[12] requires CML CML-IA Baseline method to calculate environmental impacts of

[11] ISO 21930 2007, Sustainability in building construction - Environmental declaration of building products
[12] See https://www.rijksoverheid.nl/documenten/richtlijnen/2011/10/05/praktijkboek-bouwbesluit-2012.

building products (see Table 5 for the environmental impact indicators used, and Appendix C and Appendix D for LCIA results calculated using the CML method).

Table 4 Reported impact categories and inventory flows

LCIA Indicator	Unit
Global Warming Potential (GWP)	kg CO_2 eq.
Acidification Potential	kg SO_2 eq.
Eutrophication Potential	kg N eq.
Smog Creation Potential	kg O_3 eq.
Ozone Depletion Potential	kg CFC-11 eq.
Abiotic Resource Depletion Potential of Non-renewable (fossil) energy resources (ADPfossil)	MJ, LHV

Table 5 Reported impact categories and inventory flows per Dutch building regulation

Indicator	Unit
LCIA Indicators*	
Abiotic depletion, non-fuel	kg antimony eq.
Abiotic depletion, fuel	kg antimony eq.
Global warming (GWP100)	kg CO_2 eq.
Ozone layer depletion (ODP)	kg CFC-11 eq.
Photochemical oxidation	kg ethylene eq.
Acidification	kg SO_2 eq.
Eutrophication	kg PO_4- eq.
Human toxicity	kg 1,4-dichloorbenzeen eq.
Fresh water aquatic ecotoxicity	kg 1,4-dichloorbenzeen eq.
Marine aquatic ecotoxicity	kg 1,4-dichloorbenzeen eq.
Terrestrial ecotoxicity	kg 1,4-dichloorbenzeen eq.

Note: ** Calculated using CML-IA Baseline 2016 method*

*** Resource (energy) use calculated using Cumulative Energy Demand method*

Table 6 Indicators derived from LCI

LCI parameter	Abbreviation	Description*	Unit	Method
Resource use - Use of primary resources				
Renewable primary energy carrier used as energy	RPR_E	"Renewable primary resources used as an energy carrier (fuel), are (first use) bio-based materials used as an energy source. Hydropower, solar and wind power used in the technosphere are also included in this indicator."	MJ, LHV	CED v1.11
Renewable primary energy carrier used as material	RPR_M	Renewable primary resources with energy content used as material, RPRM, are (first use) bio-based materials used as materials (e.g., wood, hemp, etc.)."	MJ, LHV	LCI indicator
Non-renewable primary energy carrier used as energy	$NRPR_E$	"Non-renewable primary resources used as an energy carrier (fuel), NRPRE , are (first use) materials such as peat, oil, gas, coal, [and] uranium used as an energy source."	MJ, LHV	CED v1.11
Non-renewable primary energy carrier used as material	$NRPR_M$	Non-renewable primary resources with energy content used as material, RPRM, are (first use) bio-based materials used as materials (e.g., oil, gas, coal, etc.)	MJ, LHV	LCI indicator
Resource use - Secondary material, secondary fuel, and recovered energy				
Secondary material	SM	"Secondary materials, SM, are materials recycled from previous use or waste (e.g., scrap metal, broken concrete, broken glass, plastic and wood) that are used as a material input from another product system. These include both renewable and non-renewable resources, with or without energy content, depending on the status of the material when it was originally extracted from the environment."	kg	LCI indicator

Renewable secondary fuel	RSF	"Renewable secondary fuels, RSF, are renewable materials with energy content that have crossed the system boundary between product systems and are used as fuel input (energy source) in another product system (e.g., biomass residue pellets, chipped waste wood)."	MJ, LHV	LCI indicator
Non-renewable secondary fuel	NRSF	"Non-renewable secondary fuels, NRSF, are non-renewable materials with energy content that have crossed the system boundary between product systems and are used as fuel input (energy source) in another product system (e.g., processed solvents, shredded tyres)."	MJ, LHV	LCI indicator
Recovered energy	RE	"Recovered energy, RE, is energy recovered from disposal of waste in previous systems, such as energy recovered from combustion of landfill gas or energy recovered from other systems using energy sources."	MJ, LHV	LCI indicator
Resource use - Mandatory inventory parameters				
Consumption of freshwater	FW	"Net freshwater entering the product system being studied that is not returned to the same drainage basin from which it originated"	m^3	LCI indicator
Indicators describing waste				
Hazardous waste disposed	HWD	-	kg	LCI indicator
Non- hazardous waste disposed	NHWD	-	kg	LCI indicator
High level radioactive waste	HLRW	-	m^3	LCI indicator
Intermediate and low-level radioactive waste	ILLRW	-	m^3	LCI indicator

Components for reuse	CRU	-	kg	LCI indicator
Materials for recycling	MR	-	kg	LCI indicator
Materials for energy recovery	MER	-	kg	LCI indicator
Recovered energy exported from the product system	EE	-	MJ, LHV	LCI indicator
Additional inventory parameters				
Biogenic carbon removal from the product	BCRP	"Biogenic CO2 , reporting the removals and emissions associated with biogenic carbon content contained within biobased products, occurring in each module"	kg CO_2	LCI indicator
Biogenic carbon emissions from the product	BCEP		kg CO_2	LCI indicator
Biogenic carbon removal from packaging	BCRK	Biogenic CO2 , reporting the removals and emissions associated with biogenic carbon content contained within biobased packaging"	kg CO_2	LCI indicator
Biogenic carbon emissions from packaging	BCEK		kg CO_2	LCI indicator
Biogenic carbon emissions from combustion of waste from renewable sources used in production	BCEW	"Biogenic CO2 , reporting the emissions from combustion of waste from renewable sources used in production processes."	kg CO_2	LCI indicator
Carbon emissions from combustion of waste from non-renewable sources used in production processes*	CWNR	Non-biogenic CO2 , reporting the emissions from combustion of waste from non-renewable sources used in production processes	kg CO_2	LCI indicator

*Note: *not included since the products included in this study does not use waste from non-renewable sources as a manufacturing energy source*

2.6 Default Service Life and End-of-Life Assumptions

The study assumes the service life for the four siding and two decking materials to be 50 and 25 years. The service life of any one product is undoubtedly variable and some products (e.g., clay brick cladding) may have a service life well beyond 50-years or be disposed of prior to the expected service life because of demolition or owner preferences (e.g. aesthetics). The selected service lives used in the project is based on the life expectancies of building materials used for residential property management and product warranty claims of manufacturers (see Sections 4.1 and 4.2 for more details). According to the guide provided by the Authority Property Management, wood siding could last up to 50 years with proper maintenance (Robertson, 2025). As per life span estimates provided by allura (2025), cedar siding lasts >75 years in average. The lifespan of decks varies depending on the materials used. Wood decks, for example, typically lasts 15 25 years with proper maintenance (Robertson, 2025). The upper limit of service life provided by Robertson (2025) for wood decking is used as the default service life of cedar decking and a sensitivity analysis s performed using the lower limit to test the validity of default service life results. The study follows waste classification in the US which is primarily governed by the Resource Conservation and Recovery Act (RCRA). According to United States Environmental Protection Agency (US EPA (2020)), about 70% and 87% of construction and demolition (C&D) wood waste and brick and clay tile waste are landfilled in 2015 respectively. Landfilling is thus considered the default waste management practice for all siding and decking products.

3 CRADLE-TO-GATE LIFE CYCLE INVENTORIES OF SIDING AND DECKING

This chapter discusses the cradle-to-gate life cycle inventories for decking and siding materials. Cradle-to-gate inventories include resource extraction, resource transportation, and manufacturing of decking and siding materials ready for shipment at the plant gate.

Decking products life cycle inventories (LCIs) are presented in section 3.1 and siding products LCIs are presented in section 3.2. Each product's manufacturing process is presented to familiarize the reader with the different steps involved in the production of each product. The study followed the information modules presented in Figure 2:

- Production stage
  A_1 – extraction (removal) of raw materials and processing; A_2 – transportation of raw materials from an extraction site to a manufacturing site; and A_3 – manufacturing of the product, including packaging;
- Construction stage
  A_4 – construction stage (building product transport to construction site); A_5 – installation;
- Use-stage
  B_2 maintenance, B_4 replacement, and B_7 water use and
- End-of-life stage

C1, deconstruction, dismantling/demolition, C2, transport from building site to waste processing, C3, sorting/separation, and C4, disposal).

Section 3.1 and 3.2 provide cradle-to-gate inventories for each decking and siding product. Section 3.3 provides installation and use inventories and Section 3.4 describes the default end-of-life inventory.

3.1 Decking Cradle-to-gate Inventory

This section describes the cradle-to-gate life cycle inventories of decking manufacturing. For both WRC) and WPC decking the reference flow is 1000 board feet of decking ready for shipment at the facility gate.

3.1.1 WRC Decking

This LCI is based on the data gathered in 2023 for the 2022 calendar year. The WRC decking manufacturing process is depicted in Figure 3. WRC logs are harvested from forests located in the Pacific Northwest of the United States and from coastal British Columbia (Gonzalez, 2004). Harvested trees are delimbed and converted into logs and then transported to the mills to manufacture lumber. The lumber is then used to make various WRC products, mainly WRC siding and decking products. WRC products are often used without being treated for weather resistance as WRC is naturally resistant to decay and insect damage (Gonzalez, 2004). WRC decking is produced at both large sawmills, called integrated mills, that convert logs into various sizes of lumber and decking, and small-scale remanufacturers who produce both siding and decking from rough green lumber purchased from large sawmills or integrated mills. Both siding and decking typically leave the mills without any paint or stain applied. Painting/staining is a third-party process occurring in transit or just prior to installation.

Cradle-to-gate flow data

The cradle-to-gate LCI for WRC decking includes the A1, A2 and A3 modules described earlier.

Resource extraction (A1) from forests involves harvesting and reforestation (either by natural regeneration or planting). In B.C., harvested sites are reforested 20% by natural regeneration and 80% by planting (BC Government, 2024). A1 includes the fuel use and ancillary materials associated with the following processes: harvesting, nursery operations, and forest management that includes site preparation and planting, and subsequent forest management operations e.g. thinning, etc. (see Table 7). Activities associated with harvesting include felling, delimbing, and bucking trees into optimal log lengths. In coastal B.C., these logs are then typically moved from the stump to a landing prior to transport to a sawmill. The outputs from this system process are logs ready for transport at a designated landing while harvest residues are left onsite.

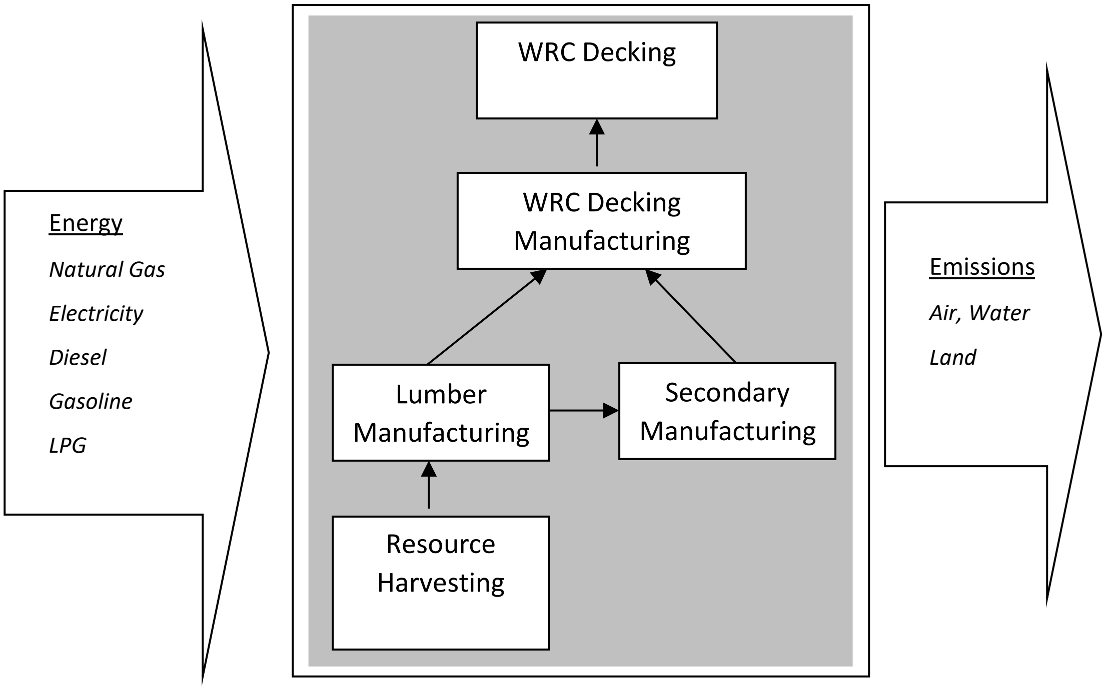


Figure 3 Schematic representation of cradle-to-gate WRC decking manufacturing

The technosphere flows for resource extraction are shown in Table 7. Background LCI data sources used to model material and energy inputs used for resource extraction from forests are presented in Table 14.

Table 7 Technosphere flows for resource extraction per cubic meter of WRC

Resource extraction flows	Unit	Quantity per cubic meter
Inputs – nursery operations		
WRC seeds	g	0.014
Peat	kg	0.023
Nitrogen fertilizer	g	0.623
Phosphorus fertilizer	g	0.230
Potassium fertilizer	g	0.623
Electricity	kWh	0.016
Diesel	L	2.35E-04
Natural Gas	MJ	0.436
Propane	L	3.02E-04
Transportation - materials and fuels	tkm	0.037
Waste		
Waste (plastic wrapping)	kg	4.63E-04
Transportation – waste*	tkm	5.97E-06

Inputs – Forest management (site preparation, planting, fertilizer application, thinning)**		
Nitrogen fertilizer	kg	0.755
Phosphorus fertilizer	kg	0.128
Gasoline	L	0.022
Inputs – Forest road building		
Diesel	L	0.182
Gasoline	L	0.006
Hydraulic fluid	L	0.002
Motor oil	L	4.37E-04
Grease	kg	2.00E-04
Inputs – Forest harvesting		
Diesel	L	3.411
Gasoline	L	0.171
Propane	L	0.019
Hydraulic fluid	L	0.038
Motor oil	L	0.008
Grease	L	0.004
Outputs		
Round wood***	m^3	1.000
Waste		
Harvesting residues****	kg (oven dry)	11.520

Note: * *Landfilling*
** *Source: Puettmann., 2019.*
*** *Density of WRC is 329 kg per cubic meter (oven dry weight based on green volume reported in Nielson et al., 1985)*
**** *Estimated based on the biomass ratios provided by MacDonald (2009) for WRC harvesting (3.5% applied). This does not include slash and stumps left on-site.*

Resource Transportation (A_2) starts at the forest landing and includes loading and transporting the logs to the mill by a combination of truck and water (log boom or barge). Harvesting activities generate logs (measured in m^3) which are then delivered to a sawmill. Table 8 shows the weighted average resource transportation modes and distances of the two lumber mills which participated in the survey. The three remanufacturing mills surveyed received lumber from 5 – 119 km via road (i.e. using trucks).

Table 8 Resource transportation modes and distances

Transportation mode	Average distance (km)	Average tkm per m^3
Truck	237	280.79
Water - log boom	115	193.75
Water - barge	104	8.42

Product manufacturing (A3) for WRC decking includes log debarking, cutting debarked logs into lengths, and edging and trimming cut lengths into rough green lumber. Next, rough green lumber is sorted by width, thickness, and length. Finally, lumber is planed and the planed lumber (green) leaves the mill as packaged decking.

WRC lumber manufacturing and decking manufacturing produce a main product and co-products. Table 9 summarizes mass and revenue-based allocation factors used for modeling. Mass allocation factors were calculated based on the mass of main product and co-products while Freight on Board (FoB) prices in 2022 reported by the survey participants were used to calculate economic allocation factors.

Table 9 Weighted average mass and economic allocation factors

Manufacturing Process		Allocation Factors (%)						Total
		Main Product	Co-products					
			Bark	Pulp chips	Sawdust	Planer shavings	Hog fuel	
Rough green lumber	*Mass*	*38.91%*	*0.94%*	*34.94%*	*7.69%*	*0.14%*	*17.38%*	*100%*
	Economic	97.07%	0.04%	2.00%	0.33%	0.01%	0.55%	100%
Decking	*Mass*	*32.26%*	-	*30.09%*	*19.38%*	*1.36%*	*16.90%*	*100%*
	Economic	98.96%	-	0.51%	0.23%	0.02%	0.28%	100%

A mass balance between roundwood inputs and lumber outputs was performed to check the validity of the firsthand data gathered from lumber manufacturing mills. The LCI flows for WRC rough lumber and decking manufacturing are provided in Table 10 and Table 11. Background LCI data sources used to model material and energy inputs used for WRC rough green lumber and decking manufacturing are presented in Table 15.

Table 10 Inventory flows and process emissions for the production of WRC rough green lumber

	Unit	*Amount per Mfbm manufactured*	*Amount per m³****
Material inputs			
Roundwood	m³	4.63	8.34
Hydraulic fluid	L	0.37	0.67
Lubricating fluid	L	0.33	0.59
Motor oil	L	0.03	0.06
Greases	kg	0.01	0.02
Antifreeze	L	0.33	0.59
Lumber wrap	Kg	0.47	0.84
Polyethylene	Kg	0.01	0.02
Stickers	Kg	1.00	1.79
Dunnage	Kg	3.71	6.68
Energy			
Electricity purchased	kWh	106.27	191.29
Diesel fuel	L	4.77	8.58
Gasoline	L	0.15	0.27

Propane	L	0.33	0.59
Surface water	L	111.42	200.56
City water	L	55.71	100.28
Solid waste			
Wood waste *	kg (oven dry)	0.003	0.01
Material transportation	tkm	0.45	
Co-products*			
Pulp chips	tonne (oven dry)	0.03	1.86
Bar	kg (oven dry)	1.03	0.05
Sawdust	tonne (oven dry)	0.23	0.41
Planer shaving	tonne (oven dry)	0.004	0.01
Hog fuel	tonne (oven dry)	0.51	0.92

Note: *Weighted average inputs and process emissions unallocated*
* *Landfilled*
** *Sold*
*** *Conversion factor 1.8m³/Mfbm provided in Neilson et al. (1985) applied*

Table 11 Inventory flows and process emissions for the production of WRC decking

	Unit	*Amount*	
		per Mfbm Manufactured	*per m² Manufactured***
Material inputs			
Roundwood	m^3	4.53	0.06
Lumber	Mfbm	0.05	6.46E-04
Hydraulic fluid	L	0.59	8.45E-03
Lubricating fluid	L	1.37	0.02
Motor oil	L	0.04	6.36E-04
Greases	Kg	0.01	1.35E-04
Antifreeze	L	0.01	2.04E-04
Plastic strapping	kg	0.01	1.40E-04
Lumber wrap	kg	1.98	0.03
Polyethylene	kg	0.24	3.40E-03
Stickers	kg	2.20	0.03
Dunnage	kg	0.04	6.07E-04
Energy			
Elec. Purchased	kWh	175.01	2.51
Diesel fuel	L	6.81	0.10
Gasoline	L	0.06	8.43E-04
Propane	L	0.07	1.00E-03
Co-products			
Pulp chips	tonne (oven dry)	0.51	0.01
Sawdust	tonne (oven dry)	0.33	4.74E-03
Planer shavings	tonne (oven dry)	0.02	3.33E-04
Hog fuel	tonne (oven dry)	0.29	4.13E-03

Note: Mfbm installed product requires 1.03 Mfbm manufactured (based on 3% installation waste)
Weighted average inputs and process emissions unallocated
** Given out for recycling*
*** 69.69 m² per MFBM (calculated based on Nielson, et.al., 1985)*

3.1.2 Wood-plastic decking

This LCI for wood-plastic decking was developed using the information available in existing North American literature and EPDs . Formulations were developed in line with common North American wood-plastic composite (WPC) decking products. WPC formulations included recycled plastic to cover the spectrum of available products on the market.

3.1.2.1 Overview of current industry practices

Major wood plastic decking manufacturers, for example Trex, use 95% of recycled materials in WPC formulations. Wood fibre inputs are sourced from reclaimed timber and sawdust while plastic overwraps used for common household items such as paper towels and toilet paper, dry cleaner bags, newspaper bags, and grocery and shopping bags are used as recycled plastic sources (Trex, 2023).

Sources of recycled PE include either curbside collections or grocery store bags collected in store recycling programs. Most WPC manufacturers use plastic grocery store bags as a source of PE because they are typically cleaner than curbside collections and hence, do not normally require washing to remove contaminants prior to use (Climenhage, 2003). This practice enables WPC producers to avoid using both water and energy to wash and dry contaminated plastic bags.

3.1.2.2 Wood-plastic decking formulations

Wood-plastic decking is modeled based on the composition reported in the EPD published by Huidong Meixin Plastic Lumber Products Manufacturing Co., Ltd., 2021. for NewTechWood wood plastic composite decking. This product is available in North America. The wood fibre is assumed to be sawdust supplied by local sawmills. The recycled PE are assumed to be grocery bags collected through store recycling programs. The product content reported in the NewTechWood EPD is used as the composition of WPC formulation in updating the report:

- Wood flour – 55.7%
- Recycled HDPE – 37.9%
- Other additives – 6.4%
    - ✓ Lubricants (e.g., polyester) – 1.9 %
    - ✓ Coupling agents (maleic anhydride) – 4.50%

3.1.2.3 Product Manufacturing

WPC decking manufactured using either virgin or recycled PE is shown in Figure 4. The manufacturing of WPC involves two main unit processes - raw material preparation and extrusion.

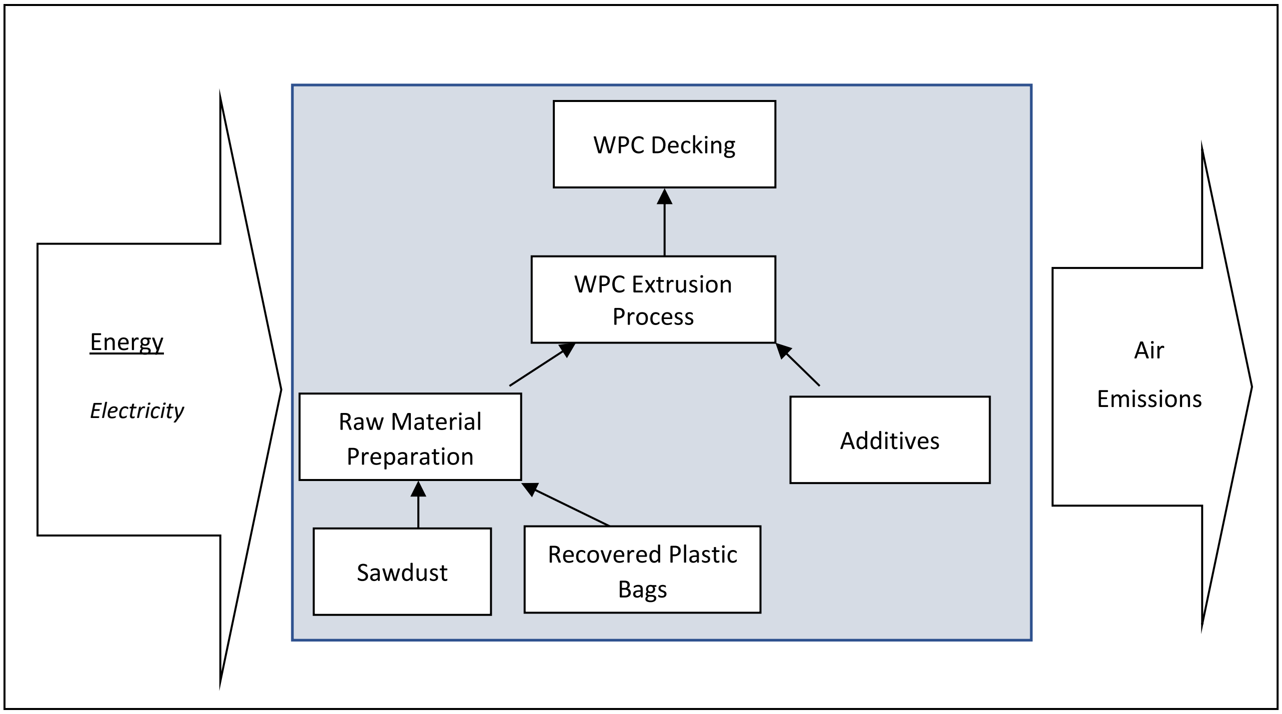


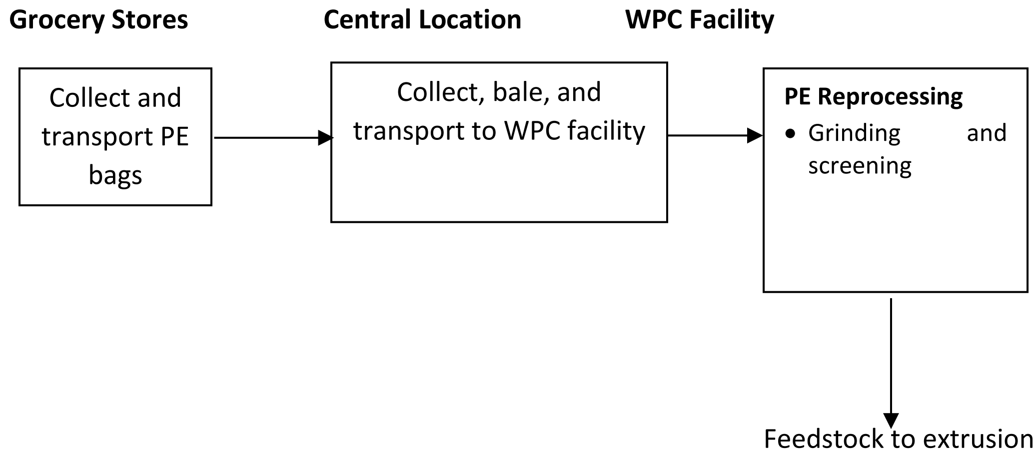
Figure 4 Cradle-to-gate WPC decking manufacturing diagram

A1 Raw material preparation

Raw material production includes transport of wood by-products (sawdust) and grocery bags to the mill gate, wood flour manufacturing and the reprocessing of plastic bags. Other inputs such as pigments and coupling agents are purchased from third-party suppliers. Additives are delivered to manufacturing facilities by trucks (LDED, 2005). The raw material preparation processes occurring within a WPC facility are discussed in detail below.

Recycled PE films

Plastic bags received from grocery store collections are considered to be the source of recycled HDPE for manufacturing of WPCs. Figure 5 depicts the PE film recycling processes. Key steps include transport of collected grocery bags to a WPC facility and PE reprocessing. The normal practice occurring in the transport of collected grocery bags by retailers is a back haul process. For example, grocery stores back haul in-store collected bags to the local distribution centers. Distribution centers collect these bags from retailers and bale in a compactor typically used for cardboard. Baled bags are sent to recyclers by truck (Edgecombe, 2008). PE reprocessing involves bale shredding, washing, drying, densification, grinding and screening. As discussed earlier, this study assumes no washing and drying are required in this process.



Source: Adapted from Climenhage (2003).

Figure 5 Schematic representation of the PE recycling process

<u>Production of wood flour</u>

The process of wood flour production includes the transportation and grinding of and pre-drying of wood flour prior to mixing with the PE polymer. It is assumed that the facility receives dry planer shavings that are then converted into wood flour using a single pair of hammermills. Dust generated in this process is pneumatically collected during wood flour making process and conveyed to a silo for reprocessing into WPC (LDED, 2005). It is assumed that the WPC facility follows this practice in order to avoid particulate emissions.

A3 – Wood-plastic composite process

The manufacturing of wood-plastic deck boards (Englund, 2005) incorporates two additional unit processes:

- Extrusion – blending and profile extrusion and downstream processing – cooling, sizing, and surfacing
- Regrinding of defective products and trimmings

<u>Extrusion</u>

Environmental releases occur mainly from energy use in wood-fibre drying, blending/compounding and profile extrusion, and downstream processing (cooling, sizing, and surfacing). In addition, there are some gaseous emissions, mainly CO_2 from wood and some minor emissions from polymers and occasional emissions from additives occur in venting during extrusion (Englund, 2006). These fugitive emissions are assumed to be minor (less than 1%) and therefore ignored in developing the LCI. Electricity is used as the primary energy source for extrusion. The quantity of emissions stemming from the extrusion process differs from extruder to extruder (Englund, 2008a).

The manufacturers of extruders listed on the web site for Washington State University's WPC Information Center (www.wpcinfo.org) were contacted to determine the energy consumption and the emissions associated with the extrusion process. Among the mills contacted,only Milacron Inc. provided the quantity of energy and other ancillary materials required to produce a ton of wood-plastic deck board. This data was used to develop the life cycle inventory.

Regrinding

In addition to the two-unit processes above, a regrinding process is used to reprocess defective products and trimmings into WPCs. Defective products and trimmings can be sent to a regrind silo for recycling after milling with the use of a pair of regrind hammermills. This material is reprocessed to 1/8" particle size approximately. Dust from regrinding can also be pneumatically collected and conveyed to regrind silo for reprocessing (LDED, 2005). It is common for manufacturers to add 5-10% of regrind into their mix (Englund 2008b).

Cradle-to-gate flow data (A1- A3)

The energy and material input data required for these unit processes and material transportation distances were collected from literature and personal communications with experts in the WPC field (see Table 12 for references). A description of the raw material and process energy data and transportation distances used for this study are provided below.

3.1.2.4 Raw material Life cycle inventory of WPC manufacturing

Based on the WPC formulations discussed earlier, quantities of raw materials and ancillary materials required for the production of 1,000 board feet of wood-plastic decking with density of 1180 kg/m3 (Huidong Meixin Plastic Lumber Products Manufacturing Co., Ltd., 2021) are shown in Table 12. Both distilled and potable water are used for barrel cooling and product cooling, respectively. Water can be reused for cooling. The other ancillary materials used in the process are gear box oil and grease. (K. Dave, email communication, January 23, 2024).

Process energy

The electricity required for the WPC extrusion process is based on information provided by Milacron Inc.'s Twin Screw extruder model. Energy data for regrinding of WPC output wastes are calculated based on the information available from the Louisiana Department of Economic Development (LDED, 2005). Regrinding requires about 15 kWh of electricity per 1000 board feet of WPCs to mill defective products to particle size of 1/8". Electricity requirements for the production of 1,000 board feet of wood-plastic lumber are reported in Table 12.

Table 12 Life cycle inventory for 1000 board feet of wood-plastic lumber (A1-A3)

Inputs from technosphere, materials	**Unit**	**Quantity per 1000 bfm**	**Remarks**
Wood flour	kg	1,676.01	Based on Huidong Meixin Plastic Lumber Products Manufacturing Co., Ltd. (2021)
HDPE	kg	1,140.41	
Lubricants - polyester	kg	57.17	
Maleic Anhydride	kg	135.41	
Gear box oil	l	0.04	Amount required for Twin Screw Extruder (Milacron Inc., 2024)
Inputs from technosphere, energy			
Electricity	kWh	102.26	Operation of hammermills for producing wood flour (calculated based on Rajendran, et.al., 2018)
Electricity	kWh	24.53	PE shredding (calculated based on Vecoplan, 2018)
Electricity*	kWh	3,812.74	Amount required for Twin Screw Extruder (Milacron Inc., 2024)
Electricity	kWh	15.00	LDED, 2005
Output			
WPC	kg	3009.00	

*Note: *Amount needed for extrusion process including drive train, drying, heating and cooling.*
Density of WPC is 1,180 kg/m^3; 1 Mbfm = 2.55 m^3; 1 Mfbm installed product requires 1.050 Mfbm manufactured (Installation waste 5%[13])

Raw material transport

Raw material transportation is based on the information available on Washington State University's WPC web site (https://wpcinfo.org/producers/decking-railing-and-fencing/), which contains locations of WPC decking manufacturers and suppliers of raw materials in North America, and Google search for raw material suppliers closer to the cities chosen. It is assumed that WPC factories purchase raw materials from nearby raw material suppliers in order to save transportation costs. Additives are delivered to manufacturing facilities via truck packed in reusable packed bags. The assumed raw material transport distances to each of three US manufacturing locations and calculated tkm are shown in Table 13. Diesel combination trucks and diesel single unit trucks are assumed to be used for the transportation of raw materials and ancillary materials (gear box oil) from the collection points to the manufacturing facility, respectively. Ancillary materials are assumed to be transported 20 km to the three factory locations.

[13] https://www.trex.com/deck-ideas/how-many-deck-boards-do-i-need-/

Table 13 Raw material transport distances for each US manufacturing locations

Market region in the US	Factory location	Raw material	Transportation distances (km)	Transportation requirement per 1000 bfm of WPC (measured in tons kilometers (tkm))
Northeast	Winchester, Virginia	Bailed HDPE films	300	342.63
		Planer shaving	150	179.61
		Additives	750	151.65
Mid-West	Lamar, Missouri	Bailed HDPE films	800	913.67
		Planer shaving	400	478.97
		Additives	350	70.77
Northwest	Shingle Springs, California	Bailed HDPE films	50	57.10
		Planer shaving	1200	1436.92
		Additives	70	14.15

3.1.2.5 LCI data sources

Table 14 summarizes the LCI data sources used to model environmental impacts of the inputs, energy sources, ancillary materials, and transport of WRC and WPC.

Table 14 Background LCI data sources used to model material and energy inputs used for WRC and WPC resource extraction, transportation, and decking manufacturing

Input	LCI data source
RAW MATERIAL	
Nitrogen fertilizer	Nitrogen fertilizer, production mix, at plant NREL/US U
Phosphorus fertilizer	Phosphorous fertilizer, production mix, at plant NREL/US U
Planer shavings	Planer shavings, at planer mill, US SE/kg NREL/US U
Lubricants (polyester)	Polyester resin, unsaturated, at plant/US- US-EI U
Maleic Anhydride	Maleic anhydride, at plant/US- US-EI U
OTHER MATERIAL	
Lumber wrap	Polyethylene, HDPE, granulate, at plant/US- US-EI U
Stickers	

Lath and dunnage	Rough green lumber, softwood, at sawmill, US PNW/kg/US
City water	Tap water, at user/US- US-EI U
Peat	Peat {RoW}| production | Cut-off, U
ANCILLARY MATERIAL	
Gear box oil	Lubricating oil, at plant/US- US-EI U
Lubricating oil	
Motor oil	
Antifreeze	Ethylene glycol, at plant NREL/RNA U
Grease	Proxy_Oil and grease, at plant NREL/US U
ENERGY	
Diesel	Diesel, burned in building machine/GLO US-EI U
Gasoline	Gasoline, combusted in equipment NREL/US U
Propane	Propane, burned in building machine {GLO}| propane, burned in building machine | Cut-off, U
Electricity - BC	Electricity, medium voltage, at grid, British Columbia/CA US-EI U
Electricity - Missouri	Electricity, medium voltage, at grid, Missouri/US US-EI U
Natural gas	Natural gas, combusted in industrial equipment NREL/RNA U
TRANSPORT	
Truck transport	Transport, combination truck, diesel powered NREL/US U
	Transport, single unit truck, diesel powered NREL/US U
WASTE DISPOSAL	
Wood waste	Disposal, wood untreated, 20% water, to sanitary landfill/US* US-EI U

3.2 Siding Cradle-to-Gate Inventory

3.2.1 WRC Siding

WRC siding is manufactured at both integrated mills and at remanufacturing mills that purchase rough green lumber from other facilities. Manufacturing facilities are located in Agassiz, Barriere, Revelstoke, and Vancouver Island.

3.2.1.1 Process overview

The western red WRC siding manufacturing process is illustrated in Figure 6. WRC siding undergoes the same rough green lumber manufacturing processes described above for WRC decking and then is subsequently kiln-dried and planed before it is ready to leave the mill. Kiln-drying is the most energy intensive step in WRC siding manufacturing and therefore, compared to WRC decking, WRC siding is a more energy intensive building material.

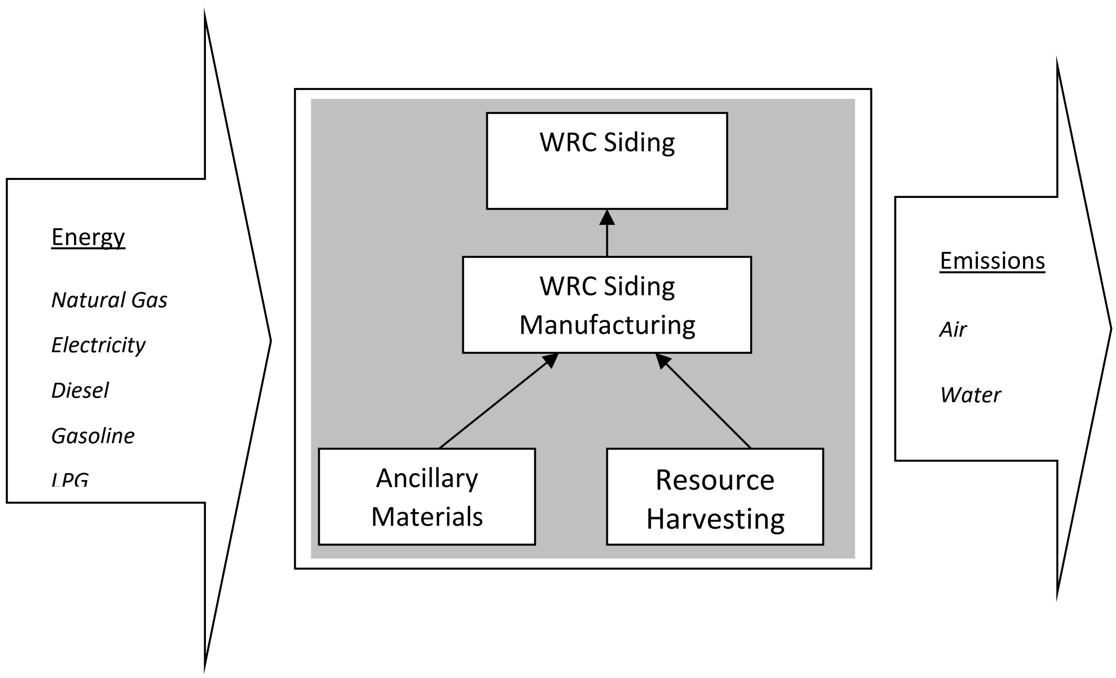


Figure 6 Cradle-to-gate WRC siding manufacturing diagram

3.2.1.2 Gate-to-gate flow data

A mass balance between roundwood inputs and siding outputs was performed to check the validity of the firsthand data gathered from lumber manufacturing mills. WRC siding mills use ancillary materials (hydraulic fluids, motor oils, and greases in various manufacturing processes such as sawing, planning, kiln drying etc.) and packaging materials (e.g. lumber wraps, steel/plastic strapping, corrugated cardboard etc.). Table 15 summarizes inputs from the technosphere and process emissions for producing 1 m^3 and 1,000 board feet of WRC siding. A summary of the LCI data sources used to model ancillary material and energy use is also provided in Table 16.

Table 15 Life cycle inventory flows for the production of WRC siding

	Unit	*Amount*		
		per Mfbm manufactured	*per m²** manufactured*	*per oven dry tonne manufactured*
Material inputs				
Roundwood	m³	4.62	0.05	2.54
Lumber	Mfbm	0.07	7.79E-04	0.04
Hydraulic fluid	L	1.41	0.02	0.77
Lubricating fluid	L	2.91	0.03	1.60
Motor oil	L	0.11	1.24E-03	0.06
Greases	kg	0.02	2.53E-04	0.01
Antifreeze	L	0.03	3.98E-04	0.02
Polyethylene	kg	0.45	0.01	0.25
Kiln stick	kg	10.31	0.12	5.66
Lumber wrap	kg	3.76	0.04	2.07
Dunnage	m³	0.55	0.01	0.02
Paint	L	2.12E-03	2.49E-05	1.17E-03
Stickers	kg	4.25E-03	4.98E-05	2.33E-03
City water	L	28.97	0.34	15.92
Energy				
Electricity, purchased	kWh	332.31	3.89	182.58
Diesel fuel	L	11.05	0.13	6.07
Gasoline	L	0.08	8.89E-04	0.04
Natural gas	GJ	0.34	3.98E-03	0.19
Propane	L	1.57	0.02	0.86
Co-products				
Pulp chips	tonne (oven dry)	0.52	0.01	0.29
Sawdust	tonne (oven dry)	0.31	3.68E-03	0.17
Planer shaving	tonne (oven dry)	0.04	4.74E-04	0.02
Hog fuel	tonne (oven dry)	0.24	2.85E-03	0.13
Waste				
Wood waste*	tonne (oven dry)	2.11E-03	2.48E-05	1.16E-03
Transportation				
Lumber	tkm	16.94	0.20	9.31
Ancillary material	tkm	8.72E-04	1.02195E-05	4.79E-04

Note: Weighted average inputs and process emissions unallocated

**Given out for recycling*

*** 85.33 m² per MFBM (estimated based on Neilson, et.al., 1985)*

Table 16 LCI data sources used to model ancillary materials and energy sources

Inputs	LCI Data Source
MATERIAL	
Hydraulic fluids	Lubricating oil, at plant/US- US-EI U
Lubricating oil	
Motor oil	
Grease	Proxy_Oil and grease, at plant NREL/US U
Antifreeze	Ethylene glycol, at plant NREL/RNA U
Plastic strap	Polyethylene, HDPE, granulate, at plant/US- US-EI U
Lumber wrap	
Polyethylene	Polyethylene, HDPE, granulate, at plant/US- US-EI U
Paint	Acrylic dispersion, 65% in H2O, at plant/US- US-EI U
Sticker	Rough green lumber, softwood, at sawmill, US PNW/kg/US
Tap water	Tap water, at user/US- US-EI U
ENERGY	
Electricity	Electricity, medium voltage, at grid, British Columbia/CA US-EI U
Propane	Propane, burned in building machine {GLO}| propane, burned in building machine | Cut-off, U
Gasoline	Gasoline, combusted in equipment NREL/US U
Diesel	Diesel, burned in building machine/GLO US-EI U
Natural gas	US-EI2.2
Transportation	
Truck	Transport, combination truck, diesel powered NREL/US U

3.2.2 Clay Brick Siding (Facing Brick)

This section describes the production of clay brick siding and outlines the life cycle inventory developed for the assessment.

This study relied on three existing LCI data sources to develop an inventory for clay brick manufacturing: the clay extraction data and material input data available in the U.S.–Canada Industrywide Clay Brick EPD (NSF Certification, LLC., 2020), the Building for Environmental and Economic Sustainability Technical Manual and User Guide (BEES® 2.1) (Kneifel, et.al., 2021), and LCA report published by the Athena Sustainable Materials Institute (Venta, 1998) product for clay brick manufacturing.

In the US, largest brick production occurs in Texas[14]. The inventory for electricity-production and transportation distances was adjusted to be representative of Texas, since Texas is a more central location in terms of the three US marketing regions assessed in this LCA study.

3.2.2.1 Manufacturing Overview

Clay bricks are primarily composed of raw clay that is quarried typically near the production facility. Heavy machinery is used to extract the clay and 20-ton trucks are used to forward the raw clay to the manufacturing facility where it is crushed and combined with water, sand, and trace amounts of barium carbonate, lignosulphate, manganese dioxide, chromite, bentonite, and specialty clay, i.e. fire clay. In total, clay accounts for 97% of manufacturing inputs on a mass basis. The moistened clay mixture is then extruded into bricks, glazed, and then fired. Figure 7 illustrates the processes that are included within the raw materials extraction and manufacturing unit process: clay extraction, the production and sourcing of ancillary materials, and the brick forming and firing process (Venta, 1998).

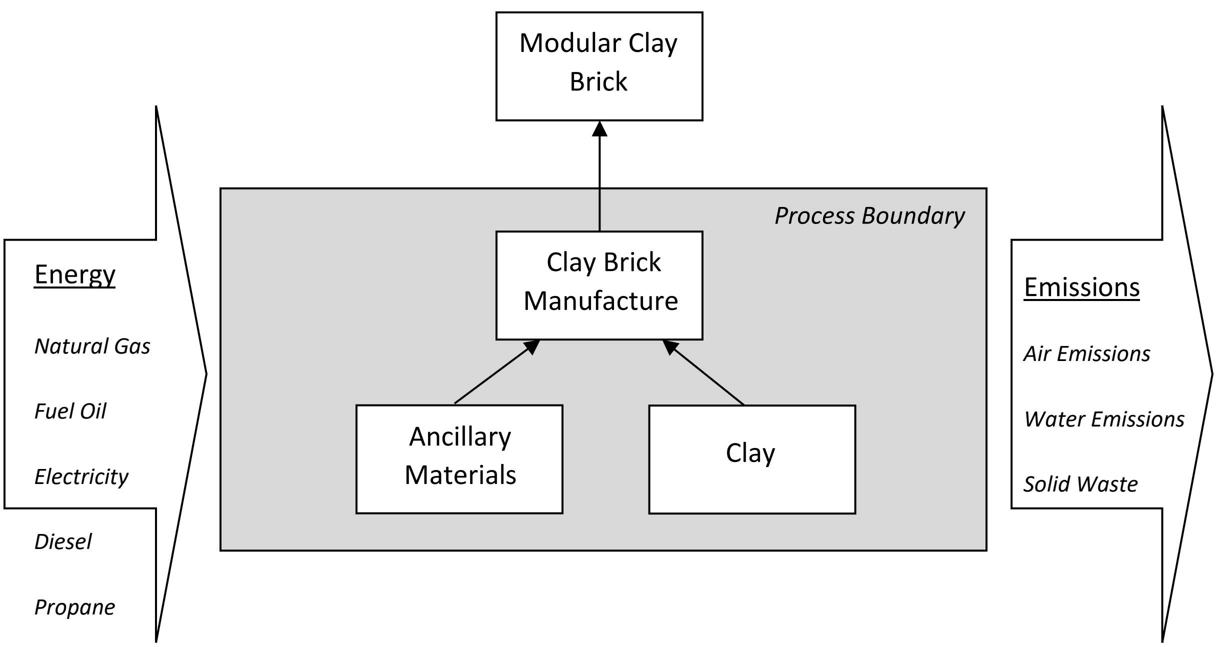


Figure 7 Cradle-to-Gate Clay Brick Manufacture Process Diagram

Clay Extraction LCI

Clay extraction is typically completed in operations nearby (15 miles on average) to the location that the bricks are formed, fired and finished. The raw clay is extracted using diesel-fueled machinery and may undergo some primary crushing before being loaded onto trucks and transported to the manufacturer. The updated LCI data for clay extraction obtained from Athena Sustainable Materials Institute (ASMI) for 2008 is shown in Table 17.

[14] https://www.linquip.com/blog/brick-manufacturers-in-usa-globally-2023 /

Table 17 Material and Energy Inputs for Raw Material Mining per One Tonne of Clay

Input	Unit	Amount
Ancillary materials		
Motor oil	L	0.035
Greases	L	0.0353
Hydraulic fluids	L	0.0114
Energy Input		
Fuel Oil	L	0.0580
Diesel Fuel	L	1.4498
Electricity	kWh	0.3447

Source: ASMI, 2008

Brick Manufacturing LCI

Brick manufacturing consumes primarily clay as a material input and natural gas in the firing process. Ash is added to the clay during brick production. The typical input mixture contains 99.2% of clay (or shale) and 0.8% bottom ash by mass (Kneifel, et.al., 2021). Table 18 shows the weighted average resource inputs and process emissions from brick manufacturing.

Table 18 Resource Inputs and Process Emissions for Manufacturing One Tonne Clay Bricks

Manufacturing material Inputs	Unit	Amount per tonne
Clay and shale[3]	kg	948.11
Secondary material (ash, grog, etc.)[3]	kg	37.12
Pigments[3]	kg	9.01
Additives[3]	kg	5.00
Water[3]	*L*	*1325.47*
Transportation[2]	tkm	24
Energy Input		
Natural gas[2]	m^3	51.70
Electricity[2]	kWh	49.50
Air Emissions[1]		
Process particulates<10 microns	kg	0.1617
Process particulates<2.5 microns	kg	0.0281
CO	kg	0.564
*Process CO2	kg	60.2537
Sulfur oxides (SOX)	kg	0.425
Nitrogen oxides (NOX)	kg	0.215
VOC	kg	0.0283
Hydrochloric acid (HCl)	kg	0.148
Hydrofluoric acid (HF)	kg	0.080

Solid Waste		
Brick waste (3%)[2]	kg	3.00
Transportation**		
Materials	tkm	24.98
Ancillary materials	tkm	1.64E-03

*Note: *Process CO_2 emitted through breakdown of limestone $CaCO_3$ into CaO and CO_2 during firing process*
***Assumed 24km for raw materials, other materials, and fuels*
Density: 2120 kg/m^3
Source: 1. ASMI, 2008
2. Kneifel, et. al., 2021
3. The Brick Industry Association, 2020

A summary of the LCI data sources used to model material and energy use is provided in Table 19.

Table 19 LCI data sources used to model ancillary materials and energy sources

Input	LCI Data Source
Additives	Barite {CA-QC}| production | Cut-off, U; Chemicals inorganic, at plant/GLO US-EI U
Lubricating oil	Lubricating oil, at plant/US- US-EI U
Greases	Proxy_Oil and grease, at plant NREL/US U
Hydraulic fluids	Lubricating oil, at plant/US- US-EI U
Fuel oil	Residual fuel oil, combusted in industrial boiler NREL/US U
Electricity	Electricity, medium voltage, at grid, Texas/US US-EI U
Diesel	Diesel, burned in building machine/GLO US-EI U
Natural gas	Natural gas, combusted in industrial boiler NREL/US U
Truck transport	Transport, combination truck, diesel powered NREL/US U

3.2.3 FC Siding

This section describes the production of FC siding and the life cycle inventory used for the assessment. Material and energy input to manufacture FC siding were drawn from Certain Teed weatherboard siding provided in the BEES manual (Kneifel, et. al., 2021).

3.2.3.1 Manufacturing Overview

FC board is an aggregate product comprised primarily of Portland cement, fly ash, silica, cellulose, and primer. The constituent materials are combined in a mixer to produce a slurry which is shaped into siding and then dried in a natural gas-powered kiln. Gasoline, diesel, and propane are used as fuel to power facility vehicles, including forklifts. The finished product is shipped to the building site where it is fastened into place in a manner similar to wood siding. Figure 8 shows the cradle to gate processes in the manufacturing of FC siding.

Manufacturing location is considered to be Roaring River, North Carolina, USA based on CertainTeed's manufacturing plant location in North America.

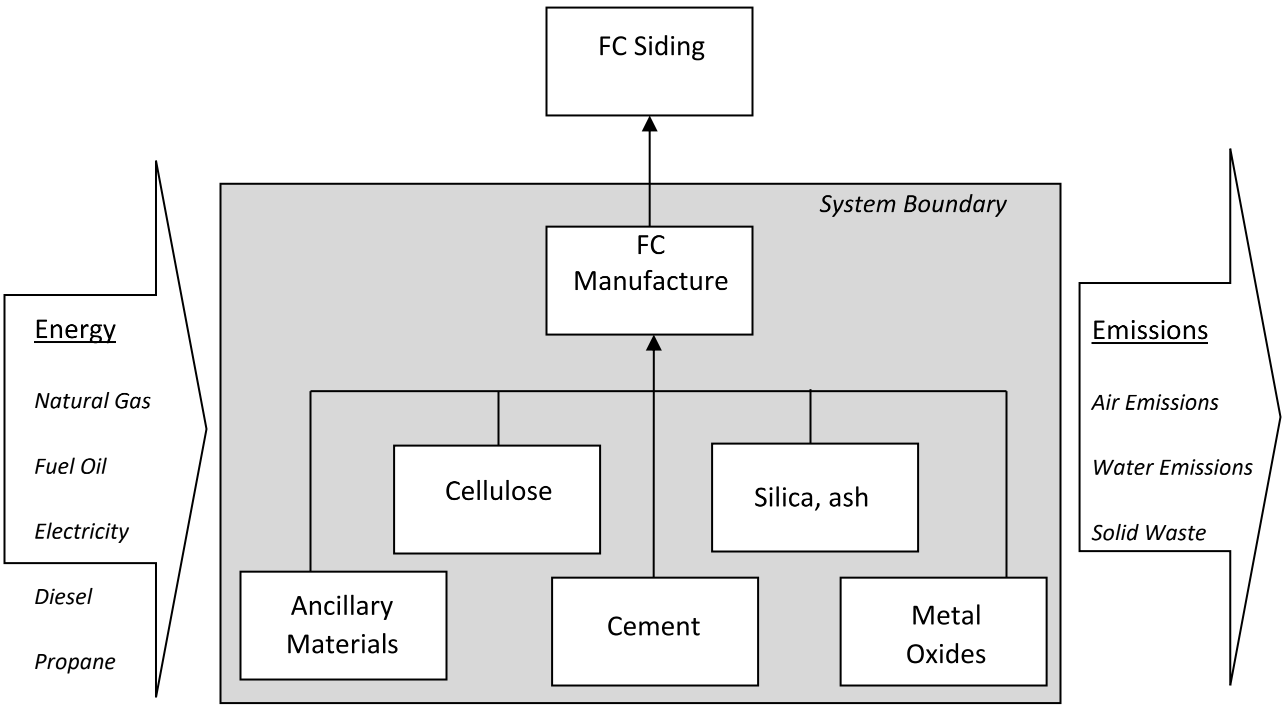


Figure 8 Cradle-to-Gate FC Siding Manufacturing Process Diagram

3.2.3.2 Raw Materials Transportation

The locations of manufacturing facilities were chosen considering the leading manufacturers[15] and their main plant locations in the three market regions in the US: Reno, Nevada and Cleburne, Texas, and Peru, Illinois.

Cement and sand were assumed to come from local sources while the other materials were assumed to come from facilities located within the manufacturing region. The assumed material transportation distances are found in Table 20.

[15] FC siding facility locations

Table 20 Materials Transportation Distances for FC Siding

Raw Material	Distance (km)	tkm per one tonne FCcement siding manufactured
Cement (Local)	60	21.39
Cellulose (Regional)	250	15.96
Silica sand (Local)	60	15.32
Fly ash (Regional)	250	96.56
Primer (Regional)	250	0.50

3.2.3.3 Manufacturing LCI

FC siding is primarily comprised of silica sand and Portland cement, with smaller amounts of cellulose pulp and ancillary materials also being part of the mix. Water is also added and circulated to prepare the mixture for the extruder.

Manufacturing waste is equivalent to 6.4% of all input materials excluding the primer (Kneifel, et. al., 2021). Table 21 shows the technosphere flows used to model the FC manufacturing process per tonne of product. A summary of the LCI data sources used to model ancillary material and energy use is provided in Table 22.

Table 21 FC Manufacturing Flows per One Tonne (manufactured)

Material Input	Unit	Amount
Portland Cement	kg	356.44
Fly ash	kg	386.23
Silica sand	Kg	255.36
Cellulose pulp	Kg	63.84
Primer	Kg	2.00
Energy Input		
Natural gas	m^3	4.61
Diesel Fuel	L	0.075
Gasoline	L	0.005
Propane	L	0.049
Electricity	kWh	20.99
Solid Waste Emissions		
Material waste*	%	6.4

*Note: *Excluding primer*

Estimated based on the FC constituents reported in Kneifel, et. al., 2021 for CertainTeed weatherboard siding

Table 22 LCI data sources used to model ancillary materials and energy sources

Input	LCI Data Source
MATERIALS	
Portland Cement	Portland cement, at plant NREL/US U
Silica Sand	Silica sand, at plant/US** US-EI U
Cellulose Pulp	Chemi-thermomechanical pulp, at plant/US- US-EI U
Primer	Alkyd paint, white, 60% in H2O, at plant/US- US-EI U
ENERGY	
Natural gas	Natural gas, combusted in industrial boiler NREL/US U
Diesel Fuel	Diesel, burned in building machine/GLO US-EI U
Gasoline	Gasoline, combusted in equipment NREL/US U
Electricity	Electricity, medium voltage, at grid, Texas/US US-EI U
Propane	LPG combustion, at industrial furnace/US S
Transportation	
Material transportation	Transport, combination truck, diesel powered NREL/US U

3.2.4 Vinyl Siding

This section describes the production of polyvinyl chloride siding, hereafter referred to as PVC or vinyl siding.

3.2.4.1 Manufacturing Overview

Vinyl is manufactured from chlorine obtained from common salt and ethylene produced from natural gas (Vinyl Institute, 2019). The cradle-to-gate processes for the manufacture of vinyl siding are shown in Figure 9.

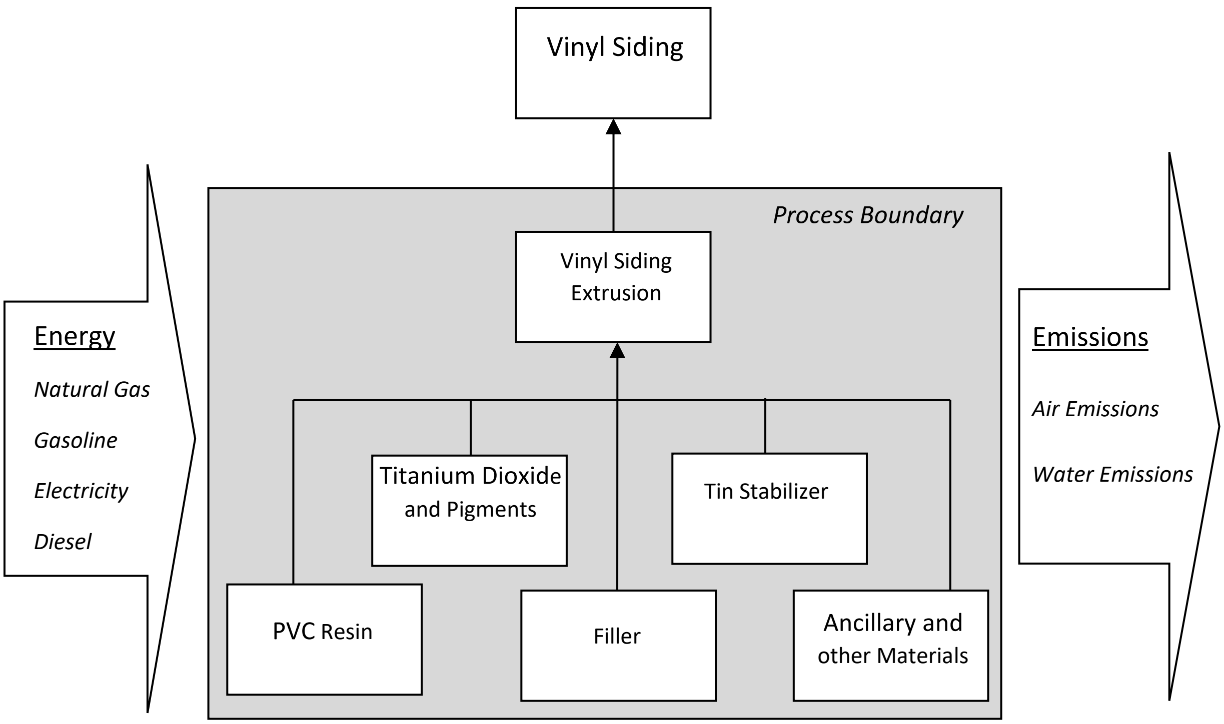


Figure 9 Cradle-to-Gate Vinyl Siding Manufacturing Process Diagram

3.2.4.2 Manufacturing LCI

This study draws LCI data on vinyl siding manufacturing available in the LCA report compiled by Sustainable Solutions Corporation (2016) for the Vinyl Siding Institute. It is assumed that vinyl siding meets ASTM D3679 guidelines for testing methods for the materials, dimensions, warp, shrinkage, impact strength, expansion, appearance, and wind load resistance (Vinyl Siding Institute, 2022). The constituents of vinyl siding are: PVC, filler (calcium carbonate), titanium dioxide, process aid, an impact modifier (chlorinated polyethylene), tin stabilizer, chlorinated polyethylene, sealant, pigments and lubricant. Lubricant and stabilizers are typically a paraffin and calcium stearate blend and organo-tin mercaptide respectively (Kneifel, 2021). Vinyl siding comes with either PVC capstock (capstock is a material co-extruded with PVC) or acrylonitrile styrene acrylate (ASA) capstock. Table 23 provides the manufacturing material and energy use input data for the production of one tonne of PVC siding with PVC capstock and ASA capstock. Raw material transport distances are provided in Table 24.

Table 23 Material and Energy Inputs for Manufacturing of One Tonne PVC Siding (manufactured)

LCI flows	Unit	Amount	
		PVC capstock	ASA capstock
Material Inputs			
PVC resin	kg	804.00	690.00
ASA	kg	-	120.00
Filler (calcium carbonate)	kg	111.00	100.00
Impact Modifier (acrylic or chlorinated PET)	kg	19.00	11.00
Titanium Dioxide	kg	14.00	9.00
Tin Stabilizer (organo-tin mercaptide)	kg	6.00	7.00
Process aid	kg	5.00	0.00
Lubricant (paraffin/calcium stearate)	kg	17.00	17.00
Chlorinated polyethylene	kg	7.00	24.00
Sealant	kg	8.00	0.00
Calcium stearate	kg	6.00	0.00
Pigments	kg	1.00	2.00
Energy Inputs			
Electricity	kwh	249.00	249.00
Natural Gas	m^3	3.11	58.33
Propane	l	2.36	1.31E-04
Gasoline	l	1.51E-03	0.00
Water use			
Inflow	l	219.00	219.00
Outflow	l	143.00	143.00
Air emissions			
Dichloroethane	kg	7.01E-07	7.01E-07
Vinyl chloride	kg	6.63E-02	6.63E-02
Waste			
Landfill	kg	26.90	5.56
Incineration	kg	0.00	2.07

Sources: Sustainable Solutions Corporation, 2016; Kneifel et. al., 2021

Table 24 **Raw material transportation**

Input	tkm per tonne of vinyl siding manufactured	
	Truck	Rail
Raw materials	3.27	2.89

Source: Sustainable Solutions Corporation, 2016

3.2.4.3 Secondary LCI Data Sources

Secondary LCI data sources used as inputs for vinyl siding manufacturing are shown in Table 25. Given data unavailability for calcium stearate and pigments, proxy datasets were used for these constituents (Table 25).

Table 25 **LCI data sources for inputs used in vinyl siding manufacturing**

Input	Data source
PVC resin	Polyvinyl chloride resin, at plant NREL/RNA U
ASA	Acrylonitrile-butadiene-styrene copolymer resin, at plant NREL/RNA U
Filler (calcium carbonate)	Limestone, milled, loose, at plant/US* US-EI U
Impact Modifier (acrylic or chlorinated PET)	Polyethylene terephthalate, granulate, amorphous, at plant/US- US-EI U
Titanium Dioxide	Titanium dioxide, production mix, at plant/US- US-EI U
Tin Stabilizer (organo-tin mercaptide)	Tin, at regional storage/US- US-EI U
Process aid	Methyl methacrylate, at plant/US- US-EI U and Methyl acetate, at plant/US- US-EI U (proxy created using 50% methyl methacrylate and 50% methyl acrylate)
Calcium stearate	Proxy_Zinc stearate, at plant NREL/US U (proxy zinc stearate data)
Paraffin wax	Paraffin, at plant/US- US-EI U
Pigments	Proxy_Pigment, at plant NREL/US U (proxy pigment data)
Electricity	Electricity, medium voltage, at grid, 2019/US US-EI U
Natural gas	Natural gas, combusted in industrial boiler NREL/US U
Propane	LPG combustion, at industrial furnace/US S

4 LIFE CYCLE INVENTORY FOR TRANSPORTATION TO CUSTOMER(A4), INSTALLATION (A5) AND USE (B2, B4, B7)

This section discusses the ancillary material requirements and processes involved in the transportation to a hypothetical building site (A4), installation (A5), maintenance (B2),, replacement B4, and   of the siding and decking products during their service lives. The use phase inventory considers all inputs and processes associated with the installation, use, and maintenance of these products for three U.S. hypothetical building site locations. The section concludes with a summary of use phase inventories for each of the siding and decking products.

4.1 Decking Installation and Use Inventory

It is assumed that a residential light duty 100 square-foot deck (10’x10’) is installed according to WRCLA’s and Trex’s installation guidelines (Trex, 2024). Installation specifications for WRC and WPC decking are shown in Table 26. As per these specifications, both WRC and WPC decking have the same joist span and fastener specifications and both the substructure and fasteners are ignored for comparison purposes.

Table 26 Installation guidelines for WRC and WPC decking installation

Criteria	WRC Specifications	WPC Specifications****
Size of boards (Nominal)	5/4 x 6*	1 x 6
Joist span	16 inches*	16 inches
Fasteners	2-1/2” galvanized screws (no. 8 or 10)**	2-1/2” galvanized screws (no. 8 or 10)
Gaps between boards and solid objects (e.g. walls)	Width-to-width – 1/4"***	Width-to-width – 1/4"
	End-to-end – 1/8”***	End-to-end – 1/8”
	Abutting solid objects – 1/4"**	Abutting solid objects – 1/4"

Sources:
* WRCLA 2024a
** WRCLA 2024b
*** P. Lang (email communication, December 18, 2008))
**** Trex 2024

Energy used for the power guns/drills in the installation is assumed to be minor and therefore, ignored in the LCIs for both products. Both WRC and WPC decking have similar cleaning guidelines. For example, both types of decking should be kept free from dirt, debris, and mold to maintain their service life. Dirt and debris should be removed twice a year while washing with a detergent and bleach to kill mold and mildew is recommended at least once a year (WRCLA, 2024c) and Trex (2024). Table 27 shows the included and excluded material inputs and processes from the installation and use phase modules. Transportation, installation and other maintenance inputs specific to each material are discussed below.

Table 27 Included and excluded flows from delivery (A4), installation (A5, and maintenance (B2) modules

Module		Inputs and processes	
		WRC decking	WPC decking
A4 – decking delivery	Included	Transportation to building site	Transportation to building site
A5 – installation	Included	Decking boards, on-site waste landfilled	Decking boards, on-site waste landfilled
	Excluded	Energy used for the power guns/drills, substructure and fasteners	Energy used for the power guns/drills, substructure and fasteners
B2 –maintenance	Excluded	Detergent and bleach?	Detergent
		Power washing	Power washing

4.1.1 WRC

Transport (A4): It is assumed that WRC decking boards originate at 100 km distance from Vancouver and are shipped directly to the distribution centers in the three cities. Transport of WRC decking boards to Seattle is assumed to be done by diesel combination trucks while transport to New York and Minneapolis is done by both rail and truck (i.e. a 50:50 modal split). It is assumed that WRC decking is installed in the hypothetical building sites located 20 km away from the distribution centers in the three cities and diesel single unit trucks are used for this transportation. The transport to the hypothetical building sites in the three market regions is shown in Table 28.

Table 28 WRC decking transportation modes and distances to three marketing regions

Market region in the US	**Building site**	**Transport distances (km)**		**Tkm per 75-year building life**	
		Rail	**Truck**	**Rail**	**Truck**
Northeast	New York	2,500.00	2,500.00	716.91	716.91
Midwest	Minneapolis	1,500.00	1,500.00	430.14	430.14
Northwest	Seattle	-	250.00	-	71.7

Installation (A5) and Use phase inputs (B2, B4): According to WRCLA's specifications, installation of a 100 square-foot deck requires about 238 linear feet of 5/4 x 6 boards (WRCLA 2024d). The baseline LCA profile is an untreated deck that over time, and depending on the maintenance practice, will take on a natural weathered appearance. In order to determine the potential significance of a regular stain treatment on the baseline LCA profile a stain treatment LCA was also developed for WRC decking (see sensitivity section). WRCLA decking calculator allows 10% for trim waste for installation that is assumed to be disposed of in a landfill. According to Robertson (2025), it is assumed that a WRC deck can last 25 years with proper maintenance and care. Therefore, no replacement is assumed to occur during the modeled 25-year service life. Later a sensitivity analysis incorporating a 100% board replacement over the life of the deck is considered to determine the significance of this assumption on the baseline study results. The baseline installation and use phase inputs calculated for the functional unit are shown in Table 30.

4.1.2 Wood-plastic decking

Transport (A4): The transport distances from existing WPC facilities to the hypothetical building sites are shown in Table 29. Truck transportation is assumed and LCI data available in the US EI 2.2 database are used to model the environmental impacts of transport of decking in the three regions in the US.

Table 29 WPC decking transportation to hypothetical building sites in the three marketing regions

Market region in the US	Building site	Transport distances (km)	tkm per 75-year building life
North East	New York	655	886.89
Mid West	Minneapolis	900	1218.66
North West	Seattle	1522	2060.85

Installation (A5) and Use phase (B2, B7) inputs: According to Trex product specifications, lengths of deck boards available in the market are 12', 16', and 20'[16]. A 100 square-foot deck requires 240 linear feet of 5/4 deck boards that is assumed to be met using twenty 20' WPC boards. Installation produces 5% on-site waste[17] which is assumed to be disposed of in a landfill. Major manufacturers, like Trex, offer a 25-year warranty on their WPC decking (Trex, 2024). Therefore, it is assumed that no replacement is needed with proper maintenance and care. The calculated installation and use phase inputs are shown in Table 30.

[16] See https://www.trex.com/products/decking/transcend-decking-and-railing/
[17] See https://www.decks.com/calculators/decking-calculator

Table 30 Summary of installation inputs and waste and maintenance inputs calculated for the functional unit (100 ft^2) of WRC and WPC decking

	Unit	WRC decking (oven dry)*	WPC decking
Decking material	kg	306.9	1354.05
Installation waste	kg	30.69	67.71
Detergent[18]**	kg	15	15
Water for power washing **	L	285	285

Note: Energy used for the power guns/drills in the installation are excluded
Power washing excluded
*Fasteners are included. Need 350 screws[19] (1.73 kg of screws[20]) per 100 ft deck.
** Total amount needed for a 75-year building life to remove dirt, debris, and mold

4.2 Siding Installation and Use Inventory

It is assumed that siding products are installed over a standard stud wall. Wall construction is similar for all sidings[21]. While considering the similarities, wall construction is ignored in developing the use phase inventories.

The installation and use phase inventories were created according to associations, institutions, and/or major manufacturers guidelines. According to these guidelines, all siding products considered in this study require washing with a solution of a mild detergent and oxygen-based bleach to remove dirt, dust, and to kill mold and mildew spores at least once a year (WRCLA, (2024e), Polymeric Exterior Products Association (PEPA) (2025), Brick Industry Association (2017).

The use phase includes siding installation, and maintenance over the 50-year service life. Siding installation creates on-site waste that is assumed to be disposed in a landfill. Table 31 shows the included and excluded material inputs and processes from the installation and use phase modules. The use phase inventories developed for each type of siding are discussed below.

18 https://defywoodstain.com/products/defy-wood-cleaner#:~:text=Use%206%20oz.,ft.

19 https://www.manasquanfasteners.com/product/decking_and_fastener_blog_5#:~:text=The%20general%20rule%20of%20thumb,%2C%20and%2016%22%20joist%20spacing.

20 https://www.maxxt-tech.com/blog/how-many-drywall-screws-per-pound-your-handy-guide-for-accurate-estimates/#:~:text=Typically%2C%20a%20pound%20of%201,screws%20has%20approximately%2092%20screws.

21 See https://portsidebuilders.com/steps-toward-new-home-framing-walls/#:~:text=Exterior%20walls%20are%20framed%20with,and%20down%20to%20the%20floor.

Table 31 Included and excluded flows from delivery (A4), installation (A5), and maintenance (B2) modules

Module		Inputs and processes			
		WRC siding	FC	Vinyl siding	Brick siding
A4 – siding delivery	Included	Transportation to building site	Transportation to building site	Transportation to building site	Transportation to building site
	Excluded	-	-	-	-
A5 – installation	Included	Siding boards, trims/strips, fasteners, on-site waste landfilling	Siding boards, trims/strips, fasteners, on-site waste landfilling	Siding boards, trims/strips, fasteners, on-site waste landfilling	Bricks, cement mortar mixture, , on-site waste landfilling
	Excluded	Energy used for the power guns/drills, wall construction	Energy used for the power guns/drills, wall construction	Energy used for the power guns/drills, wall construction	Energy used for the power guns/drills, wall construction
B2 – maintenance	Included	Paint, detergent	Paint, detergent	Detergent	Detergent
	Excluded	Power washing	Power washing	Power washing	Power washing

4.2.1 WRC

The WRC siding mills reported production of four types of siding: bevel, board and batten, tongue and groove, and channel siding. Of the four types of siding, bevel siding was the most prevalent product produced[22]. Bevel siding (½" x 6") is assumed to be the typical or generic siding type in developing the installation and use phase LCIs.

Transport (A4): WRC remanufacturing occurs in B.C. It is assumed that WRC siding is transported from Vancouver to distribution centers in Seattle, Minneapolis and New York by truck. It is assumed that diesel combination trucks are used to transport siding to distribution centers in Seattle. Siding is delivered to the hypothetical building sites located 20 km away from distribution centers by diesel single unit trucks. The modes of transport considered for New York and Minneapolis are equally split between rail and truck (see Table 32).
Installation (A5) and Use phase inventory (B2, B4): Installation, use, and maintenance are assumed to occur according to the specifications of WRCLA. Energy required for power guns during installation is again assumed to be minor and is omitted from the LCA boundary.

As per Robertson (2025), it is assumed that WRC siding has a service life of 50 years, and no replacement occurs during the service life with proper care and maintenance practices. As per WRCLA (2024e), it is considered that an initial flood-coat primer and paint finish is applied and then three top-coat paint

[22] See https://www.realcedar.com/siding/profiles/bevel-siding/

applications (100% acrylic latex exterior paint) are done during the siding lifetime. Table 33 shows the installation and use phase inputs and the on-site waste for a functional unit while the secondary data sources used for modeling are shown in Table 34.

4.2.2 Fiber-Cement

As per Kneifel (2021), 5/16” lap siding is considered as the generic fiber-cement siding for this comparative LCA study.

Transport (A4): FC manufacturers are located throughout North America with a higher number of facilities found in Eastern North America. It was assumed that FC board is trucked 600 km to New York and 1100 km to Minneapolis and 2750 km to Seattle (see Table 32 for transport distances to the default building location in Minneapolis).

Installation (A5) and Use phase inventory (B2, B4): Reference flows for the installation and use phase inputs are calculated for the functional unit (100 ft^2 with a 50-year service life) according to the guidelines developed by major producers such as James Hardie[23] based on the expected service life for the siding product. It is considered that unfinished fiber-cement siding is used and primed (one coat of alkyd primer) and painted (two coats of 100% acrylic latex) prior to installation. Major FC siding manufacturers give a 50-year service life warranty[24] and therefore it is assumed that no replacement occurs during the service life. Two applications of a 100% acrylic latex topcoat are applied during the remainder of the service life in line with Kneifel (2021). Installation and use phase inputs and on-site waste calculated for the functional unit and the original LCI data sources used are shown in Table 33 and Table 34 respectively.

4.2.3 Vinyl

It is assumed that vinyl siding is installed according to the guidelines of PEPA (2025). Transportation and use phase inputs of vinyl siding to the hypothetical building sites and installation inputs are presented below.

Transportation (A4): While considering the North American vinyl siding manufacturers and their manufacturing plant locations, the majority of vinyl siding manufacturers are located in Eastern North America. Thus, it was assumed that vinyl siding was transported 500 km to New York, and 2310 km to Minneapolis, and 2500 km to Seattle from manufacturing facilities, all by truck (see Table 32).

Use phase inventory (B2, B4): Many manufacturers offer a 50-year lifetime. The service life of vinyl siding is considered to be 50 years according to Vinyl Siding Institute (2022). Vinyl siding does not require routine maintenance other than cleaning to maintain appearance (Kneifel, 2021). A summary of the installation

[23] See http://www.jameshardiepros.com/
[24] See https://www.goodfellowinc.com/wp-content/uploads/importation/3-Revetement/Revetement_04/Revetement/siding-fibro-ciment-certainteed-specification.pdf.

and use phase inputs and on-site waste calculated and the LCI data sources used are shown in Table 33 and Table 34 respectively.

4.2.4 Clay Brick

Bricks are manufactured, primarily in Eastern USA[25], before they are trucked to building sites where they are installed using cement mortar and brick ties to secure the brick siding to the structure.

Transportation (A4), Installation (A5) and Use phase Inventory (B2, B4): Installation of bricks requires the bricks themselves, Type N cement mortar, and mesh lath. Clay brick cladding is a very durable cladding with a service life well beyond 50 years. For the purposes of this study, clay brick cladding is considered to have a minimum service life of 100-years per EPD published by Interstate Brick (2020) and hence, its environmental flows and resulting environmental burdens are essentially cut in half to generate the normalized 50-year service life considered in this study. Brick manufacturing is also primarily located in Eastern USA. It was assumed that bricks were transported by truck to the New York and Minneapolis locations (250 km) and rail to Seattle. Transportation distances and the amounts of material inputs and on-site are shown in Table 32 and Table 33 respectively. Table 34 summarizes the LCI data sources used to develop this inventory.

Table 32 Transportation Distances to building locations

Siding type	Materials	Mode	Distance (km)			tkm per 100 ft^2 installed product*		
			Minneapolis	Seattle	New York	Minneapolis	Seattle	New York
Brick	Bricks	Truck	250		250	385.88	-	385.88
		Rail	-	3100	-	-	4,785.00	-
	Cement in Mortar	Truck	60	60	60	6.20	6.20	6.20
	Aggregate in Mortar	Truck	60	60	60	15.84	15.84	15.84
	Steel mesh lath	Truck	250	250	250	0.71	0.71	0.71
WRC		Truck	1500	250	2500	114.47	16.22	162.15
		Rail	1500	-	2500	114.47	-	162.15
FC		Truck	1100	2750	600	251.63	629.06	137.25
Vinyl		Truck	2310	2500	500	66.96	72.38	14.48

Note: *75-year building life

[25] https://us.metoree.com/categories/7369/#manufacturers

Table 33 Summary of the installation and use phase LCI calculated per functional unit (100 ft^2 installed) of siding products

Inputs		Unit	WRC siding[1]	Fiber-cement[2]	Vinyl siding[3]	Brick siding[4]	Comment
Siding materials	Mass (kg)		64.86	228.75	28.95	1029.00	
	Plank size		1/2”x 6”	5/16”x8-1/4”	12’x9”	-	
	Overlap		1”	1-1/4”	-	-	
Starter strip		Linear feet	1x2 – length 10’ (size: 1x2)	1/4"x2” – length 10’ (1/4"x2”)	Length 10’	-	
Corner trim		Linear feet	No corner trim (mitered corner)	7/16”x31/2” – 1.75 (7/16”x31/2”)	30	-	
Cement in Mortar		kg	-	-	-	22.25	
Sand in Mortar		kg	-	-	-	85.23	
Lime		kg	-	-	-	4.73	
Water in Mortar		kg	-	-	-	6.81	
Metal lath[26]		kg	-	-	-	12.63	
Galvanized steel		kg	0.75	0.75			fasteners
Aluminum		kg			0.36		fasteners
Alkyd primer Alkyd primer		l	-	2.84	-	-	Paint
Acrylic paint		l	12.98	12.98	-		paint
On-site waste		kg (%)	6.48 (10%)	10.35 (5%)	1.44 (5%)	51.45 (5%)	
Cleaner[27,*]		kg	15	15	15	10.0	Cleaner
Water use**		L	285	285	285	190	

Sources: 1. Kneifel, 2021, WRCLA 2024e, and WRCLA 2024f

2. Kneifel, 2021

3. Kneifel, 2021. LCI based on 50 year expected service life.

4. IRONROCK, 2021, Kneifel, 2021.

Note: *Total amount of cleaner needed for a 75-year building life

Total amount of water needed for power washing during 75-year building life to remove dirt, debris, and mold

[26] See https://www.bmp-group.com/docs/default-source/literature/galvanized-diamond-mesh-lath-2-5.pdf?sfvrsn=0#:~:text=2.5%20lb%20lath%20is%20required%20for%20cultured%20stone%2Fbrick%20applications.&text=Metal%20lath%20shall%20be%20fabricated,conforming%20to%20Specification%20A653%2FA653M.

[27] See http://www.homedepot.com/p/Simple-Green-128-oz-House-and-Siding-Cleaner-Pressure-Washer-Concentrate-2300000118201/203643078

Table 34 LCI data sources used to model installation, use phase inputs and product transportation

Inputs	LCI Data Source
Steel	Cold rolled sheet, steel, at plant NREL/RNA U
Paint	Alkyd paint, white, 60% in solvent, at plant/US- US-EI U and Acrylic dispersion, 65% in H2O, at plant/US- US-EI U
Stain	Alkyd paint, white, 60% in H2O, at plant/US- US-EI U
Aluminum	Aluminum ingot, production mix, at plant NREL/US U
Cement	Portland cement, at plant NREL/US U
Sand	Sand, at mine/US* US-EI U
Transport	Transport, combination truck, diesel powered NREL/US U and Transport, single unit truck, gasoline powered NREL/US U
Electricity	Electricity, medium voltage {MRO, US only}| market for | Alloc Def, S
Lime	Limestone, milled, loose, at plant/US* US-EI U
Water	Tap water, at user/US* US-EI U

5 END-OF-LIFE INVENTORY

This chapter describes the treatment of the end of life (EoL) processes (i.e., removal at the end of service life (C1), transportation to a waste disposal site (C2), waste sorting or separation (C3) and disposal of solid waste (C4). In residential buildings, removal of decking and siding at the end of service life is done primarily by manual labor. Hence, environmental impacts from dismantling (C1) are considered to be minor.

5.1 Waste disposal at the end of service life

Solid waste disposal at the end of service life of decking and siding are discussed under the EoL modules below.

Demolition (C1)
Dismantling of decking and siding at the end of the service life is generally done by manual labour, so there are no energy-related environmental burdens.

Waste transport (C2)
It is assumed that dismantled decking and siding are sent to a waste transfer station (located 20 km from the building site) where the waste is sorted and then disposed of. Table 35 summarizes the transportation inventory of the decking and siding product systems to a waste transfer station.

Table 35 End of life transportation inventory to waste disposal on 100 ft^{2}installed product basis

Material	Mode	Distance (km)	tkm
WRC decking	Truck	20	1.84
WRC siding	Truck	20	0.78
Brick siding	Truck	20	19.55
FC siding	Truck	20	2.57
Vinyl siding	Truck	20	0.37

Waste sorting/separation (C3)

Environmental impacts from handling waste in waste transfer station was modeled by modifying sorting infrastructure dataset (Sorting plant for construction waste/US*/I US-EI U) available in US-EI2.2 database to sorting operations.

Disposal (C4)

The study looked into existing literature on construction and demolition (C&D) waste disposal practices occurring in the US to develop a default end-of-life scenario. US EPA (2020) estimates that C&D waste, including wood and bricks, is primarily disposed of in landfills. The default EoL disposal practices chosen for the decking and siding product systems based on US EPA (2020):

Decking:

- WRC decking – 69% landfilling, 20% fuel, 8% mulch, and 3% recycled into engineered wood
- WPC decking – 100% landfilling (note that WPC is not recyclable, so is the option for disposal[28]).

Siding:

- WRC siding – 69% landfilling and 31% incineration
- Brick siding – 85% landfilling[29] and 15% recycling (aggregates)
- FC siding – 100% landfilling
- Vinyl siding – 80% landfilling and 20% incineration according to Vinyl Siding Institute (2022).

Secondary datasets used to model EoL of WRC decking and siding, WPC decking, brick, FC, and vinyl sidings are shown in Table 36.

[28] See https://www.mexytech.com/can-composite-decking-be-recycled.html
[29] See https://recyclenation.com/2014/06/how-to-recycle-bricks/

Table 36 LCI data sources used to model EoL of decking and siding materials

Material	Disposal Practice	LCI Data Source
WRC decking	Landfilling	Disposal, Wood untreated, 0% water, to sanitary landfill/US* US-EI U
WPC decking	Landfilling	Disposal, plastics, mixture, to US sanitary landfill/US US-EI U
WRC siding	Landfilling	Disposal, wood untreated, 0% water, to sanitary landfill/US* US-EI U
	Incineration	Disposal, wood untreated 0% water, to municipal incineration/US* US-EI U
FC siding	Landfilling	Disposal, cement, hydrated, 0% water, to residual material landfill/US* US-EI U
Vinyl siding	Landfilling	Disposal, inert material, 0% water, to sanitary landfill/US* US-EI U
	Incineration	Disposal, polyvinylchloride, 0% water, to municipal incineration/US* US-EI U
Brick siding	Landfilling	Disposal, plastics, mixture, to US sanitary landfill/US US-EI U

5.2 Landfill Gas Management

WRC decking and siding disposed in landfills decay and emit methane under anaerobic conditions. Evidence suggests that wood does not fully decompose under anaerobic conditions. The fraction of wood that does not decompose in anaerobic conditions is considered to go into long-term storage (De la Cruz, et. al., 2013; Wang et.al., 2013;)

The study looked into the Fraction of Degradable Organic Carbon (DoCf) that is reported in the recent literature to model landfill decomposition of wood. As per the estimates of the US Forest Service, (DoCf) of solid-wood varies from as little as 3% (Micales and Skog, 1997) to 23% (stated in Skog., 2008 based on Eleazer et al. 1997). US Forest Service uses this recent estimate for carbon accounting of wood products disposed in landfills. Wang et.al. (2011) estimates using reactors under laboratory conditions that methane production is only 7.9% of the predicted amount using the carbon conversion default suggested by IPCC. In addition, Wang et.al. (2011) report that the decomposition rates vary from product to product as well. The authors measured the decomposition of hardwood (HW), softwood (SW), plywood (PW), oriented strand board (OSB), particleboard (PB) and medium-density fiberboard (MDF) that they tested in laboratory-scale landfills, and the test results are shown in Table 37 below. DOCfs of wood reported in the literature widely varies between 0 to 9.1. These findings are either laboratory based or 46 year decay period, and hence, may not represent actual decay conditions and long term decay in landfills. The US EPA (2023) estimates for lumber is based on literature review and expert opinion which is consistent with the literature review conducted by Micales and Skog (1997). A 3% DoCf was applied based on US EPA (2023) and Micales and Skog (1997) to model WRC landfilling at EoL.

Table 37 Decomposition factors reported in the literature

Wood type	Carbon content (% carbon in dry wood)	Fraction of Degradable Organic Carbon that Decomposes (DOC_f)	Description	Source
Hard wood – red oak	41	7.8	Lab scale landfill bio-reactor	1
Hard wood – eucalyptus	45	0.0	Lab scale landfill bio-reactor	1
Soft wood – spruce	41	1.8	Lab scale landfill bio-reactor	1
Soft wood – radiata pine	46	0.1	Lab scale landfill bio-reactor	1
Plywood	46	1.4	Lab scale landfill bio-reactor	1
OSB – soft wood	47	0.0	Lab scale landfill bio-reactor	1
Particle board	38	1.3	Lab scale landfill bio-reactor	1
MDF	37	1.1	Lab scale landfill bio-reactor	1
Softwood		~3%	Literature review	2
Hard wood	49.6-49.9	8.7%	Buried in landfill for 46 years	3
Softwood	50.7-50.9	9.1%	Buried in landfill for 46 years	3
Lumber		3%	Literature review and expert opinion	4

Sources:(1) – Wang et.al. , 2011; (2) Micales and Skog, 1997; (3) Ximenes et al. 2008, (4) US EPA, 2023

Table 38 summarizes the assumptions used to model the production and capture of methane from the landfilling of wood-based materials at the end of their service lives. The landfill gas management modelling results are shown in Table 39.

Table 38 Landfill gas management modelling assumptions

Process	Unit	Amount
Carbon content of WRC wood*	%	51.54
Degradable organic carbon fraction of wood**	%	3
% carbon emitted as CH_4**	%	50
Average Capture Efficiency**	%	90
Methane oxidation factor at the landfill cover layer**	%	10
Methane flaring/utilization efficiency***	%	>99

Sources: **Lamlom and Savidge, 2003*
***US EPA, 2023*
****US EPA, 2024*

Table 39 Landfill gas management net greenhouse gas* emissions per 100 ft^2 installed basis

	Emission	Amount (kg)
WRC Decking: 92.07 kg (oven dry)	CO_2	4.98
	CH_4	0.09
WRC Siding: 38.92 kg (oven dry)	CO_2	2.10
	CH_4	0.04

Note: *Greenhouse gas emissions not captured

6 BIOGENIC CARBON

Wood entering a product system from nature accounts for its biogenic carbon content as material inherent properties. According to International Organization for Standardization (ISO) 21930 (2017), this biogenic carbon sequestered in harvested wood products and emissions throughout the product system shall be reported as flow of carbon between nature and the technosphere in the GWP (biogenic) indicator calculations. WRC siding and decking are solid wood products while wood FC is an input in their product formulations. WRC products from WRCLA members come from forests that are independently certified as legal and sustainable[30], and hence WRC products are accounted as having net zero carbon emissions from land use change. These guidelines were also applied to wood fibre content in WPC decking and FC siding as well. Summary results are presented in Table 40. Biogenic carbon entering the product system was characterized as -1 kg CO_2e/kg CO_2 of biogenic carbon and biogenic carbon leaves the product system as emissions or in C1 to C4 information modules as +1 kg CO_2e/kg CO_2 (ISO, 2017).

Table 40 and Table 41 summarizes biogenic carbon balance calculated for the decking and siding product systems included in this study. Negative net GWPs indicate that WRC decking, WPC decking, and WRC siding contain more sequestered carbon in the product than the life cycle GHG emissions.

[30] See http://www.realcedar.com/why-real-cedar/certification/ and http://certificationcanada.org/en/certification/certification-maps

Table 40 Carbon removals and emissions of WRC rough green lumber, decking and siding

Product	Parameter	Amount (kg CO_2eq)						
		A1	A2	A3	A4	A5	B2, B4,	C1, C2, C3, C4
WRC rough green lumber (per Mbfm)	BCRP	-1119.14	-	-	-	-	-	-
	BCEP	0.09	0.22	1.39	-	-	-	381.56
	BCRK*	-	-	-	-	-	-	-
	BCEK*	-	-	-	-	-	-	-
	BCEW	-	-	-	-	-	-	-
WRC decking per 100 ft^2	BCRP	-173.99					-347.99	
	BCEP	0.01	0.02	0.28	0.11	1.09	3.9	177.98
	BCRK*	-	-	-	-	-	-	-
	BCEK*	-	-	-	-	-	-	-
	BCEW	-	-	-	-	-	-	-
WRC siding per 100 ft^2	BCRP	-36.70					-73.55	
	BCEP	4.23E-03	0.02	0.45	0.06	0.60	1.89	37.62
	BCRK*	-	-	-	-	-	-	-
	BCEK*	-	-	-	-	-	-	-
	BCEW**	-	-	-	-	-	-	-

Note: *Survey participants do not use biobased packaging

**Survey participants use natural gas and propane to dry lumber

Table 41 Summary results from biogenic carbon balance calculated for decking and siding product systems (100 ft² installed product)

Product	kg CO_2eq		
	Biogenic Carbon uptake	Biogenic Carbon emissions*	Biogenic Carbon balance
WRC decking	-521.98	183.43	-338.55
WPC decking	- 1,382.71	426.20	-956.51
WRC siding	-110.33	40.64	-69.69
FC siding	-22.14	4.64	-17.50
Vinyl siding	-	3.07	3.07
Brick siding	-	1.99	1.99

Note: *Aggregate of biogenic carbon emissions throughout the cradle-to-grave product life cycle

7 LIFE CYCLE IMPACT ASSESSMENT OF WRC LUMBER, DECKING AND SIDING PRODUCT SYSTEMS

This section summarizes the life cycle impact assessment (LCIA) results for WRC rough green lumber and decking product systems under the impact assessment methodology described in Section 2.7. A contribution analysis is conducted by life cycle stage for WRC rough green lumber and decking product systems and presented per thousand board feet (Mbfm) and the service life (75 years) of residential building, respectively. The contribution analysis helps identify the significant life cycle stages for each product alternative satisfying the functional unit and in turn, helps determine the key life cycle stages and/or parameters for further evaluation and sensitivity analysis. Section 5.1 presents the LCIA results of contribution analysis for the individual product systems, and Section 5.2 presents comparative results for residential decking systems. In order to succinctly report the LCIA results, this section focuses on the Minneapolis location (centrally located relative to Seattle and New York); however, detailed results for Seattle and New York are also available in the appendices (see Appendix E, F and G).

7.1 Results – WRC rough green lumber

LCIA results calculated for 1000 board feet of WRC rough lumber (Mfbm) are presented in Table 42 and Table 43, on absolute and percentage basis, respectively. Resource extraction is the dominant stage where >75% of impacts and abiotic depletion (fossil fuel) occur due to diesel used for harvesting. Although ozone depletion effects from roundwood transportation is minor (<1%), significant impacts occur in global warming, acidification, eutrophication, and smog impacts categories due to fossil fuel use to power log trucks. Contributions from lumber manufacturing is small (<10%) in all impact categories except its ozone depletion impacts. Even though roundwood transportation uses more fossil fuel relative to lumber manufacturing, the ozone depletion impacts from roundwood transportation is relatively small. This is due to the overall ozone depletion contributions from a variety of inputs used for lumber manufacturing (i.e. diesel, gasoline, propane, electricity, lubricating fluid, grease, tap water, etc.) that are significantly higher than diesel used to power log trucks.

WRC rough green lumber is the input to manufacture value-added products such as WRC decking and siding. As a result, any improvements to WRC lumber's environmental profile should focus on reducing diesel use for harvesting. In addition, more efficient lumber recovery is another area that mills should focus on as the participated mills currently have 35 – 46% lumber recovery. Improving lumber recovery during sawmilling would reduce resource extraction and transportation inputs and their subsequent effect on WRC lumber and value-added products (decking, siding etc.) manufacturing LCIA results proportionally.

Table 42 LCIA Results Summary, 1000 board feet of WRC rough green lumber on absolute value basis

Impact category	Unit	Total	A1: Resource extraction from forests	A2: Roundwood transportation	A3: Lumber manufacturing
GWP100 - fossil	kg CO_2-eq	208.99	173.50	26.93	8.56
GWP100 – biogenic emissions	kg CO_2-eq	1.69	0.09	0.22	1.39
GWP100 – biogenic C removals	kg CO_2-eq	-1119.14	-1119.14	-	-
GWP100 – total	kg CO_2-eq	-908.46	-945.55	27.15	9.95
Ozone depletion	kg CFC-11 eq	1.13E-05	9.91E-06	9.24E-08	1.25E-06
Acidification	kg SO_2 eq	0.92	0.70	0.15	0.07
Eutrophication	kg N eq	0.14	0.12	0.01	4.23E-03
Smog	kg O_3 eq	26.66	20.32	4.31	2.04
Abiotic depletion (fossil fuels)	MJ, LHV	2,881.00	2,405.18	336.42	139.39

Table 43 LCIA Results Summary, 100 ft2 of WRC rough green lumber on percentage basis

Impact category	Unit	Total	A1: Resource extraction from forests	A2: Roundwood transportation	A3: Lumber manufacturing
GWP100 - fossil	%	100.00%	83.02%	12.89%	4.10%
GWP100 – biogenic C emissions	%	100.00%	5.33%	13.02%	82.25%
GWP – biogenic C removals	%	100.00%	100.00%	100.00%	-
GWP - total	%	100.00%	104.08	-2.99	-1.10
Ozone depletion	%	100.00%	88.06%	0.82%	11.11%
Acidification	%	100.00%	75.92%	16.35%	7.72%
Eutrophication	%	100.00%	88.33%	8.55%	3.12%
Smog	%	100.00%	76.21%	16.15%	7.64%
Abiotic depletion (fossil fuels)	%	100.00%	83.48%	11.68%	4.84%

7.2 Results –Decking

LCIA results for decking systems are presented in accordance with the life cycle stages and modules described in Section 2.4.

7.2.1 WRC Decking

The LCIA results for 100 ft^2 of WRC installed in a residential building with a 75 year service life for Minneapolis are depicted in Table 44 and Table 45 on an absolute and percent basis, respectively (the LCIA results calculated on a per m^2 basis are shown in Appendix H).

Transportation to consumer and roundwood harvesting from forests are the dominant stages where significant impacts contributions occur in all impact categories. Significant impacts from these two stages are due to fossil fuel (diesel) used for long distance transportation to consumer and harvesting. Two WRC board replacements are done during the 75-year building life that includes twice the amount of roundwood harvesting from forests, transportation to a facility, decking manufacturing, and decking transportation to consumer. Consequently, the highest GWP (fossil), ozone depletion, acidification, smog, and abiotic depletion (fossil) effects occur during the replacement stage (B4) due to significant impacts occur from diesel used for forest harvesting and long-distance transportation to consumer. Second highest ozone depletion effects and significant impacts in other impact categories occur in decking maintenance (B2) stage that can be traced to deck cleaning. Decking maintenance (B2) is also responsible for significant impacts in global warming, acidification, eutrophication, and abiotic depletion (fossil fuel) from the use of cleaning agents (detergent and bleach). WRC decking landfilling at the disposal stage (C4) emits biogenic carbon and eutrophication. The second highest biogenic carbon emissions occur in the installation phase due to landfilling decking installation waste. WRC decking is a net carbon sequester when accounts for biogenic carbon removals sequestered in the product and carbon emissions that occur during its life cycle. The impacts in other stages (A2, C1, C2, and C3) are small (<1%).

Table 44 LCIA Results Summary, 100 ft² of WRC decking installed in residential building in Minneapolis for building lifetime (75 years) by life cycle stage – absolute values

Impact Category	Unit	Total	Resource extraction	Roundwood transport	Decking manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	kg CO_2 eq	145.25	11.61	1.97	1.60	19.14	5.02	-	25.05	78.69	-	-	0.90	-	1.27
GWP100 – biogenic C emissions	kg CO_2-eq	183.43	0.01	0.02	0.28	0.11	1.09	-	0.93	3.02	-	-	0.01	-	177.97
GWP – biogenic C removal	kg CO_2-eq	-521.98	-173.99	-	-	-	-	-		-347.99	-	-	-	-	-
GWP100 -total	kg CO_2-eq	-193.30	-162.37	1.98	1.88	19.26	6.11	-	25.97	-266.28	-	-	0.90	-	179.24
Ozone depletion	kg CFC-11 eq	9.45E-06	6.63E-07	3.27E-09	2.47E-07	9.53E-07	3.71E-08	-	3.55E-06	3.81E-06	-	-	1.67E-09	-	1.79E-07
Acidification	kg SO_2 eq	0.83	0.05	0.01	0.01	0.14	0.02	-	0.12	0.47	-	-	4.57E-03	-	0.01
Eutrophication	kg N eq	0.19	0.01	0.00	0.00	0.01	-0.01	-	0.07	0.02	-	-	3.70E-04	-	0.08
Smog	kg O_3 eq	21.55	1.36	0.31	0.36	4.29	0.19	-	1.59	13.02	-	-	0.12	-	0.30
Abiotic depletion (fossil fuel)	MJ, LHV	1883.49	160.99	24.54	30.27	245.95	51.82	-	313.49	1027.14	-	-	12.52	-	16.78

Table 45 LCIA Results Summary, 100 ft^2 of WRC decking installed in residential building for building lifetime (75 years) by life cycle stage – percent basis

Impact Category	Unit	Total	Resource extraction	Roundwood transport	Decking manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	%	100.00%	8.00	1.35	1.10	13.18	3.46	<1%	17.24	54.18	<1%	<1%	<1%	<1%	<1%
GWP100 – biogenic C emissions	%	100.00%	<1%	<1%	<1%	<1%	<1%	<1%	0.50	1.64	<1%	<1%	<1%	<1%	97.03
GWP – biogenic C removals	%	100.00%	33.33	<1%	<1%	<1%	<1%	<1%	<1%	66.67	<1%	<1%	<1%	<1%	<1%
GWP100 – total	%	-100.00%	-84.00	1.03	<1%	9.96	3.16	<1%	13.44	-137.76	<1%	<1%	<1%	<1%	92.73
Ozone depletion	%	100.00%	7.02	<1%	2.62	10.09	<1%	<1%	37.62	40.31	<1%	<1%	<1%	<1%	1.90
Acidification	%	100.00%	5.60	1.30	1.54	17.13	2.53	<1%	13.84	56.20	<1%	<1%	<1%	<1%	1.31
Eutrophication	%	100.00%	4.22	<1%	<1%	5.16	-4.31	<1%	38.10	11.83	<1%	<1%	<1%	<1%	43.96
Smog	%	100.00%	6.31	1.44	1.67	19.89	<1%	<1%	7.40	60.41	<1%	<1%	<1%	<1%	1.41
Abiotic depletion (fossil fuel)	%	100.00%	8.55	1.30	1.61	13.06	2.75	<1%	16.64	54.53	<1%	<1%	<1%	<1%	<1%

Note: Minneapolis location

7.2.2 WPC decking

The LCIA results for 100 ft^2 of WPC installed in a residential building with a 75 year service life for Minneapolis are presented in Table 46 and Table 47 on an absolute and percentage basis, respectively.

In the cradle-to-grave life cycle of WRC decking, significant environmental impacts occur in resource extraction (A1) and manufacturing (A3) stages. After deck construction, two WPC board replacements are done during the 75-year building life that includes twice the amount of resource extraction, raw material transportation to WPC manufacturing and transportation of WPC decking boards to consumer. Consequently, the highest contributions in all impact categories occur from WPC board replacement stage (B4). Most of the impacts in the manufacturing stage (A3) can be traced to electricity consumption for WPC manufacturing. The electricity grid in Missouri, USA was used to model electricity consumption. These significant impacts come from 70% of coal that is used for generating electricity in Missouri. The significant impacts in WPC resource extraction come mainly from the material inputs (polyester resin, maleic anhydride, planer shavings, etc.). WPC decking emits substantial amounts of biogenic carbon. Almost all biogenic carbon emissions occur in the resource extraction phase that can be traced to hog fuel used for kiln drying. WPC decking is a net carbon emitter when accounts for biogenic carbon sequestered in the product and emissions that occur in its life cycle. The impacts occurring in other stages (A2, A5, B2,, C1, C2, C3 and C4) are insignificant (<5%).

Table 46 LCIA Results Summary, 100 ft^2 of WPC decking for building lifetime (75 years) by life cycle stage – absolute values

Impact Category	Unit	Total	Resource extraction	Roundwood transport	Decking manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	kg CO_2 eq	2,536.84	182.62	20.82	537.07	38.54	7.48	-	25.05	1,573.06	-	-	4.18	-	148.02
GWP100 – biogenic C emissions	kg CO_2-eq	426.20	139.61	0.17	1.45	0.31	0.15	-	0.93	283.39	-	-	0.04	-	0.14
GWP – biogenic C removals	kg CO_2-eq	-1,382.71	-460.90	-	-	-	-	-		-921.81	-	-	-	-	-
GWP –total	kg CO_2-eq	1,580.33	-7.07	20.99	538.53	38.85	7.63	-	25.97	934.65	-	-	4.22	-	148.16
Ozone depletion	kg CFC-11 eq	1.12E-04	1.82E-05	3.46E-08	1.74E-05	6.41E-08	4.85E-08	-	3.55E-06	7.14E-05	-	-	7.78E-09	-	1.70E-06
Acidification	kg SO_2 eq	12.77	0.75	0.11	3.07	0.21	0.02	-	0.12	8.34	-	-	0.02	-	0.12
Eutrophication	kg N eq	9.75	0.18	0.01	1.92	0.02	0.04	-	0.07	4.34	-	-	1.72E-03	-	3.17
Smog	kg O_3 eq	140.83	10.41	3.29	25.24	6.08	0.21	-	1.59	90.46	-	-	0.58	-	2.96
Abiotic depletion (fossil fuel)	MJ, LHV	28084.67	2863.35	259.93	5524.40	481.01	52.97	-	313.49	18363.30	-	-	58.37	-	167.86

Table 47 LCIA Results Summary, 100 ft^2 of WPC decking for building lifetime (75 years) by life cycle stage – percent basis

Impact Category	Unit	Total	Resource extraction	Raw material transport	Decking manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	%	100.00%	7.20	<1%	21.17	1.52	<1%	<1%	<1%	62.01	<1%	<1%	<1%	<1%	5.83
GWP100 – biogenic C emissions	%	100.00%	32.76	<1%	<1%	<1%	<1%	<1%	<1%	66.49	<1%	<1%	<1%	<1%	<1%
GWP – biogenic C removals	%	100.00%	33.33	<1%	<1%	<1%	<1%	<1%	<1%	66.67	<1%	<1%	<1%	<1%	<1%
GWP100 – total	%	100.00%	-8.78	1.33	34.08	2.46	0.48	0.00	1.64	59.14	0.01	0.00	0.27	0.00	9.38
Ozone depletion	%	100.00%	16.17	<1%	15.47	<1%	<1%	<1%	3.16	63.54	<1%	<1%	<1%	<1%	1.51
Acidification	%	100.00%	5.88	<1%	24.05	1.66	<1%	<1%	<1%	65.32	<1%	<1%	<1%	<1%	<1%
Eutrophication	%	100.00%	1.85	<1%	19.69	<1%	<1%	<1%	<1%	44.49	<1%	<1%	<1%	<1%	32.51
Smog	%	100.00%	7.39	2.33	17.92	4.32	<1%	<1%	1.13	64.23	<1%	<1%	<1%	<1%	2.10
Abiotic depletion (fossil fuel)	%	100.00%	10.20	<1%	19.67	1.71	<1%	<1%	1.12	65.39	<1%	<1%	<1%	<1%	<1%

7.2.3 LCIA Results Comparison – Alternative Decking Products

Table 48 presents a side-by-side life cycle comparison of the two decking product alternatives over the 75-year building life. The same results are depicted graphically in Figure 10, but have been normalized to the WPC result profile. The WRC decking life cycle impact assessment measures are all significantly lower than those reported for the WPC product formulations except for biogenic carbon emissions. Both WRC and WPC contain atmospheric carbon sequestered in wood in products that go into long term storage in landfills at EoL. Note that WPC decking emits >17 times higher fossil GHG emissions; overall (total) GWP of WRC decking becomes a negative number when accounts for overall life cycle fossil and biogenic carbon emissions and biogenic removals (i.e. carbon sequestered in the product that goes into the permanent storage in landfills). These results indicate that the WRC deck could be built more than ten times over the 75-year building life and still outperform WPC deck across almost all of the LCIA measures.

In WPC decking system, about 15 times higher fossil fuel consumption occurs than WRC decking system that can be traced to electricity use for resource extraction (A1) and manufacturing (A3) stages High fossil fuel consumption associated with electricity use can be traced to coal used for electricity generation. This contributes to drastically higher contributions in all impact categories in the WPC board replacement (B4). Consequently, WPC decking shows multiple times higher impacts in all impacts categories than WRC decking system.

Table 48 LCIA Result Comparison for WRC and WPC decking for building lifetime (75 years) –absolute basis, base case

Impact Category	Unit	WRC	WPC
GWP100 – fossil	kg CO_2 eq	145.25	2,536.84
GWP100 – biogenic C emissions	kg CO_2 eq	183.43	426.20
GWP100 – biogenic C removals	kg CO_2 eq	-521.98	-1,382.71
GWP100 – total	kg CO_2 eq	-193.30	1,580.33
Ozone depletion	kg CFC-11 eq	9.45E-06	1.12E-04
Acidification	kg SO_2 eq	0.83	12.77
Eutrophication	kg N eq	0.19	9.75
Smog	kg O_3 eq	21.55	140.83
Abiotic resource depletion (fossil fuel)	MJ, LHV	1,883.49	28,084.67

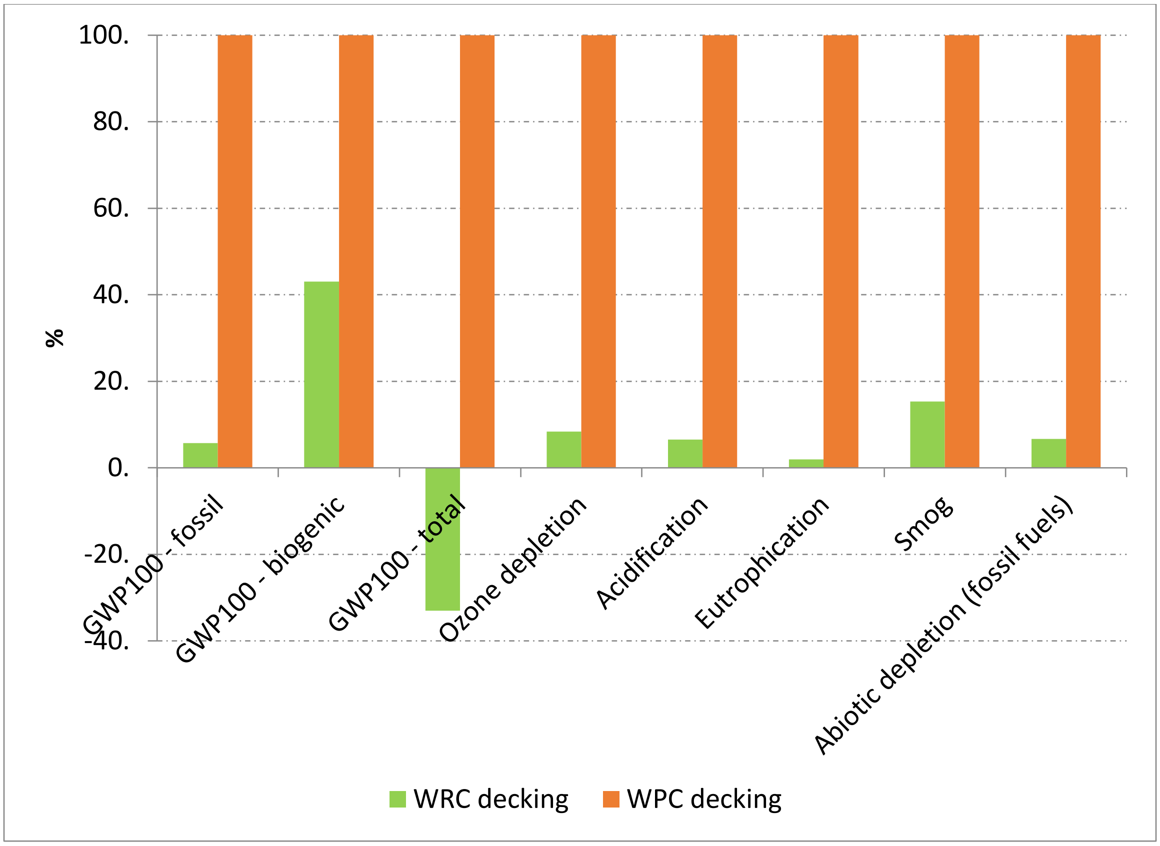


Figure 10 LCIA Result Comparison for WRC and WPC decking for building lifetime (75 years) – percentage basis, base case

7.3 Life Cycle Impact Assessment of Siding Product Systems

This chapter summarizes the LCIA results for each residential exterior siding/cladding product system via a contribution analysis by life cycle stages and modules presented in Section 2.4. The contribution analysis helps identify the significant life cycle stages for each product alternative and in turn, helps determine the key life cycle stages and/or parameters for further evaluation via sensitivity analysis. LCIA results for the individual product alternatives on a functional equivalent basis are presented and comparisons are made at the end. In order to succinctly report the LCIA results this section focuses on the Minneapolis location (centrally located relative to Seattle and New York); however, detailed results for Seattle and New York are also available in the appendices (see Appendix J, K and L).

7.3.1 Results – WRC siding

The LCIA results for 100 ft^2 of WRC siding for the Minneapolis location are depicted in Table 49and Table 50 on an absolute and percent basis, respectively (the LCIA results calculated on a per m^2 basis are shown in Appendix I).

From a 100-year GWP fossil perspective, 100 ft^2 of WRC siding will emit over 106 kg (CO_2 equivalent basis) of greenhouse gases over a 75 years building life cycle. Results indicate that transportation to consumer (A4), siding installation (A5), maintenance (B2) and replacement (B4) phases of the WRC siding life cycle are the primary contributing stages to the products total environmental impact across all LCIA indicators. Maintenance is the dominant phase of the product's life cycle with high contributions in global warming, ozone depletion, acidification, eutrophication, smog and fossil fuel depletion. Most of these impacts can be traced back to the production, use and disposal of paint and cleaning agents. Paint and cleaning agents are responsible for >88% and 28 – 63% of GWP (fossil), ozone depletion, acidification, eutrophication, and smog impacts, respectively. The majority of smog effects occur during siding transportation and are explained by diesel combustion. Significant contributions occur in the resource extraction phase in global warming, smog effects, and fossil fuel depletion that can be traced to diesel used for harvesting from forests. Landfilling siding at the end of life emits highest biogenic carbon emissions during siding life cycle and causes significant eutrophication impacts. Total carbon emissions substantially goes down when account for biogenic carbon sequestered in the product.

Table 49 LCIA Results Summary, 100 ft^2 of WRC siding for building lifetime (75 years) by life cycle stage – absolute basis

Impact Category	Unit	Total	Resource extraction	Roundwood transport	Siding manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	kg CO_2 eq	106.13	8.49	2.31	2.39	10.19	12.44	-	51.75	17.91	-	-	0.19	-	0.46
GWP100 – biogenic C emissions	kg CO_2-eq	40.64	4.23E-03	0.02	0.45	0.06	0.60	-	1.32	0.57	-	-	1.73E-03	-	37.62
GWP – biogenic C removal	kg CO_2-eq	-110.25	-36.7	-	-	-	-	-		-73.55	-	-	-	-	-
GWP100 – total	kg CO_2-eq	36.52	-28.21	2.33	2.84	10.25	13.04	-	53.07	-55.07	-	-	0.19	-	38.08
Ozone depletion	kg CFC-11 eq	1.24E-05	4.85E-07	3.84E-09	3.64E-07	5.07E-07	1.63E-06	-	7.84E-06	1.49E-06	-	-	3.54E-10	-	4.72E-08
Acidification	kg SO_2 eq	0.53	0.03	0.01	0.02	0.08	0.06	-	0.23	0.10	-	-	9.69E-04	-	0.01
Eutrophication	kg N eq	0.22	0.01	9.90E-04	1.10E-03	0.01	0.03	-	0.14	0.02	-	-	7.84E-05	-	0.02
Smog	kg O_3 eq	10.37	0.99	0.36	0.49	2.28	0.62	-	2.94	2.38	-	-	2.65E-02	-	0.27
Abiotic depletion (fossil fuel)	MJ, LHV	1615.33	117.71	28.83	46.95	130.90	206.68	-	810.37	265.53	-	-	2.65	-	5.71

Table 50 LCIA Results Summary, 100 ft^2 of WRC siding for building lifetime (75 years) by life cycle stage – percentage basis

Impact Category	Unit	Total	Resource extraction	Roundwood transport	siding manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	%	100.00%	8.00	2.18	2.25	9.60	11.72	<1%	48.76	16.88	<1%	<1%	<1%	<1%	<1%
GWP100 – biogenic C emissions	%	100.00%	<1%	<1%	1.10	<1%	1.48	<1%	3.24	1.39	<1%	<1%	<1%	<1%	92.57
GWP – biogenic C removal	%	100.00%	33.29	<1%	<1%	<1%	<1%	<1%	<1%	66.71	<1%	<1%	<1%	<1%	<1%
GWP100 – total	%	100.00%	-77.23	6.38	7.77	28.06	35.72	<1%	145.30	-150.79	<1%	<1%	<1%	<1%	104.27
Ozone depletion	%	100.00%	3.92	<1%	2.95	4.10	13.16	<1%	63.38	12.08	<1%	<1%	<1%	<1%	<1%
Acidification	%	100.00%	6.39	2.38	3.38	14.22	10.96	<1%	42.21	18.67	<1%	<1%	<1%	<1%	1.61
Eutrophication	%	100.00%	2.61	<1%	<1%	2.32	12.85	<1%	63.42	9.36	<1%	<1%	<1%	<1%	8.48
Smog	%	100.00%	9.59	3.52	4.77	22.00	6.00	<1%	28.36	22.94	<1%	<1%	<1%	<1%	2.57
Abiotic depletion (fossil fuel)	%	100.00%	7.29	1.78	2.91	8.10	12.79	<1%	50.17	16.44	<1%	<1%	<1%	<1%	<1%

7.3.2 Results – FC siding

The LCIA results for 100 ft^2 of FC siding for the Minneapolis location are depicted in Table 51 and Table 52 on an absolute and percent basis, respectively.

From a 100-year GWP fossil perspective, 100 ft^2 of FC siding will emit over 243 kg (CO_2 equivalent basis) of greenhouse gases over its complete life cycle during 75 years building life. Resource extraction is the dominant phase that contributes to highest impacts in fossil and biogenic carbon emissions, acidification, and smog effects, and Portland cement is the main contributor in A1 that contributes towards global warming (fossil) (>82%), ozone depletion (>48%), acidification (>83%), eutrophication (50%), smog (>87%), and abiotic depletion of fossil (>59%) impacts. Transportation to consumer (A4), siding installation (A5), maintenance (B2), and replacement (B4) phases of the FC siding life cycle contribute significantly towards fossil carbon emissions, ozone depletion, acidification, eutrophication, and abiotic depletion of fossil fuel. Siding maintenance (B2) is the highest contributing phase towards ozone depletion, eutrophication, and abiotic depletion impacts that come from paint use. Highest biogenic carbon emissions occur in the resource extraction phase that can be traced to hog fuel consumption for kiln drying in the production of planer shavings used to produce pulp. Total carbon emissions go down by about 8% when account for biogenic C sequestered in the product. Significant eutrophication impacts occur from landfilling FC siding at the end of life. Contributions from siding end of life stage (i.e. dismantling of FC siding (C1), waste transportation to sorting facility (C2), and sorting (C3) are minor (<1%).

Table 51 LCIA Results Summary, 100 ft^2 of FC siding for building lifetime (75 years) by life cycle stage – absolute basis

Impact Category	Unit	Total	Resource extraction	Roundwood transport	Siding manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	kg CO_2 eq	234.86	91.83	2.17	3.94	15.91	7.39	-	51.75	60.62	–	–	0.63	0.00	0.63
GWP100 – biogenic C emissions	kg CO_2-eq	4.64	1.92	0.02	0.01	0.13	0.13	-	1.32	1.11	–	–	5.71E-03	0.00	6.30E-04
GWP100 – biogenic C removals	kg CO_2-eq	-22.14	-14.76	–	–	–	–	-		-7.38	–	–	–	–	–
GWP100 – total	kg CO_2-eq	217.36	78.99	2.18	3.95	16.04	7.52	-	53.07	54.34	–	–	0.63	0.00	0.63
Ozone depletion	kg CFC-11 eq	1.22E-05	1.80E-06	3.60E-09	5.24E-08	2.65E-08	9.63E-07	-	7.84E-06	1.42E-06	–	–	1.16E-09	0.00	1.09E-07
Acidification	kg SO_2 eq	1.08	0.42	0.01	0.01	0.09	0.03	-	0.23	0.28	–	–	3.19E-03	0.00	0.01
Eutrophication	kg N eq	0.36	0.06	9.28E-04	3.05E-03	0.01	0.01	-	0.14	0.04	–	–	2.58E-04	0.00	0.08
Smog	kg O_3 eq	16.10	5.30	0.34	0.10	2.51	0.36	-	2.94	4.30	–	–	0.09	0.00	0.16
Abiotic depletion (fossil fuel)	MJ, LHV	2,122.45	460.60	27.04	51.35	198.63	125.43	-	810.37	431.53	–	–	8.74	0.00	8.74

Table 52 LCIA Results Summary, 100 ft^2 of FC siding for building lifetime (75 years) by life cycle stage – percentage basis

Impact Category	Unit	Total	Resource extraction	Resource transport	siding manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	%	100.00%	39.10	<1%	1.68	6.78	3.15	<1%	22.03	25.81	<1%	<1%	<1%	<1%	<1%
GWP100 – biogenic C emissions	%	100.00%	41.40	<1%	<1%	2.80	2.82	<1%	28.41	23.82	<1%	<1%	<1%	<1%	<1%
GWP100 – biogenic C removals	%	100.00%	66.67	<1%	<1%	<1%	<1%	<1%	0.00	33.33	<1%	<1%	<1%	<1%	<1%
GWP100 – total	%	100.00%	36.34	1.00	1.82	7.38	3.46	<1%	24.41	25.00	<1%	<1%	<1%	<1%	<1%
Ozone depletion	%	100.00%	14.74	<1%	<1%	<1%	7.88	<1%	64.16	11.65	<1%	<1%	<1%	<1%	<1%
Acidification	%	100.00%	39.35	1.11	<1%	8.13	2.83	<1%	20.90	26.10	<1%	<1%	<1%	<1%	<1%
Eutrophication	%	100.00%	17.15	<1%	<1%	1.92	4.12	<1%	40.12	12.15	<1%	<1%	<1%	<1%	23.35%
Smog	%	100.00%	32.90	2.12	<1%	15.61	2.21	<1%	18.27	26.74	<1%	<1%	<1%	<1%	<1%
Abiotic depletion (fossil fuel)	%	100.00%	21.70	1.27	2.42	9.36	5.91	<1%	38.18	20.33	<1%	<1%	<1%	<1%	<1%

7.3.3 Results – Vinyl siding

The LCIA results for 100 ft^2 of vinyl (PVC) siding for the Minneapolis location are shown in Table 53 and Table 54 on an absolute and percent basis, respectively.

In the course of the life cycle of vinyl siding a total of about 125 kg (CO_2 equivalent basis) of fossil greenhouse gases are released. Highest impacts in GWP fossil, ozone depletion, acidification, eutrophication, smog, abiotic depletion (fossil fuel) occur in the resource extraction phase (A1) mainly from PVC resin production while significant contributions occur from other inputs (filler, impact modifier, titanium dioxide, and tin). Siding replacement accounts for A1, A2, A3, A4, and A5 phases and second highest contributions occur towards GWP fossil in the replacement (B4) for the same reasons noted for A1. The third highest contributions towards GWP fossil occur in maintenance (B2) phase that comes from the cleaner used for periodic siding cleaning. Significant fossil greenhouse gas emissions occur from incineration of vinyl siding waste at the disposal (C4) phase. Highest eutrophication impacts occur from the cleaner used in the maintenance phase. Impact contributions from resource transportation (A2), siding manufacturing (A3), and transportation to consumer (A4) are small although significant smog effects occur in the A4 phase in the siding life cycle. Contributions from other phases (i.e., dismantling (C1), waste transportation (C2), and waste sorting (C3) are minor (<1%). Small amounts of biogenic carbon emissions occur in resource extraction (A1), installation (A5), and maintenance (B2) phases in the vinyl siding life cycle. Total carbon emissions increases when account for biogenic carbon emissions.

Table 53 LCIA Results Summary, 100 ft^2 of vinyl (PVC) siding for building lifetime (75 years) by life cycle stage – absolute basis

Impact Category	**Unit**	**Total**	**Resource extraction**	**Roundwood transport**	**Decking manufacturing**	**Transport to Customer**	**Installation**	**Use**	**Maintenance**	**Replacement**	**Operational water use**	**Dismantling**	**Waste Transport**	**Sorting**	**Disposal**
			A1	**A2**	**A3**	**A4**	**A5**	**B1,**	**B2**	**B4**	**B7**	**C1**	**C2**	**C3**	**C4**
GWP100 - fossil	kg CO_2 eq	125.11	45.30	3.80	3.09	4.23	1.82	-	29.12	29.12	-	-	0.09	-	12.61
GWP100 – biogenic C emissions	kg CO_2-eq	3.07	0.94	0.03	0.08	0.03	0.27	-	0.68	0.68	-	-	8.22E-04	-	1.02E-01
GWP – biogenic C removals	kg CO_2-eq	-	-	-	-	-	-	-	<1%	-	-	-	-	-	-
GWP100 – total	kg CO_2-eq	128.19	46.23	3.83	3.18	4.27	2.09	-	29.80	29.80	-	-	0.09	-	12.71
Ozone depletion	kg CFC-11 eq	7.81E-06	2.54E-06	6.33E-09	1.14E-07	7.04E-09	7.64E-09	-	1.34E-06	1.34E-06	-	-	1.68E-10	-	2.42E-07
Acidification	kg SO_2 eq	0.52	0.18	0.03	0.01	0.02	0.01	-	0.13	0.13	-	-	4.59E-04	-	0.02
Eutrophication	kg N eq	0.17	0.05	2.11E-03	0.01	1.81E-03	1.36E-03	-	0.03	0.03	-	-	3.72E-05	-	0.01
Smog	kg O_3 eq	7.32	1.94	0.87	0.10	0.67	0.08	-	1.83	1.83	-	-	0.01	-	0.22
Abiotic depletion (fossil fuel)	MJ, LHV	1911.31	882.05	47.48	36.62	52.86	17.18	-	518.10	518.10	-	-	1.26	-	42.27

Table 54 LCIA Results Summary, 100 ft^2 of vinyl (PVC) siding for building lifetime (75 years) by life cycle stage – percentage basis

Impact Category	Unit	Total	Resource extraction	Resource transport	siding manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	%	100.00%	36.20	3.04	2.47	3.38	1.45	<1%	20.02	23.28	<1%	<1%	<1%	<1%	10.08%
GWP100 - biogenic	%	100.00%	30.54	1.01	2.74	1.12	8.94	<1%	30.12	22.18	<1%	<1%	<1%	<1%	3.33%
GWP – biogenic C removals	%	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%
GWP100 - total	%	100.00%	36.07	2.99	2.48	3.33	1.63	0.00	20.26	23.25	<1%	0.00	0.07	0.00	9.91
Ozone depletion	%	100.00%	32.52	<1%	1.46	<1%	<1%	<1%	45.52	17.13	<1%	<1%	<1%	<1%	3.10%
Acidification	%	100.00%	35.56	5.53	2.14	4.52	1.95	<1%	22.30	24.85	<1%	<1%	<1%	<1%	3.06%
Eutrophication	%	100.00%	29.09	1.25	3.30	1.07	<1%	<1%	42.78	17.76	<1%	<1%	<1%	<1%	3.92%
Smog	%	100.00%	26.54	11.89	1.34	9.14	1.09	<1%	21.79	24.99	<1%	<1%	<1%	<1%	3.06%
Abiotic depletion (fossil fuel)	%	100.00%	46.15	2.48	1.92	2.77	<1%	<1%	16.40	27.11	<1%	<1%	<1%	<1%	2.21%

7.3.4 Results – Brick siding

The LCIA results for 100 ft^2 of brick siding for the Minneapolis location are presented in Table 55 and Table 56 on an absolute and percent basis, respectively.

During the life cycle of clay brick a total of about 279 kg (CO2 equivalent basis) of fossil greenhouse gases are emitted and >63% of these emissions are a function of clay brick manufacturing. Brick siding manufacturing (A3) is the dominant phase in the brick siding life cycle where the highest impact contributions occur in acidification, eutrophication, and abiotic depletion of fossil fuels. Significant ozone depletion and smog effects also occur during the manufacturing phase. These impacts come from natural gas use as an energy source to manufacture brick siding. Brick siding installation (A5) is the second largest contributing phase towards fossil greenhouse gas emissions that can be traced to cement mortar used for the installation. Significant acidification and smog impacts also occur in the installation phase for the same reason. Brick siding transportation to consumer (A4) cause highest smog effects and significant acidification and eutrophication impacts from diesel use for transportation. Small amount of biogenic greenhouse gas emissions occur in the brick siding life cycle. Note that total GWP emissions slightly increases when account for life cycle biogenic carbon emissions. Landfilling of bricks in the disposal phase (C4) causes significant ozone depletion and eutrophication impacts. Impact contributions from dismantling siding (C1), and sorting (C3) at the end of life are minor (<1%).

Table 55 LCIA Results Summary, 100 ft^2 of brick siding for building lifetime (75 years) by life cycle stage – absolute basis

Impact Category	**Unit**	**Total**	**Resource extraction**	**Roundwood transport**	**Siding manufacturing**	**Transport to Customer**	**Installation**	**Use**	**Maintenance**	**Replacement**	**Operational water use**	**Dismantling**	**Waste Transport**	**Sorting**	**Disposal**
			A1	**A2**	**A3**	**A4**	**A5**	**B1,**	**B2**	**B4**	**B7**	**C1**	**C2**	**C3**	**C4**
GWP100 - fossil	kg CO_2 eq	279.23	5.54	2.38	177.66	27.44	41.34	-	16.70	-	-	-	3.18	-	5.00
GWP100 – biogenic C emissions	kg CO_2-eq	2.65	0.01	0.02	0.23	0.20	1.47	-	0.62	-	-	-	0.03	-	0.08
GW – biogenic C removals	kg CO_2-eq	-	-	-	-	-	-	-		-	-	-	-	-	-
GWP100 - total	kg CO_2-eq	281.88	5.54	2.40	177.89	27.64	42.80	-	17.32	-	-	-	3.20	-	5.08
Ozone depletion	kg CFC-11 eq	5.67E-06	9.19E-07	3.96E-09	1.12E-06	4.07E-08	4.88E-07	-	2.37E-06	-	-	-	5.91E-09	-	7.28E-07
Acidification	kg SO_2 eq	0.75	0.05	0.01	0.23	0.15	0.16	-	0.08	-	-	-	0.02	-	0.04
Eutrophication	kg N eq	0.05	3.39E-03	1.02E-03	0.06	0.01	-0.09	-	0.05	-	-	-	1.31E-03	-	0.02
Smog	kg O_3 eq	14.21	1.56	0.38	3.60	4.38	1.56	-	1.06	-	-	-	0.44	-	1.23
Abiotic depletion (fossil fuel)	MJ, LHV	3548.58	80.60	29.74	2371.60	343.35	403.22	-	208.99	-	-	-	44.33	-	66.74

Table 56 LCIA Results Summary, 100 ft^2 of brick siding for building lifetime (75 years) by life cycle stage – percentage basis

Impact Category	**Unit**	**Total**	**Resource extraction**	**Resource transport**	**siding manufacturing**	**Transport to Customer**	**Installation**	**Use**	**Maintenance**	**Replacement**	**Operational water use**	**Dismantling**	**Waste Transport**	**Sorting**	**Disposal**
			A1	**A2**	**A3**	**A4**	**A5**	**B1,**	**B2**	**B4**	**B7**	**C1**	**C2**	**C3**	**C4**
GWP100 - fossil	%	100.00%	1.98%	0.85%	63.62%	9.83%	14.80%	<1%	5.98%	<1%	<1%	<1%	1.14%	<1%	1.79%
GWP100 – biogenic C emissions	%	100.00%	<1%	<1%	8.56%	7.59%	55.41%	<1%	23.30%	<1%	<1%	<1%	1.09%	<1%	3.09%
GWP100 – biogenic C removal s	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GWP100 – total	%	100.00%	1.97	0.85	63.11	9.81	15.18	0.00	6.14%	<1%	<1%	<1%	<1%	<1%	<1%
Ozone depletion	%	100.00%	16.20%	<1%	19.71%	<1%	8.61%	<1%	41.77%	<1%	<1%	<1%	<1%	<1%	12.83%
Acidification	%	100.00%	7.07%	1.76%	30.78%	20.50%	21.69%	<1%	10.27%	<1%	<1%	<1%	2.16%	<1%	5.77%
Eutrophication	%	100.00%	6.36%	1.92%	113.77%	21.60%	-165.08%	<1%	90.63%	<1%	<1%	<1%	2.46%	<1%	28.34%
Smog	%	100.00%	10.99%	2.65%	25.32%	30.80%	10.96%	<1%	7.48%	<1%	<1%	<1%	3.11%	<1%	8.69%
Abiotic depletion (fossil fuel)	%	100.00%	2.27%	0.84%	66.83%	9.68%	11.36%	<1%	5.89%	<1%	<1%	<1%	1.25%	<1%	1.88%

7.3.5 LCIA Results Comparison – Alternative Siding Products

Comparative assessment results of the four siding product systems are shown in Table 57, Table 58, and Figure 11. Table 57 presents base case results of the four siding products. WRC siding LCIA results benchmarked against other siding products are provided in Table 58 while Figure 11 depicts the comparative assessment results on percentage basis. In terms of fossil fuel dependence, WRC siding is the least fossil fuel intensive siding system and brick is the most fossil fuel dependent residential siding systems. Vinyl siding uses a significant amount of fossil fuel in its production relative to WRC siding. The global warming potential measure indicates that WRC siding produces the least fossil greenhouse gases of the four siding product systems studied. WRC siding is >50% less GWP100 fossil intensive than clay brick and FC siding. Both WRC siding and FC siding contains biogenic carbon sequestered in the products. Overall life cycle GWP (total) of WRC siding significantly goes down when account for biogenic carbon sequestered in the product that goes to long term storage in landfills at EoL. Total GWP of fibre cement goes down by slightly since FC contains a small amount of sequestered carbon. WRC siding and FC siding cause more or less the same ozone depletion but their ozone depletion impacts are significantly higher than vinyl and brick sidings. WRC, vinyl, and brick siding have similar acidification impacts. Acidification impacts of FCcement siding about two times higher compared to WRC, brick, and vinyl sidings. FC siding has the highest eutrophication impacts while brick is least impact material among all siding systems. WRC siding demonstrates a higher eutrophication potential than vinyl and brick. The sensitivity analysis portion of this report (Section 7.1) revisits a number of assumptions governing the study to ensure the validity and robustness of the results obtained.

Table 57 LCIA Result Comparison of Siding Alternatives–absolute basis, base case

Impact category	Unit	WRC siding	FC siding	Vinyl siding	Brick siding
GWP100 – fossil	kg CO_2 eq	106.13	234.86	125.11	279.23
GWP100 – biogenic C emissions	kg CO_2 eq	40.64	4.64	3.07	2.65
GWP – biogenic C removals	kg CO_2 eq	-110.25	-22.14	-	-
GWP100 – total	kg CO_2 eq	36.52	217.36	128.19	281.88
Ozone depletion	kg CFC-11 eq	1.24E-05	1.22E-05	7.81E-06	5.67E-06
Acidification	kg SO_2 eq	0.53	1.08	0.52	0.75
Eutrophication	kg N eq	0.22	0.36	0.17	0.05
Smog	kg O_3 eq	10.37	16.10	7.32	14.21
Abiotic depletion (fossil fuels)	MJ	1,615.33	2,122.45	1,911.31	3,548.58

Table 58 WRC siding benchmark results against alternative siding products

Impact category	Unit	WRC against fibre cement	WRC against vinyl	WRC against brick
GWP100 – fossil	kg CO_2 eq	-128.73	-18.98	-173.10
GWP100 – biogenic C emissions	kg CO_2 eq	36.00	37.57	38.65
GWP – biogenic C removals	kg CO_2 eq	-88.11	-110.25	-110.25
GWP100 – total	kg CO_2 eq	-180.84	-91.67	-244.70
Ozone depletion	kg CFC-11 eq	-7.80E-07	4.62E-06	8.17E-06
Acidification	kg SO_2 eq	-0.57	0.03	-0.02
Eutrophication	kg N eq	-0.13	0.08	0.21
Smog	kg O_3 eq	-5.76	3.42	0.08
Abiotic depletion (fossil fuels)	MJ	-621.04	-288.19	-1,038.31

Note: Negative numbers show smaller impact score while positive numbers depict higher impact score of WRC compared to alternatives

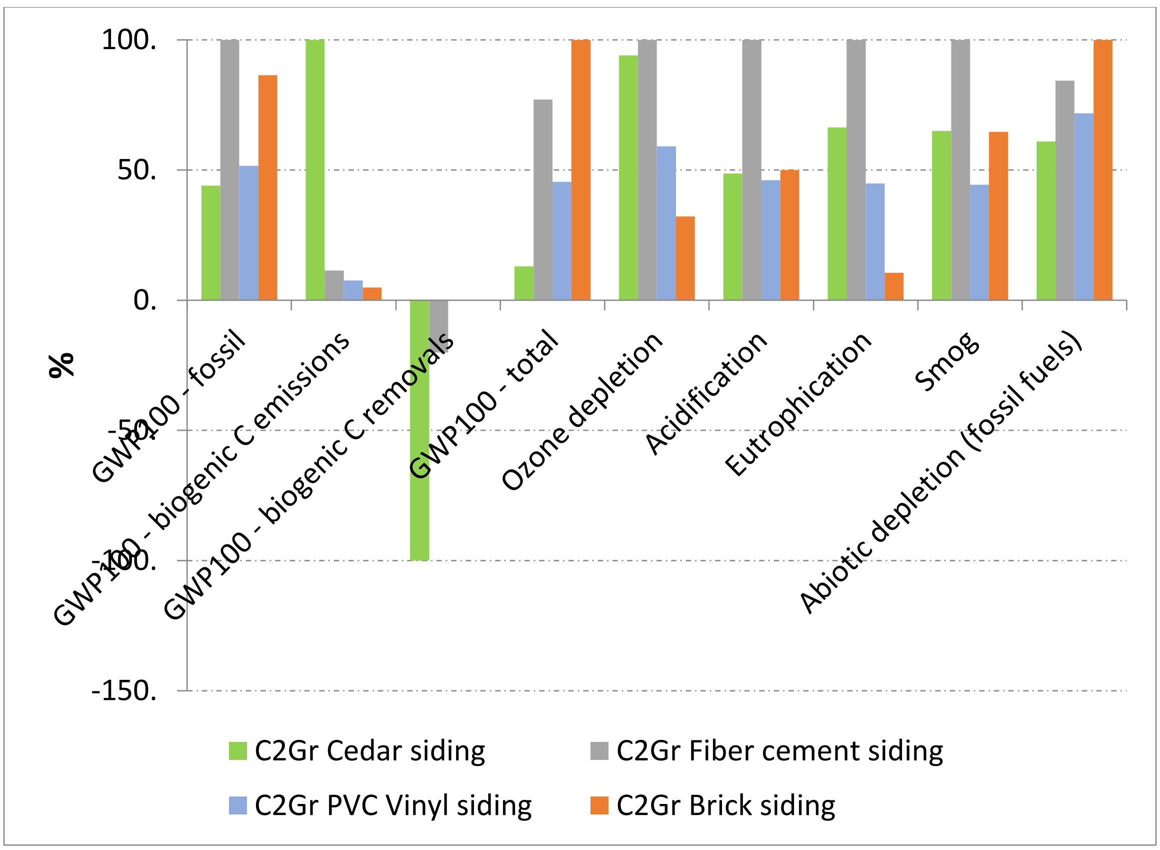


Figure 11 Comparative LCIA Results of Siding Alternatives – percentage basis, base case

8 INTERPRETATION

In this section, the LCI and LCIA sections are revisited to address the uncertainties associated with the LCIA results. WRC (lumber, decking and siding), WPC decking, and fibre cement siding contain atmospheric carbon sequestered in the products. Sensitivity of base case findings are discussed and where feasible sensitivity checks are performed to evaluate consistency and validity of study results to provide context for conclusions and recommendations.

8.1 Sensitivities

The main sources of uncertainties are: mass allocation applied to partition environmental flows between main products and co-products from wood products manufacturing, and the quality of the data. The data quality assessment procedure provided in the UL Environment PCR, Part A (UL Environment, 2022), Section 7.1 evaluates the LCI data sources used to model environmental impacts associated with the production of energy and ancillary materials, and transportation modes. In addition, uncertainties surrounding assumptions and changes in major contributors in the decking and siding product systems are evaluated via a sensitivity.

8.1.1 Allocation sensitivity

As stated in Section 2.5, the study followed mass allocation for the base case assessments per the PCR Part B published by UL Environment (2019) for Structural and Architectural Wood Products EPD Requirements. Uncertainty surrounding allocation was evaluated by applying economic allocation based on revenues for the main product and co-products produced during rough green lumber, decking and siding manufacturing phases (A3). Revenues were calculated using the FoB prices reported by the survey respondents. Note that the FoB prices are not mentioned in this report due to the confidentiality of the information provided by the survey respondents. Table 59 summarizes calculated economic allocation factors. The results of allocation sensitivity analysis are shown in Table 60. All Environmental impacts indicators go up slightly with revenue-based allocation.

Table 59 Economic allocation factors calculated for the manufacturing phase (A3) of WRC rough green lumber, decking, and siding product systems

	Economic allocation factor (%)		
	Rough green lumber	**WRC decking**	**WRC siding**
Main product	97.07%	98.96%	99.43%
Co-products			
Bark	0.04%	0.00%	0.00%
Pulp chips	2.00%	0.51%	0.29%
Sawdust	0.33%	0.23%	0.13%
Planershavings	0.01%	0.02%	0.02%
Hog fuel	0.55%	0.28%	0.13%

Table 60 Summary results of allocation sensitivity analysis of WRC rough green lumber, decking and siding against WRC base case scenarios per Mbfm basis for building lifetime (75 years)

Impact category	Unit	WRC Rough green lumber*		WRC Decking		WRC Siding	
		Base case	Allocation sensitivity	Base case	Allocation sensitivity	Base case	Allocation sensitivity
GWP100 - fossil	kg CO_2 eq	208.99	221.79	145.25	155.18	106.13	114.03
GWP100 – biogenic C emissions	kg CO_2 eq	1.69	3.77	183.43	185.18	40.64	41.99
GWP – biogenic C removals	kg CO_2 eq	-1119.14	-1119.14	-521.98	-521.98	-110.25	-110.25
GWP100 - total	kg CO_2 eq	-908.46	-893.58	-193.3	-181.62	36.52	45.77
Ozone depletion	kg CFC-11 eq	1.13E-05	1.31E-05	9.45E-06	1.10E-05	1.24E-05	1.35E-05
Acidification	kg SO_2 eq	0.92	1.02	0.83	0.91	0.53	0.60
Eutrophication	kg N eq	0.14	0.14	0.19	0.20	0.22	0.25
Smog	kg O_3 eq	26.66	29.70	21.55	23.78	10.37	12.24
Abiotic depletion (fossil fuels)	MJ	2,881.00	3,089.35	1,883.49	2,071.13	1,615.33	1,765.79

Note: *Crade-to-gate impacts

8.1.2 Sensitivities of decking product systems

Decking results sensitivity was investigated by modeling alternative replacement rates, maintenance throughout the lifecycle and manufacturing location.

The baseline LCA results for WRC decking assume no replacement of the deck boards during the 25-year service life. However, some replacement may occur due to rot and other board related failures over time. A 100% WRC decking board replacement scenario was constructed to explore the sensitivity of replacement effects. It is assumed that board replacement occurs in the middle of the 25-year service life with 100% new WRC.

In addition, WRC decking is often stained prior to installation and at regular intervals thereafter to maintain a desired appearance. Therefore, a second scenario was developed where the WRC boards were stained during installation and every three years thereafter during the 25-year service life to determine the degree to which staining of boards would influence the overall base case LCIA results.

In addition, it was assumed that WPC decking manufacturing occurs in Missouri in USA. Missouri is a carbon intensive electricity grid since Missouri uses fossil fuel (mainly coal) to generate electricity, and it was found that electricity is a major contributor towards overall environmental footprint of WPC decking. A sensitivity analysis was conducted by replacing Missouri electricity grid with BC electricity grid which is mostly hydro and less carbon intensive.

Summary results from the sensitivity analysis conducted for WRC and WPC decking systems are shown in Table 61 and Figure 12. While the sensitivity analysis for the WRC decking indicates a fair degree of possible variability within its product system, none of these results would markedly change the baseline comparative results of WRC decking against WPC decking.

Table 61 Summary results of sensitivity analysis conducted for WRC and WPC decking systems on absolute basis (building lifetime 75 years)

Impact category	Unit	WRC Decking			WPC Decking	
		Base case	Replacement sensitivity	Staining Sensitivity	Base case	Manufacturing electricity sensitivity
GWP100 - fossil	kg CO_2 eq	145.25	242.09	345.74	2,326.33	750.59
GWP100 – biogenic C emissions	kg CO_2 eq	183.43	305.71	186.41	426.20	479.16
GWP100 – biogenic C removals	kg CO_2 eq	-521.98	-1,043.96	-521.98	-1,382.71	-1,382.71
GWP100 - total	kg CO_2 eq	-193.30	-496.16	10.16	1,580.33	57.56
Ozone depletion	kg CFC-11 eq	9.45E-06	1.57E-05	4.00E-05	1.09E-04	5.66E-05
Acidification	kg SO_2 eq	0.83	1.39	1.65	12.13	2.99
Eutrophication	kg N eq	0.19	0.32	0.70	7.46	1.71
Smog	kg O_3 eq	21.55	35.92	31.47	124.78	50.77
Abiotic depletion (fossil fuels)	MJ	1,883.49	3,139.15	5,651.43	26,654.76	10,464.93

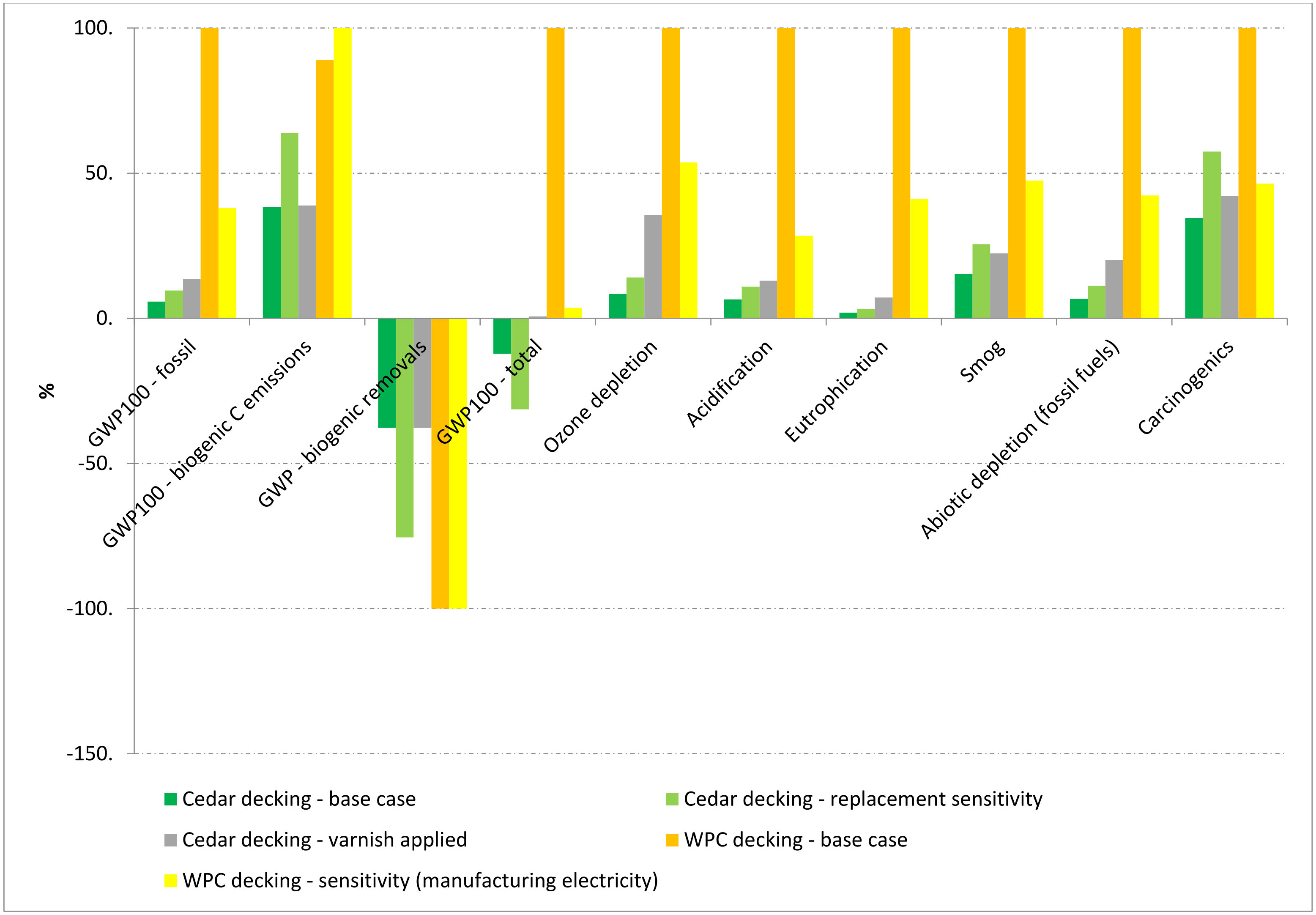


Figure 12 Summary results of sensitivity analysis conducted for WRC and WPC decking systems on percentage basis (building lifetime 75 years)

8.1.3 Sensitivities of siding product systems

The baseline siding LCA study assumptions and inputs were evaluated for their significance on the overall results within and between the siding product systems. The sensitivity cases and the ensuing results are described below for each siding product system.

WRC Siding: The baseline WRC siding LCIA results were modeled based on the assumption that WRC siding is repainted every 15 years over its life cycle. As paint was identified as a key contributor to the maintenance phase (B2) LCIA results, the frequency of repainting is increased to a 10-year cycle to determine the sensitivity of this maintenance phase change on the overall LCIA results for WRC siding. Environmental impacts increase by about (10% – 15%) in GWP (fossil), ozone depletion, acidification, eutrophication, smog, and abiotic depletion (fossil fuel) with increasing repainting to a 10-year cycle (see Table 62).

FC Siding: The vast majority of environmental impacts in the FC life cycle occur in the resource extraction (A1) phase from cement use as the main input. No sensitivity scenario was developed for FC siding since cement is the main constituent of FC with no substitutes to replace it.

Vinyl Siding: PVC polymer is a major contributor to the environmental footprint of vinyl siding manufacturing. Vinyl siding is also manufactured with ASA polymer, so a sensitivity analysis was conducted to evaluate implications of vinyl siding manufactured with ASA Capstock. Slight increase in GWP (fossil), acidification, eutrophication, and smog impacts occur with manufacturing vinyl siding with ASA polymer while ozone depletion impacts increase by >14%. A slight improvement in abiotic depletion (fossil fuel) can be obtained by switching to ASA polymer (see Table 62).

Brick Siding: The base case WRC siding LCIA results were modeled based on the assumption that natural gas is used for firing bricks. However, some brick plants in the US use landfill gas and sawdust as energy sources to fire bricks (Brick Industry Association, 2019). Whilst the exact percentages of plants that use landfill gas and sawdust to power their kilns are not known, a sensitivity scenario was developed to determine the impact of replacing natural gas with biomass. A replacement factor of 20% renewable energy (sawdust) was applied to energy use. About 10% improvements in GWP (fossil) and abiotic depletion (fossil fuel) occurs with 20% replacement of natural gas with renewable biomass. A substantial increase (>65%), however, occurs in ozone depletion impacts with this replacement.

Summary results from the sensitivity analysis conducted for WRC siding repainting (worst case) vs base case of brick siding, FC siding, and vinyl siding and best cases of vinyl and brick sidings are depicted in

Table 62 and Figure 13. The sensitivity analysis has underscored the high degree of variability in possible LCIA results for the individual siding product systems. The graphic contrasts the worst-case scenarios for WRC, relative to base case of FC and brick siding and best-case scenario for vinyl siding. The results are normalized to the highest impact product in each impact category. WRC siding with a higher repainting schedule still tends towards having a lower environmental impact in GWP (fossil) and abiotic depletion of fossil fuel. WRC siding still has the least environmental impacts across these two categories despite its assumed greater repainting requirement.

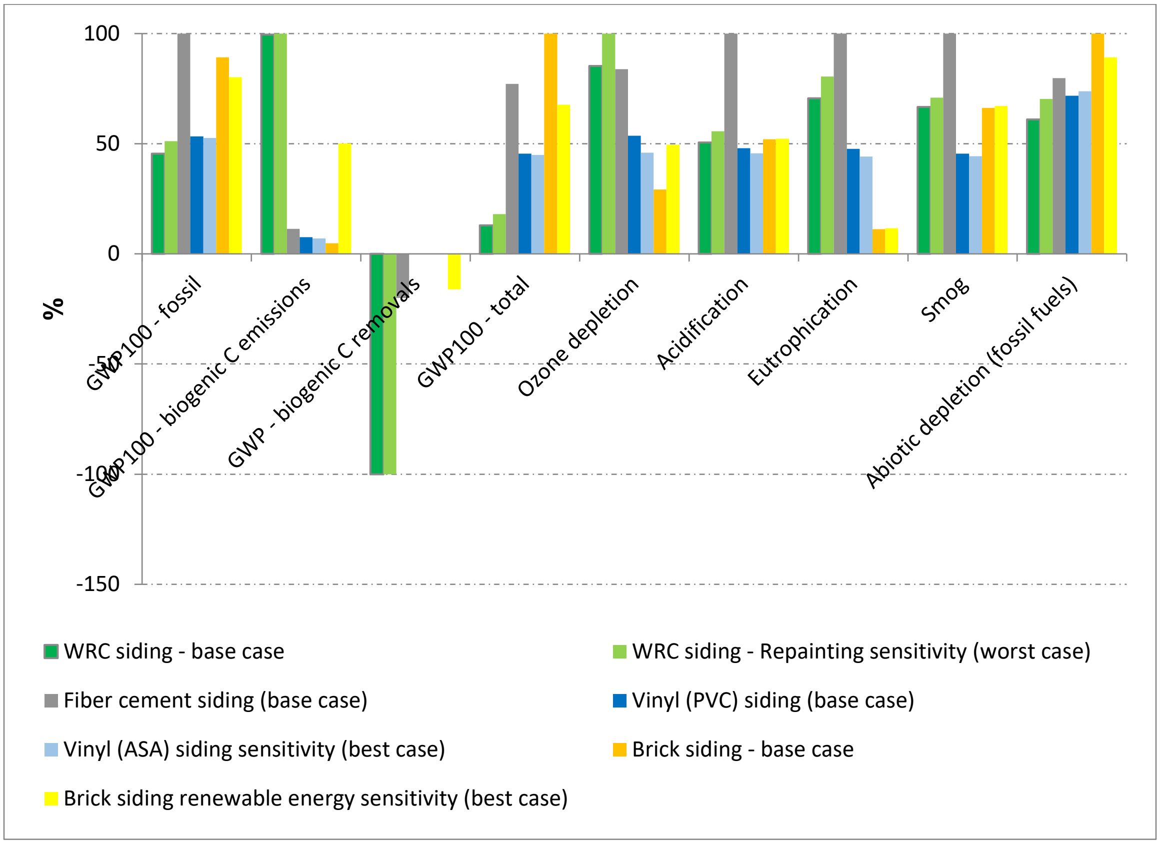


Figure 13 Sensitivity analysis summary results – WRC siding worst case vs base case of brick siding, FC siding, and vinyl siding base case and worse case on percentage basis (building lifetime - 75 years)

Table 62 Sensitivity analysis summary results – WRC siding worst case vs base case of brick siding, FC siding, and vinyl siding base case and worse case for building lifetime (75 years)

Impact category	Unit	WRC Siding		FC Siding	Vinyl Siding		Brick Siding	
		Base case	Repainting sensitivity (worst case)	Base case	Base case PVC capstock	ASC capstock	Base case	Renewable energy sensitivity
GWP100 - fossil	kg CO_2 eq	106.13	120.11	234.86	125.11	123.67	279.23	188.36
GWP100 – biogenic C emissions	kg CO_2 eq	40.64	40.84	4.64	3.07	2.88	2.65	20.47
GWP100 – biogenic C removals	kg CO_2 eq	-110.25	-110.25	-22.14	-	-	-	-17.82
GWP100 – total	kg CO_2 eq	36.52	50.70	217.36	128.19	126.56	281.88	191.01
Ozone depletion	kg CFC-11 eq	1.24E-05	1.46E-05	1.22E-05	7.81E-06	6.69E-06	5.67E-06	7.23E-06
Acidification	kg SO_2 eq	0.53	0.60	1.08	0.52	0.49	0.75	0.56
Eutrophication	kg N eq	0.22	0.29	0.36	0.17	0.16	0.05	0.04
Smog	kg O_3 eq	10.37	11.41	16.10	7.32	7.14	14.21	10.81
Abiotic depletion (fossil fuels)	MJ	1,615.33	1,871.57	2,122.45	1,911.31	1,966.46	3,548.58	2,372.89

8.2 Consistency of study results with environmental footprints reported in EPDs

The US Canada industrywide Brick published by the Brick Industry Association (2020) and the WPC EPD published by Huidong Meixin Plastic Lumber Products Manufacturing Co., Ltd. (2021) for NewTechWood reports impacts per kg of products. Per kg of product impacts reported in these EPDs were used to compare the cradle-to-gate (A1, A2, and A3) LCIA impact scores calculated in this study for brick and WPC. As for FC and vinyl sidings, impact scores for 1 m^2 of installed sidings reported in the industry averaged vinyl siding and the EPD published by the James Hardie™ (2023) for Hardie® Plank were used to evaluate the consistency of study findings. Summary results from this consistency assessment are shown in Table 63. Results from this study are close to the impact scores reported in the EPDs for WPC decking, FC, vinyl, and brick sidings except the discrepancies noted for Abiotic depletion (fossil fuels) of FC and vinyl sidings. The differences between study results and the impacts reporting in EPDs might be due to missing packaging data. However, reasons for the discrepancies could not be evaluated due to limited information reported in the EPDs.

Table 63 Comparison of cradle-to-gate study results of brick siding and WPC decking with LCIA impacts reported in EPDs

Impact category	Unit	WPC decking per kg		FC siding per 1m^2 installed*		Vinyl siding per 1m^2 installed*		Brick siding per kg	
		Study results	EPD reporting	Study results	EPD reporting	Study results	EPD reporting	Study results	EPD reporting
GWP100 - fossil	kg CO_2 eq	1.64	1.37	7.03	7.17	3.75	4.71	0.18	0.24
GWP100 - biogenic					-1.85	0.08	-	-	-
Ozone depletion	kg CFC-11 eq	7.88E-08	1.17E-07	1.33E-07	9.14E-08	1.91E-07	6.54E-07	1.98E-09	2.97E-08
Acidification	kg SO_2 eq	8.72E-03	7.06E-03	0.03	2.14E-02**	0.02	3.37E-02	2.88E-04	7.17E-04
Eutrophication (freshwater and marine)	kg N eq	4.67E-03	4.92E-03	4.66E-03	5.68E-03***	4.09E-03	6.14E-03	6.32E-05	4.19E-04
Smog	kg O_3 eq	0.09	0.09	0.41	1.95E-02****	0.21	0.02	5.38E-03	7.36E-03
Abiotic depletion (fossil fuels)	MJ	19.16	17.78	38.68	72.20	69.33	124.00	2.41	-

Note: *50-year service life
**kg H_2eq
***Marine eutrophication
****kg NMVOC eq.

8.3 Data quality assessment

8.3.1 Data sources and secondary LCI data

Data quality assessment was conducted in accordance with UL Environment (2022) Part A. Table 64 summarizes the data sources used for the decking and siding types chosen for this comparative assertion and the comments on the data quality. Both WRC decking and siding, and vinyl siding data are ranked high in quality as these data are recent (less than three years old) and geographic representative as the inventories are compiled using the primary data gathered from North American manufacturing operations. Mass balance was performed for the data gathered from WRC lumber, decking, and siding manufacturing operations to ensure the validity. The data used for WPC decking are ranked as low-medium since these data were compiled based on various sources.

WRC decking and siding data are complete and include packaging as well. However, alternative decking and siding products inventories lack packaging data as information on packaging could not be found in the literature. Besides missing packaging data, all remaining flows pertaining to the alternative decking and siding products were evaluated in the inventory analysis and included in the impact assessment. Detailed flow level assessment can be found in Appendix M.

Table 64 Cradle to Gate Manufacturing Inventory Data Quality Summary

Product	**Data type**	**Data quality**	**Remarks**
WRC Siding/Decking	Primary Survey data	High	Data gathered for 2022 calendar year. Validity checked using mass balance.
WPC decking	Secondary (Various Sources)	Low - medium	Various non-LCI data sources, information on packaging missing
Brick siding	Secondary (BEES and Athena)	Medium	Data gathered from Canadian brick operations; information on packaging missing Date/Technology/Geography/etc.
Vinyl siding	Secondary (Vinyl Siding Institute and BEES)	High	Data gathered from North American manufacturing operations; information on packaging missing
FC siding	Secondary (BEES)	Medium	Data gathered from North American operations; information on packaging missing

The quality of the secondary energy and material inputs, and transport data used for this comparative assertion was evaluated using the data quality assessment procedure provided in the UL Environment (2022) PCR Part A. The study relied on DATASMART LCI (US EI 2.2) Package LCI data (LTS, 2021) and ecoinvent 3.8 for modeling inputs of the information modules. The US-EI 2.2 is an amalgamated proprietary LCI database that consists of expanded US LCI data and modified ecoinvent 2.2 to represent the North American region. The data represent average technology specific to North American consumption mix and of recent vintage (<5 years old), and complete. However, the data merits improvement in the sense that data gaps in the US LCI data has been filled using the data from other regions (European origin) due to no existing North American data. The study had to use ecoinvent 3.8 datasets to fill the gaps when there are no sets available in US EI 2.2 for propane use for manufacturing of WRC siding and peat used to produce WRC seedlings. Although ecoinvent 3.8 has a recent vintage (<5 years old), its datasets do not represent north American conditions interns of geographic and technological coverage. Mixing different background data sources causes data quality issues with respect to geographic and technological representativeness.

Secondary data sources used for modeling are documented in the report to enable users to reproduce the LCIA results. The overall data quality ranking is “Fair” since the study used best available LCI data to model background material and energy inputs and processes.

8.3.2 Influence on main impact contributors

As for decking product systems, more than two-thirds of impact contributions across all the impact categories occur in the production (A1-A3) and construction (A4) stages and during replacement (B4) in the operation stage. For WRC decking, firsthand data gathered from actual resource extraction, transportation and decking manufacturing operations were used and impacts were modeled using recent background LCI datasets representative of north American conditions. For WPC decking, data used for LCI calculations were not from actual manufacturing operations since the study relied on various data sources available in the literature and electricity consumption estimates provided by extruder manufacturers. Although background LCI datasets representative of north American conditions were used to model WPC decking impacts, quality of data used for WPC decking remains a main issue since their representativeness of actual WPC manufacturing operations was not known.

As for siding product systems, one-thirds to two-thirds of impact contributions across all impact categories occur in the production (A1-A3) and construction (A4) stages and during replacement (B4) in the operation stage. For WRC siding, firsthand data gathered from actual resource extraction, transportation and siding manufacturing operations were used. Impacts were modeled using recent background LCI datasets representative of north American conditions except peat used for raising seedlings and propane use for kiln drying. For other siding products, data used for LCI calculations were from actual resource extraction and manufacturing operations occurring in north America provided in the literature. Their impacts were modeled using recent background LCI datasets representative of north American conditions. Although peat used for raising WRC seedlings is not a significant contributor, substantial impact contributions occur from propane use for kiln drying in the WRC siding manufacturing phase. The influence of using European (ecoinvent 3.8) dataset for propane to model WRC siding drying over its overall impacts were not known since there was no alternative existing background dataset for evaluation.

9 CONCLUSIONS AND STUDY LIMITATIONS

9.1 Conclusions

The following conclusions are drawn with regards to the contribution and sensitivity analysis of WRC decking and siding and the comparative LCA.

9.1.1 WRC decking

As far as the WRC decking is concerned, the resource extraction (A1), transportation to consumer (A4), and maintenance (B2) phases dominate the product's environmental profile. In addition, landfilling at the end of life significantly contributes to biogenic carbon emissions (GWP100 biogenic). Transportation can significantly contribute to WRC decking's life cycle environmental impacts.

9.1.2 WRC siding

The same factors identified for WRC decking also play an important role in the life cycle environmental burdens of WRC siding. In addition, fossil energy (natural gas and propane) is one of the most important factors as WRC siding manufacturing involves kiln drying. Currently, the survey participants do not use wood waste generated to produce energy as a substitute for fossil fuels. While taking into account the large volume of low-value wood co-products generated from WRC manufacturing, there is the potential to substantially improve the environmental profile of WRC siding if a major portion of the co-product stream is internally recycled for energy recovery for kiln drying. Unlike decking, the use phase (maintenance (B2)) of siding is significant as well because painting at installation and periodically during use contributes a significant share of the life cycle impacts. Developing innovative coatings with a lower environmental footprint or with fewer re-applications during the 75-year building life help would help improve the environmental profile of WRC siding.

9.1.3 Comparative LCA

In this study, WRC decking and siding were compared to common alternatives: wood-plastic composite (WPC) decking, brick siding, vinyl siding, and fiber-cement siding. Base case assumptions for all products were selected using industry information and common practices for each product. Base case conditions include the following:

- Decking products have a 25-year service life with no coatings and no board replacements.
- Siding products have a 50-year service life except for brick, which has a 100-year service life.
- Minneapolis is the location of final product installation.
- The wood-plastic (WPC) decking composition is about 47% wood, 45% plastic, 8% other materials.
- The WRC and fiber-cement siding products are painted at installation and thereafter every 15 years.
- 69% of all products are eventually disposed in landfill and the remainder is recycled or incinerated.
- All environmental flows are attributed ≈33% to the decking or siding product, even though, in the case of WRC, some flows could possibly be attributed to co-products of production.

- All activities or building elements common to all products are ignored.
- All unique elements are included: nails, brick ties, cement mortar and paint.
- The manufacturing location of the WRC products is taken as the Pacific Northwest.
- The manufacturing location of the wood-plastic products is taken as eastern US.
- The manufacturing location of the FC products is taken as eastern US.
- The manufacturing location of the brick products is taken as eastern US.
- The manufacturing location of the vinyl products is taken as eastern US.

Impact scores of WRC decking substantially better compared to WPC, regardless of the recycled plastic content in the WPC, across all the environmental metrics examined in this study. A sensitivity analysis was performed to test the influence of various assumptions and to provide "what-if" scenarios that might change the relative performance of the decking alternatives. Specifically, additional burdens were added to the WRC base case (a regular regime of staining and board replacement). In this WRC-worst-case comparison to WPC best-case, WRC still have less impact scores than WPC, although the WPC profiles are improved with using less carbon intensive electricity grid (BC).

WRC siding carries two additional burdens not shared with WRC decking: kiln-drying and painting. These activities have significant environmental impact. However, WRC shows lower impact scores in global warming (GWP100 fossil and total GWP100) and abiotic depletion (fossil fuel). The impact of WRC siding in ozone depletion, smog and eutrophication can be traced to paint, and the environmental results for WRC are sensitive to frequency of painting. In general, brick siding is the worst in impact scores in the base case, followed by FC siding although impact scores of brick siding relative to FC siding becomes less with the use of renewable fuel (hog fuel) for drying. In the base case, strong conclusions on relative environmental performance of WRC siding against vinyl siding in ozone depletion and smog metrics could not be drawn due to missing vinyl siding packaging and manufacturing waste treatment data. The base case relative environmental performance of WRC siding does not substantially change even in a worst case for WRC (more frequent painting). In a WRC best case (i.e., base case), WRC stands out more substantially against the other products.

9.2 Study Limitations

The study findings are limited due to no firsthand industry average data available in the literature for WPC decking, brick and FC siding types, and missing vinyl siding packaging and manufacturing waste treatment data. There was no way of validating the material and energy consumption data obtained from the literature for WPC, brick and FC, and hence is also another limitation of this study. As a result, it is not possible to comment on whether the LCIA results of the alternative products (particularly WPC, brick, and FC types) represents industry average life cycle environmental burdens. The significance of the missing vinyl LCI flows was not possible to comment since there is no available proxy data. Besides, a quantitative uncertainty analysis to evaluate low impacts differences found in siding comparisons was not possible because only a few WRC siding manufacturers participated in the survey while secondary data sources used for alternative siding materials did not report a statistical dispersion. Findings from this study are also limited due to use of European (ecoinvent 3.8) background dataset to model propane use for kiln drying of WRC siding. Another limitation is lack of precise service lives of siding and decking products evaluated in this study. Consequently, the study relied on the manufacturer warranty claims and life spans used for residential property management. Therefore, caution should be exercised in drawing strong conclusions from the comparative assertion, especially when the selected alternative products outperform WRC siding by a narrow margin.

Although it is clearly stated that the geographical conditions of the study are based on conditions found in Minneapolis, Minnesota, although central to the US, this location is not fully representative of conditions across the entire US.

Forests are not a static resource and are subjected to natural disturbances such as forest fires, and disease and pest outbreaks. Carbon implications from logging in forests with respect to this natural range of variation could not be accounted in the carbon calculations due to no data available on how logging fits in this natural range of variation.

10 RECOMMENDATIONS

There are a number of actions which could lead to improvements to the environmental profile of WRC products:

- Better lumber recovery in the mills.
- Use of mill wood waste or by-products as an energy substitute for fossil fuel in the mill.
- The use of paints or other coatings with better environmental profiles than current coatings and/or with better durability.
- The elimination of painting or coating WRC products at all.

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APPENDICES

Appendix A: Overview of Life Cycle Assessment

The international standards in the ISO 14040 and ISO 14044-series[31] set out a four-phase methodology framework for completing an LCA, as shown in Figure 14: goal and scope definition, life cycle inventory, life cycle impact assessment and interpretation.

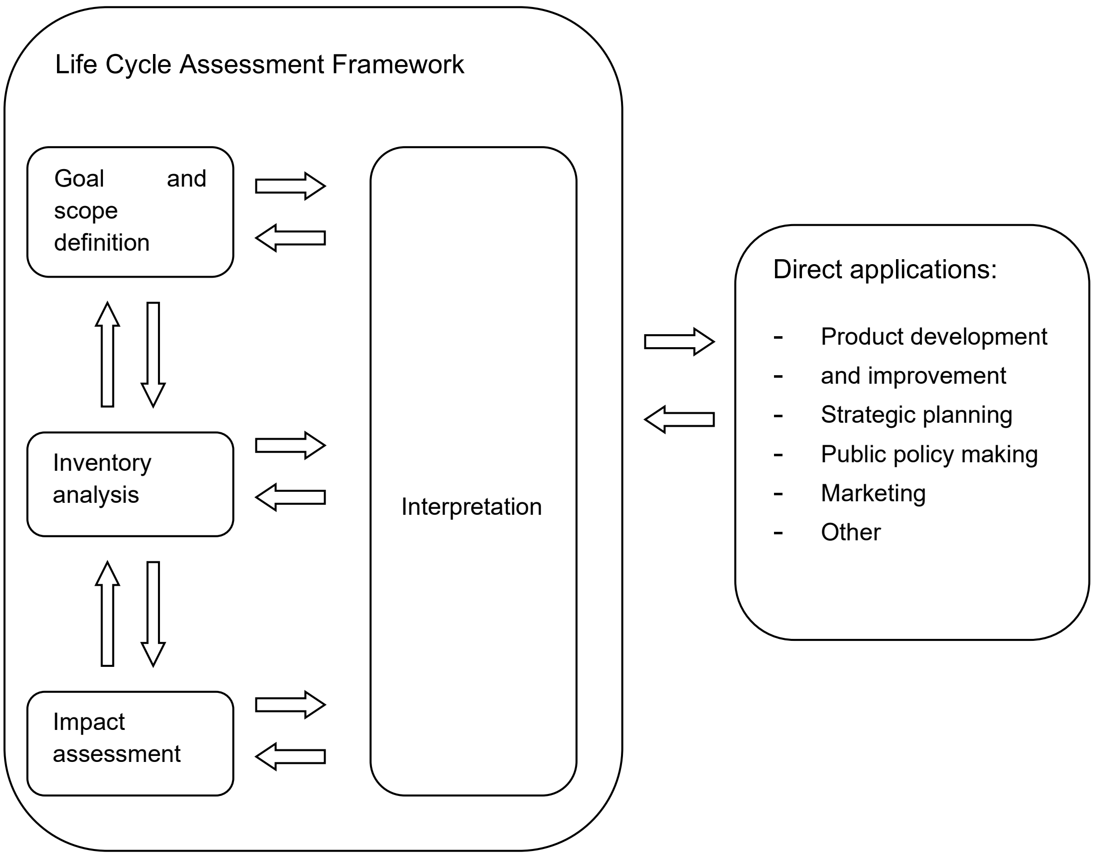

Figure 14 Life Cycle Assessment methodology: the ISO 14040 framework and applications

Goal and Scope Definition

An LCA starts with an explicit statement of the goal and scope of the study, the functional unit, the system boundaries, the assumptions and limitations and allocation methods used, and the impact categories chosen. The goal and scope includes a definition of the context of the study which explains to whom and how the results are to be communicated. The goal and scope of an LCA are clearly defined and consistent with the intended application. The functional unit is a reference unit defined for quantified performance

[31] ISO 14040:2006, *Environmental Management - Life Cycle Assessment - Principles and Framework* and ISO 14044:2006, *Environmental Management - Life Cycle Assessment – Requirements and Guidelines*.

of a product system to which all flows in the LCA are related. Allocation is the method used to partition the environmental load of a process when several products or functions share the same process (ISO, 2006b).

Life Cycle Inventory Analysis

In the inventory analysis, a flow model of the technical system is constructed using data on inputs and outputs – called **life cycle inventory** (LCI). The flow model is often illustrated with a flow chart, which includes the activities that are going to be assessed and also gives a clear picture of the technical system boundary. The input and output data needed for the construction of the model are collected (such as 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** (FU). For more information, see Box 2.

Box 2: Life cycle inventory analysis – a hypothetical example

Table A summarises input and output flows of hog fuel and pellet manufacture. The inputs used and the quantities of products produced in the two product systems are different, so a meaningful comparison of the two product systems cannot be done with the flows shown in Table A. Pellets can be used for heating, animal bedding etc., but both hog fuel and pellets perform the same function when they are used for energy. Considering the common function the two products perform, one GJ of energy (higher heating value (HHV)) was chosen as the FU. The input and output flows of pellets and hog fuel manufacture were divided by their HHV contents in the final products in order to attribute the flows to the FU. The normalized flows (LCIs) are shown in Table B. A meaningful comparison can now be made these normalized flows.

Table A Process input and output flows of two biofuels

<table>
<tr><th rowspan="3">Fuel</th><th colspan="3">Process input flows</th><th colspan="5">Environmental output flows</th></tr>
<tr><th rowspan="2">Wood waste (ton)</th><th rowspan="2">Electricity (kWh)</th><th rowspan="2">Diesel (litres)</th><th colspan="2">Fuel</th><th rowspan="2">GHGs (kg)</th><th rowspan="2">NOx (kg)</th><th rowspan="2">VOCs (kg)</th></tr>
<tr><th>Oven dry ton</th><th>HHV (GJ)</th></tr>
<tr><td>Hog fuel</td><td>1500</td><td>30</td><td>150</td><td>450</td><td>4500</td><td>560</td><td>75</td><td>5</td></tr>
<tr><td>Pellets</td><td>1300</td><td>450</td><td>25</td><td>390</td><td>3900</td><td>155</td><td>20</td><td>1</td></tr>
</table>

Life Cycle Impact Assessment

Inventory analysis is followed by impact assessment – where the life cycle inventory (LCI) data are characterized in terms of their potential environmental impact (e.g., acidification, eutrophication, global warming potential effects, etc.). The process is depicted in Figure 15. The impact assessment phase of LCA is aimed at evaluating the significance of potential environmental impacts based on the LCI results. In the classification stage, the inventory parameters are sorted and assigned to specific impact categories.

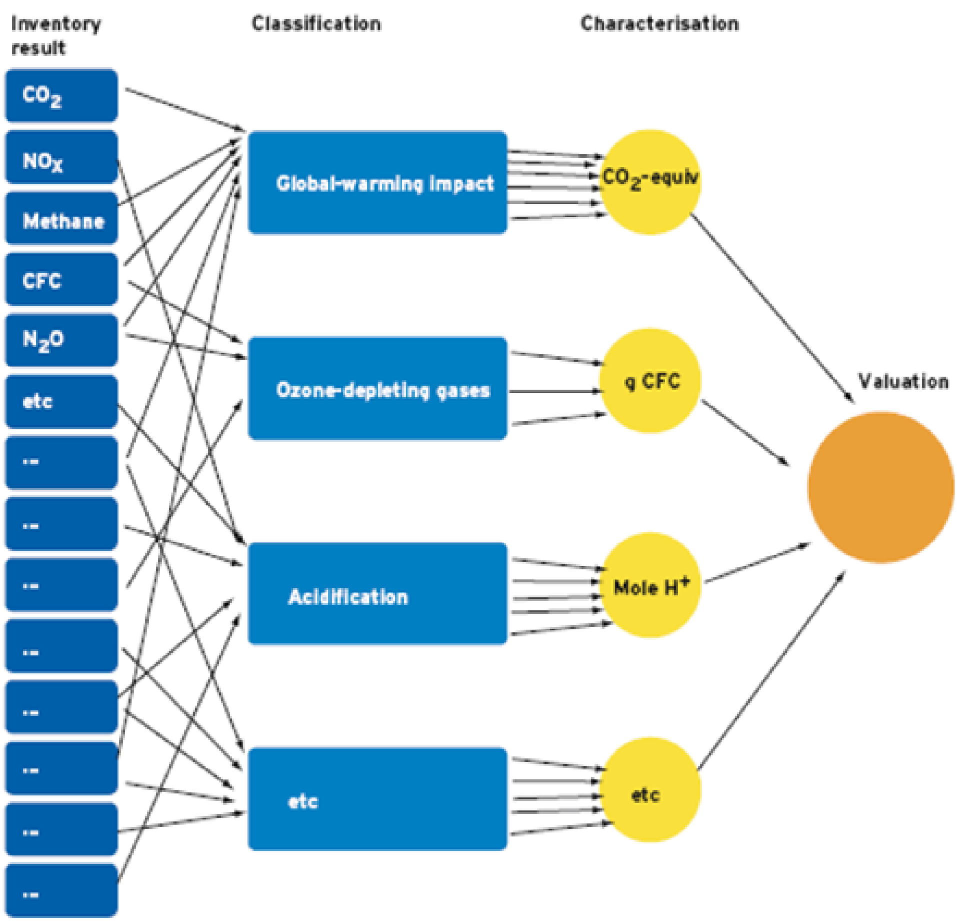

Figure 15 A graphical representation of the LCIA process

(**Source:** Bodland Birgit *et al.,*2005 p.5)

The calculation of indicator results (**characterization**) involves the **conversion** of LCI results to **common units** using impact assessment methods and the **aggregation** of the converted results within the same impact category. This conversion uses **characterization factors** (CF). The outcome of the calculation is a numerical indicator result typically stated on an equivalence basis. In many LCAs, characterization concludes the analysis; this is also the last compulsory stage according to ISO 14044:2006. However, some studies involve the further step of normalization, in which the results of the impact categories from the study are compared with the total impact in the region. During weighting, the different environmental impacts are weighted against each other to arrive at a single score for the total environmental impact. An illustration of the characterization process is provided in Box 3.

Box 3: An illustration of the characterization process

Table C summarizes GHG emissions from a hypothetical process. The common unit used in this example was CO_2equivalent, and the IPCC 2007 characterization factors were used for the conversion. The converted emissions were aggregated to obtain the global warming impact.

Table C: Characterization of global warming impacts – a hypothetical example

Emissions	*Amount (kg)*	*CF (CO_2eq.)*	*Amount (kg CO_2eq.)*
CO_2	46	1	46
CH_4	5	25	125
N_2O	2	298	596
Global warming impact			***767***

Interpretation

The results from the inventory analysis and impact assessment are summarized during the interpretation phase. Conclusions and recommendations are the outcome of the interpretation phase of the study. According to ISO 14040:2006 the interpretation should include:

- Identification of significant issues for the environmental impact,
- Evaluation of the study considering completeness, sensitivity and consistency,
- Conclusions and recommendations.

The working procedure of LCA is iterative as illustrated with the back-and-forth arrows in Figure 14. The iteration means that information gathered in a later stage can affect 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.

Appendix B: Other Parameters to be Reported in WRC EPDs

WRC rough green lumber per 1000 board feet

Parameter	Unit	Amount			
		Total	A1	A2	A3
RPR_E	MJ, LHV	165.29	2.39	0.72	162.18
RPR_M	MJ, LHV	13,327.99	-	-	13,327.99
$NRPR_E$	MJ, LHV	2897.79	2415.14	341.28	141.36
$NRPR_M$	MJ, LHV	-	-	-	-
SM	kg	-	-	-	-
RSF	MJ, LHV	40,590.65	-	-	40,590.65
NRSF	MJ, LHV	-	-	-	-
RE	MJ, LHV	-	-	-	-
FW	m^3	-	-	-	0.26
HWD	kg	0.01	0.01	-	4.08E-05
NHWD	kg	0.43	0.10	0.31	0.02
HLRW	kg	4.48E-05	2.74E-05	1.42E-05	3.16E-06
ILLRW	kg	1.02E-04	6.21E-05	3.17E-05	8.33E-06
CRU	kg	-	-	-	-
MR	kg	-	-	-	-
MER	kg	-	-	-	-
EE	MJ, LHV	-	-	-	-
BCRP	kg CO_2	-1119.14	-1119.14	-	-
BCEP	kg CO_2	1.69	0.03	0.21	1.39
BCRK	kg CO_2	-	-	-	-
BCEK	kg CO_2	-	-	-	-
BCEW	kg CO_2	-	-	-	

Note: No dangerous substance emissions (indoor air emissions, gamma or ionizing radiation emissions or chemicals released to air or leached to water and soil

WRC rough green lumber per one cubic meter

Parameter	Unit	Amount			
		Total	A1	A2	A3
RPR_E	MJ, LHV	91.83	1.33	0.40	90.10
RPR_M	MJ, LHV	7,404.44	-	-	7,404.44
$NRPR_E$	MJ, LHV	1,609.88	1,341.74	189.60	78.53
$NRPR_M$	MJ, LHV	-	-	-	-
SM	kg	-	-	-	-
RSF	MJ, LHV	22,550.36	-	-	22,550.36
NRSF	MJ, LHV	-	-	-	-
RE	MJ, LHV	-	-	-	-
FW	m^3	0.14	-	-	0.14
HWD	kg	5.56E-03	5.56E-03	-	2.27E-05
NHWD	kg	0.24	0.06	0.17	0.01
HLRW	kg	2.49E-05	1.52E-05	7.89E-06	1.76E-06
ILLRW	kg	5.67E-05	3.45E-05	1.76E-05	4.63E-06
CRU	kg	-	-	-	-
MR	kg	-	-	-	-
MER	kg	-	-	-	-
EE	MJ, LHV	-	-	-	-
BCRP	kg CO_2	-621.74	-621.74	-	-
BCEP	kg CO_2	0.94	0.02	0.12	0.77
BCRK	kg CO_2	-	-	-	-
BCEK	kg CO_2	-	-	-	-
BCEW	kg CO_2	-	-	-	

Note: No dangerous substance emissions (indoor air emissions, gamma or ionizing radiation emissions or chemicals released to air or leached to water and soil

WRC decking per 100 ft^2 installed basis

Parameter	Unit	Amount													
		Total	A1	A2	A3	A4	A5	B1	B2	B4	B7	C1	C2	C3	C4
RPR_E	MJ, LHV	124.75	0.48	0.16	98.77	1.44	2.11	-	21.23	0.18	-	-	-	0.36	-
RPR_M	MJ, LHV	6,907.06	2,302.35	-	-	-	-	-	-	4604.71	-	-	-	-	-
$NRPR_E$	MJ, LHV	1,934.17	161.66	24.90	31.02	248.88	55.72	-	336.73	1044.35	-	-	12.7	-	18.22
$NRPR_M$	MJ, LHV	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SM	kg	-	-	-	-	-	-	-	-		-	-	-	-	-
RSF	MJ, LHV	507.41	-	-	169.14	-	-	-	-	338.27	-	-	-	-	-
NRSF	MJ, LHV	-	-	-	-	-	-	-	-		-	-	-	-	-
RE	MJ, LHV	-	-	-	-	-	-	-	-		-	-	-	-	-
FW	m^3	-	-	-	3.33E-03	-	-	-	-	6.67E-03	-	-	-	-	-
HWD	kg	2.57E-03	3.77E-04	4.90E-06	7.80E-06	5.73E-05	1.12E-05	-	1.17E-03	9.16E-04	-	-	2.50E-06	-	2.14E-05
NHWD	kg	279.72	0.01	0.02	3.33E-03	0.16	12.77	-	2.58	2.59E+01	-	-	0.01	-	238.24
HLRW	kg	1.50E-04	1.84E-06	1.04E-06	7.00E-07	8.57E-06	2.66E-06	-	1.01E-04	2.96E-05	-	-	5.32E-07	-	4.20E-06
ILLRW	kg	7.76E-04	4.17E-06	2.33E-06	1.60E-06	1.91E-05	5.93E-06	-	6.67E-04	6.62E-05	-	-	1.19E-06	-	9.36E-06
CRU	kg	-	-	-	-	-	-	-	-		-	-	-	-	-
MR	kg	28.54	-	-	-	-	-	-	-		-	-	-	28.54	-
MER	kg	63.53	-	-	-	-	-	-	-		-	-	-	63.53	-
EE	MJ, LHV	-	-	-	-	-	-	-	-		-	-	-	-	13.50
BCRP	kg CO_2	-521.98	-173.99	-	-	-	-	-	-	-347.99		-	-	-	-
BCEP	kg CO_2	183.44	0.01	0.02	0.28	0.11	1.09	-	0.92	3.02	-	-	0.01	-	177.97
BCRK	kg CO_2	--	-	-	-	-	-	-	-		-	--	-	-	--
BCEK	kg CO_2	-	-	-	-	-	-	-	-		-	-	-	-	-
BCEW	kg CO_2	-	-	-	-	-	-	-	-		-	-	-	-	-

Note: No dangerous substance emissions (indoor air emissions, gamma or ionizing radiation emissions or chemicals released to air or leached to water and soil

WRC decking per one m^2 installed basis

Parameter	Unit	Amount													
		Total	A1	A2	A3	A4	A5	B1	B2	B4	B7	C1	C2	C3	C4
RPR_E	MJ, LHV	13.43	0.05	0.02	10.63	0.16	0.23	-	2.29	0.02	-	2.91E-03	-	3.85E-02	-
RPR_M	MJ, LHV	743.47	247.82	-	-	-	-	-	-	-	-	-	-	-	-
$NRPR_E$	MJ, LHV	208.19	17.40	2.68	3.34	26.79	6.00	-	36.25	-	-	-	1.37	-	1.96
$NRPR_M$	MJ, LHV	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SM	kg	-	-	-	-	-	-	-	-	-	-	-	-	-	-
RSF	MJ, LHV	54.62	-	-	18.21	-	-	-	-	36.41	-	-	-	-	-
NRSF	MJ, LHV	-	-	-	-	-	-	-	-	-	-	-	-	-	-
RE	MJ, LHV	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FW	m^3	1.08E-03	-	-	3.59E-04	-	-	-	-	7.18E-04	-	-	-	-	-
HWD	kg	2.77E-04	4.05E-05	5.27E-07	8.40E-07	6.17E-06	1.21E-06	-	1.26E-04	9.86E-05	-	-	2.69E-07	-	2.30E-06
NHWD	kg	3.01E+01	7.18E-04	2.51E-03	3.59E-04	0.02	1.37	-	0.28	2.79E+0 0	-	-	1.08E-03	-	25.6
HLRW	kg	1.62E-05	1.98E-07	1.12E-07	7.53E-08	9.22E-07	2.86E-07	-	1.09E-05	3.19E-06	-	-	5.73E-08	-	4.52E-07
ILLRW	kg	8.36E-05	4.48E-07	2.50E-07	1.72E-07	2.05E-06	6.39E-07	-	7.18E-05	7.12E-06	-	-	1.28E-07	-	1.01E-06
CRU	kg	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MR	kg	3.07	-	-	-	-	-	-	-	-	-	-	-	3.07	-
MER	kg	6.84	-	-	-	-	-	-	-	-	-	-	-	6.84	-
EE	MJ, LHV	1.45	-	-	-	-	-	-	-	-	-	-	-	-	1.45
BCRP	kg CO_2	-56.19	-18.73	-	-	-	-	-	-	-37.46		-	-	-	-
BCEP	kg CO_2	19.7	7.18E-04	1.79E-03	0.03	0.01	0.12	-	0.10	0.33	-	-	1.08E-03	-	19.16
BCRK	kg CO_2	--	-	-	-	-	-	-	-			--	-	-	--
BCEK	kg CO_2	-	-	-	-	-	-	-	-			-	-	-	-
BCEW	kg CO_2	-	-	-	-	-	-	-	-			-	-	-	-

Note: No dangerous substance emissions (indoor air emissions, gamma or ionizing radiation emissions or chemicals released to air or leached to water and soil

WRC siding per 100 ft^2 installed basis

Parameter	Unit	Amount													
		Total	A1	A2	A3	A4	A5	B1	B2	B4	B7	C1	C2	C3	C4
RPR_E	MJ, LHV	140.75	0.06	0.03	25.92	0.13	8.00	-	38.25	68.26	-	-	0.01	-	0.10
RPR_M	MJ, LHV	1,461.56	487.19	-	-	-	-	-	-	974.37	-	-	-	-	-
$NRPR_E$	MJ, LHV	1,771.90	59.10	14.63	24.08	66.23	117.84	-	917.5	563.74	-	-	2.69	-	6.10
$NRPR_M$	MJ, LHV	-	-	-	-	-	-	-	-		-	-	-	-	-
SM	kg	-	-	-	-	-	-	-	-		-	-	-	-	-
RSF	MJ, LHV	201.62	-	-	67.21	-	-	-	-	134.41	-	-	-	-	-
NRSF	MJ, LHV	-	-	-	-	-	-	-	-		-	-	-	-	-
RE	MJ, LHV	-	-	-	-	-	-	-	-		-	-	-	-	-
FW	m^3	0.15	-	-	0.05	-	-	-	-	0.1	-	-	-	-	-
HWD	kg	4.12E-03	1.37E-04	2.88E-06	5.97E-06	1.53E-05	2.83E-04	-	2.77E-03	8.88E-04	-	-	5.30E-07	-	1.71E-05
NHWD	kg	137.06	3.33E-03	0.01	3.33E-03	0.04	3.62	-	6.49	7.37	-	-	2.51E-03	-	119.52
HLRW	kg	6.41E-04	6.70E-07	6.13E-07	5.90E-07	2.28E-06	5.90E-05	-	4.50E-04	1.26E-04	-	-	1.13E-07	-	1.17E-06
ILLRW	kg	1.70E-03	1.52E-06	1.37E-06	1.32E-06	5.07E-06	1.13E-04	-	1.33E-03	2.44E-04	-	-	2.51E-07	-	2.59E-06
CRU	kg	-	-	-	-	-	-	-	-		-	-	-	-	-
MR	kg	-	-	-	-	-	-	-	-		-	-	-	-	-
MER	kg	18.10	-	-	-	-	-	-	-		-	-	-	-	18.10
EE	MJ, LHV	2.78	-	-	-	-	-	-	-		-	-	-	-	2.78
BCRP	kg CO_2	-110.33	-36.78	-	-	-	-	-	-	-73.55	-	-	-	-	-
BCEP	kg CO_2	40.64	3.33E-03	0.01	2.23E-01	0.03	0.3	-	1.32	1.13	-	-	-	-	37.62
BCRK	kg CO_2	-	-	-	-	-	-	-			-	-	-	-	-
BCEK	kg CO_2	-	-	-	-	-	-	-			-	-	-	-	-
BCEW	kg CO_2	-	-	-	-	-	-	-			-	-	-	-	-

Note: No dangerous substance emissions (indoor air emissions, gamma or ionizing radiation emissions or chemicals released to air or leached to water and soil

WRC siding per one m^2 installed basis

Parameter	Unit	Amount													
		Total	A1	A2	A3	A4	A5	B1	B2	B4	B7	C1	C2	C3	C4
RPR_E	MJ, LHV	15.15	0.01	0.00	2.79	0.01	0.86	-	4.12	7.35	-	-	1.08E-03	-	0.01
RPR_M	MJ, LHV	157.33	52.44	-	-	-	-	-	-	104.88	-	-	-	-	-
$NRPR_E$	MJ, LHV	190.73	6.36	1.57	2.59	7.13	12.68	-	98.76	60.68	-	-	0.29	-	0.66
$NRPR_M$	MJ, LHV	-	-	-	-	-	-	-	-		-	-	-	-	-
SM	kg	-	-	-	-	-	-	-	-		-	-	-	-	-
RSF	MJ, LHV	21.70	-	-	7.23	-	-	-	-	14.47	-	-	-	-	-
NRSF	MJ, LHV	-	-	-	-	-	-	-	-		-	-	-	-	-
RE	MJ, LHV	-	-	-	-	-	-	-	-		-	-	-	-	-
FW	m^3	0.02	-	-	0.01	-	-	-	-	0.01	-	-	-	-	-
HWD	kg	4.44E-04	1.48E-05	3.10E-07	6.42E-07	1.65E-06	3.04E-05	-	2.99E-04	9.56E-05	-	-	5.71E-08	-	1.84E-06
NHWD	kg	14.75	3.59E-04	1.44E-03	3.59E-04	4.66E-03	0.39	-	0.70	0.79	-	-	2.51E-03	-	12.87
HLRW	kg	6.90E-05	7.21E-08	6.60E-08	6.35E-08	2.45E-07	6.35E-06	-	4.85E-05	1.36E-05	-	-	1.22E-08	-	1.26E-07
ILLRW	kg	1.83E-04	1.64E-07	1.47E-07	1.42E-07	5.45E-07	1.21E-05	-	1.43E-04	2.63E-05	-	-	2.70E-08	-	2.79E-07
CRU	kg	-	-	-	-	-	-	-	-		-	-	-	-	-
MR	kg	-	-	-	-	-	-	-	-		-	-	-	-	-
MER	kg	1.95	-	-	-	-	-	-	-		-	-	-	-	1.95
EE	MJ, LHV	0.30	-	-	-	-	-	-	-		-	-	-	-	0.30
BCRP	kg CO_2	-11.88	-3.96	-	-	-	-	-	-	-	-	-	-	-	-
BCEP	kg CO_2	4.37	3.59E-04	1.08E-03	2.40E-02	0.00	0.03	-	0.14	0.12	-	-	-	-	4.05
BCRK	kg CO_2	-	-	-	-	-	-	-			-	-	-	-	-
BCEK	kg CO_2	-	-	-	-	-	-	-			-	-	-	-	-
BCEW	kg CO_2	-	-	-	-	-	-	-			-	-	-	-	-

Note: No dangerous substance emissions (indoor air emissions, gamma or ionizing radiation emissions or chemicals released to air or leached to water and soil

Appendix C: WRC Decking LCIA Results Calculated Using CML IA Baseline Method

Environmental impacts are calculated per 1 m^2 of installed WRC decking with no regular applications of stain over 75-year building life for Minneapolis location

Impact Category	Unit	Total	Resource extraction	Roundwood transport	Decking manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
Abiotic depletion	kg Sb eq	3.46E-05	7.33E-10	1.23E-10	6.62E-10	1.70E-09	1.31E-08	-	3.45E-05	3.26E-08	-	-	6.26E-11	-	6.15E-10
Abiotic depletion (fossil fuels)	MJ	202.74	17.33	2.64	3.26	26.47	5.58	-	33.74	110.56	-	-	1.35	-	1.81
Global warming (GWP100a)	kg CO2 eq	16.63	1.24	0.21	0.17	2.06	0.63	-	2.71	8.64	-	-	0.10	-	0.85
Ozone depletion (ODP)	kg CFC-11 eq	8.08E-07	5.35E-08	2.18E-10	2.00E-08	7.66E-08	3.33E-09	-	3.32E-07	3.07E-07	-	-	1.11E-10	-	1.44E-08
Human toxicity	kg 1,4-DB eq	7.87	0.28	0.17	0.02	1.21	0.18	-	2.09	3.72	-	-	0.08	-	0.11
Fresh water aquatic ecotoxicity.	kg 1,4-DB eq	5.99	0.01	0.06	3.74E-03	0.45	0.88	-	1.50	2.81	-	-	0.03	-	0.25
Marine aquatic ecotoxicity	kg 1,4-DB eq	12681.93	380.23	226.97	23.62	1592.69	599.29	-	3835.37	5645.61	-	-	115.77	-	262.38
Terrestrial ecotoxicity	kg 1,4-DB eq	0.03	6.78E-05	1.14E-05	2.96E-05	1.52E-04	4.02E-03	-	0.01	0.01	-	-	0.00	-	0.01
Photochemical oxidation	kg C2H4 eq	3.45E-03	1.56E-04	4.11E-05	3.86E-05	4.21E-04	2.36E-04	-	5.40E-04	1.79E-03	-	-	5.52E-05	-	1.80E-04
Acidification	kg SO2 eq	0.07	3.95E-03	9.38E-04	1.13E-03	1.21E-02	2.42E-03	-	0.01	0.04	-	-	4.04E-04	-	9.41E-04
Eutrophication	kg PO4--- eq	0.02	1.05E-03	1.90E-04	2.13E-04	2.54E-03	-2.24E-04	-	4.04E-03	0.01	-	-	7.83E-05	-	4.02E-03

Environmental impacts are calculated per 1 m^2 of installed WRC decking with regular applications of stain over 75-year building life for Minneapolis location

Impact Category	Unit	Total	Resource extraction	Roundwood transport	Decking manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
Abiotic depletion	kg Sb eq	5.60E-05	7.33E-10	1.23E-10	6.62E-10	1.70E-09	7.77E-07	-	5.36E-05	1.56E-06	-	-	6.26E-11	-	6.15E-10
Abiotic depletion (fossil fuels)	MJ	608.31	17.33	2.64	3.26	26.47	20.07	-	395.85	139.54	-	-	1.35	-	1.81
Global warming (GWP100a)	kg CO2 eq	38.08	1.24	0.21	0.17	2.06	1.40	-	21.86	10.18	-	-	0.10	-	0.85
Ozone depletion (ODP)	kg CFC-11 eq	3.60E-06	5.35E-08	2.18E-10	2.00E-08	7.66E-08	1.03E-07	-	2.82E-06	5.07E-07	-	-	1.11E-10	-	1.44E-08
Human toxicity	kg 1,4-DB eq	15.81	0.28	0.17	0.02	1.21	0.46	-	9.18	4.29	-	-	0.08	-	0.11
Fresh water aquatic ecotoxicity.	kg 1,4-DB eq	13.47	0.01	0.06	3.74E-03	0.45	1.14	-	8.17	3.34	-	-	0.03	-	0.25
Marine aquatic ecotoxicity	kg 1,4-DB eq	32,016.25	380.23	226.97	23.62	1592.69	1290.05	-	21097.42	7027.13	-	-	115.77	-	262.38
Terrestrial ecotoxicity	kg 1,4-DB eq	0.08	6.78E-05	1.14E-05	2.96E-05	1.52E-04	5.82E-03	-	0.05	0.01	-	-	5.80E-06	-	0.01
Photochemical oxidation	kg C2H4 eq	0.01	1.56E-04	4.11E-05	3.86E-05	4.21E-04	4.94E-04	-	0.01	2.30E-03	-	-	5.52E-05	-	1.80E-04
Acidification	kg SO2 eq	0.16	3.95E-03	9.38E-04	1.13E-03	0.01	5.59E-03	-	0.09	0.05	-	-	4.04E-04	-	9.41E-04
Eutrophication	kg PO4--- eq	0.05	1.05E-03	1.90E-04	2.13E-04	2.54E-03	7.68E-04	-	0.03	0.01	-	-	7.83E-05	-	4.02E-03

Appendix D: WRC Siding LCIA Results Calculated Using CML IA Baseline Method

Environmental impacts are calculated per 1 m^2 of installed WRC siding over 75-year building life for Minneapolis location

Impact Category	Unit	Total	Resource extraction	Roundwood transport	Decking manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
Abiotic depletion	kg Sb eq	3.94E-05	5.36E-10	1.44E-10	1.01E-09	9.06E-10	1.25E-06	-	3.75E-05	6.28E-07	-	-	1.33E-11	-	1.04E-09
Abiotic depletion (fossil fuels)	MJ	173.87	12.67	3.10	5.05	14.09	22.25	-	87.23	28.58	-	-	0.29	-	0.61
Global warming (GWP100a)	kg CO2 eq	11.62	0.91	0.25	0.26	1.10	1.37	-	5.57	1.94	-	-	0.02	-	0.20
Ozone depletion (ODP)	kg CFC-11 eq	1.12E-06	3.91E-08	2.56E-10	2.94E-08	4.08E-08	1.48E-07	-	7.25E-07	1.29E-07	-	-	2.36E-11	-	3.84E-09
Human toxicity	kg 1,4-DB eq	5.60	0.21	0.19	0.04	0.64	0.46	-	3.17	0.78	-	-	0.02	-	0.09
Fresh water aquatic ecotoxicity.	kg 1,4-DB eq	4.03	0.01	0.08	0.01	0.24	0.61	-	2.55	0.47	-	-	0.01	-	0.07
Marine aquatic ecotoxicity	kg 1,4-DB eq	10,352.60	278.00	266.67	49.70	847.66	1094.78	-	6448.22	1268.40	-	-	24.54	-	74.64
Terrestrial ecotoxicity	kg 1,4-DB eq	0.02	4.96E-05	1.34E-05	4.51E-05	8.07E-05	3.77E-03	-	0.01	1.98E-03	-	-	1.23E-06	-	1.70E-03
Photochemical oxidation	kg C2H4 eq	2.93E-03	1.14E-04	4.83E-05	5.73E-05	2.24E-04	4.79E-04	-	1.48E-03	4.61E-04	-	-	1.17E-05	-	5.70E-05
Acidification	kg SO2 eq	0.05	2.89E-03	1.10E-03	1.59E-03	0.01	0.01	-	0.02	0.01	-	-	8.57E-05	-	6.97E-04
Eutrophication	kg PO4--- eq	0.02	7.64E-04	2.23E-04	2.96E-04	1.35E-03	1.66E-03	-	0.01	2.15E-03	-	-	1.66E-05	-	1.02E-03

Appendix E: Life Cycle Impact Assessment of WRC Decking for New York and Seattle Locations

Environmental impacts are calculated per functional unit (100 ft^2 installed) of WRC decking over 75-year building life for New York location

Impact Category	Unit	Total	Resource extraction	Roundwood transport	Decking manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	kg CO2 eq	183.54	11.61	1.97	1.60	31.91	5.02	-	25.05	104.22	-	-	0.9	-	1.27
GWP100 - biogenic	kg CO2-eq	183.65	0.01	0.02	0.28	0.19	1.09	-	0.93	3.17	-	-	0.01	-	177.97
Ozone depletion	kg CFC-11 eq	1.14E-05	6.63E-07	3.27E-09	2.47E-07	1.59E-06	3.71E-08	-	3.55E-06	5.08E-06	-	-	1.67E-09	-	1.79E-07
Acidification	kg SO2 eq	1.12	0.05	0.01	0.01	0.24	0.02	-	0.12	0.66	-	-	4.57E-03	-	0.01
Eutrophication	kg N eq	0.21	0.01	8.43E-04	7.69E-04	0.02	-0.01	-	0.07	0.04	-	-	3.70E-04	-	0.08
Smog	kg O3 eq	30.13	1.36	0.31	0.36	7.14	0.19	-	1.59	18.73	-	-	0.12	-	0.3
Abiotic depletion (fossil fuel)	MJ, LHV	2375.41	160.99	24.54	30.27	409.92	51.82	-	313.49	1355.08	-	-	12.52	-	16.78

Environmental impacts are calculated per functional unit (100 ft^2 installed) of WRC decking over 75-year building life for Seattle location

Impact Category	Unit	Total	Resource extraction A1	Roundwood transport A2	Decking manufacturing A3	Transport to Customer A4	Installation A5	Use B1,	Maintenance B2	Replacement B4	Operational water use B7	Dismantling C1	Waste Transport C2	Sorting C3	Disposal C4
GWP100 - fossil	kg CO2 eq	94.62	11.61	1.97	1.60	2.27	5.02	-	25.05	44.94	0.08	-	0.90	-	1.27
GWP100 - biogenic	kg CO2-eq	183.14	0.01	0.02	0.28	0.02	1.09	-	0.93	2.83	1.32E-03	-	0.01	-	177.97
Ozone depletion	kg CFC-11 eq	6.6E-06	6.63E-07	3.27E-09	2.47E-07	3.77E-09	3.71E-08	-	3.55E-06	1.91E-06	3.12E-09	-	1.67E-09	-	1.79E-07
Acidification	kg SO2 eq	0.44	0.05	0.01	0.01	0.01	0.02	-	0.12	0.21	3.00E-04	-	4.57E-03	-	0.01
Eutrophication	kg N eq	0.16	0.01	8.43E-04	7.69E-04	9.72E-04	-0.01	-	0.07	4.80E-03	1.43E-04	-	3.70E-04	-	0.08
Smog	kg O3 eq	9.77	1.36	0.31	0.36	0.36	0.19	-	1.59	5.16	2.56E-03	-	0.12	-	0.3
Abiotic depletion (fossil fuel)	MJ, LHV	1230.55	160.99	24.54	30.27	28.30	51.82	-	313.49	591.84	0.91	-	12.52	-	16.78

Appendix F: Life Cycle Impact Assessment of WPC Decking for New York and Seattle Locations

Environmental impacts are calculated per functional unit (100 ft^2 installed) of WPC decking over 75-year building life for New York Location

Impact Category	Unit	Total	Resource extraction	Roundwood transport	Decking manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	kg CO2 eq	2505.365	182.62	20.82	537.07	28.04	7.48	-	25.05	1552.08	-	-	4.18	-	148.02
GWP100 - biogenic	kg CO2-eq	425.9416	139.61	0.17	1.45	0.23	0.15	-	0.93	283.22	-	-	0.04	-	0.14
Ozone depletion	kg CFC-11 eq	0.000112	1.82E-05	3.46E-08	1.74E-05	4.67E-08	4.85E-08	-	3.55E-06	7.14E-05	-	-	7.78E-09	-	1.70E-06
Acidification	kg SO2 eq	12.598	0.75	0.11	3.07	0.15	0.02	-	0.12	8.23	-	-	0.02	-	0.12
Eutrophication	kg N eq	9.735535	0.18	0.01	1.92	0.01	0.04	-	0.07	4.33	-	-	1.72E-03	-	3.17
Smog	kg O3 eq	135.8565	10.41	3.29	25.24	4.43	0.21	-	1.59	87.14	-	-	0.58	-	2.96
Abiotic depletion (fossil fuel)	MJ, LHV	27691.82	2863.35	259.93	5524.40	350.06	52.97	-	313.49	18101.40	-	-	58.37	-	167.86

Environmental impacts are calculated per functional unit (100 ft^2 installed) of WPC decking over 75-year building life for Seattle Location

Impact Category	Unit	Total	Resource extraction	Roundwood transport	Decking manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	kg CO2 eq	2616.73	182.62	20.82	537.07	65.17	7.48	-	25.05	1626.32	-	-	4.18	-	148.02
GWP100 - biogenic	kg CO2-eq	426.85	139.61	0.17	1.45	0.53	0.15	-	0.93	283.83	-	-	0.04	-	0.14
Ozone depletion	kg CFC-11 eq	1.13E-04	1.82E-05	3.46E-08	1.74E-05	1.08E-07	4.85E-08	-	3.55E-06	7.15E-05	-	-	7.78E-09	-	1.70E-06
Acidification	kg SO2 eq	13.21	0.75	0.11	3.07	0.36	0.02	-	0.12	8.64	-	-	0.02	-	0.12
Eutrophication	kg N eq	9.78	0.18	0.01	1.92	0.03	0.04	-	0.07	4.36	-	-	1.72E-03	-	3.17
Smog	kg O3 eq	153.44	10.41	3.29	25.24	10.29	0.21	-	1.59	98.87	-	-	0.58	-	2.96
Abiotic depletion (fossil fuel)	MJ, LHV	29081.91	2863.35	259.93	5524.40	813.43	52.97	-	313.49	19028.13	-	-	58.37	-	167.86

Appendix G: Life Cycle Impact Assessment of WRC Siding for New York and Seattle Locations

Environmental impacts are calculated per functional unit (100 ft^2 installed) of WRC siding over 75-year building life for New York Location

Impact Category	Unit	Total	Resource extraction	Roundwood transport	Decking manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	kg CO2 eq	112.50	8.49	2.31	2.39	14.43	12.44	-	51.75	20.03	-	-	0.19	-	0.46
GWP100 - biogenic	kg CO2-eq	40.68	4.23E-03	0.02	0.45	0.09	0.60	-	1.32	0.58	-	-	1.73E-03	-	37.62
Ozone depletion	kg CFC-11 eq	1.27E-05	4.85E-07	3.84E-09	3.64E-07	7.19E-07	1.63E-06	-	7.84E-06	1.60E-06	-	-	3.54E-10	-	4.72E-08
Acidification	kg SO2 eq	0.58	0.03	0.01	0.02	0.11	0.06	-	0.23	0.12	-	-	9.69E-04	-	0.01
Eutrophication	kg N eq	0.23	0.01	9.90E-04	1.10E-03	0.01	0.03	-	0.14	0.02	-	-	7.84E-05	-	0.02
Smog	kg O3 eq	11.80	0.99	0.36	0.49	3.23	0.62	-	2.94	2.85	-	-	2.65E-02	-	0.27
Abiotic depletion (fossil fuel)	MJ, LHV	1697.13	117.71	28.83	46.95	185.43	206.68	-	810.37	292.80	-	-	2.65	-	5.71

Environmental impacts are calculated per functional unit (100 ft² installed) of WRC siding over 75-year building life for Seattle location

Impact Category	Unit	Total	Resource extraction	Roundwood transport	Decking manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	kg CO2 eq	92.39	8.49	2.31	2.39	1.03	12.44	-	51.75	13.33	-	-	0.19	-	0.46
GWP100 - biogenic	kg CO2-eq	40.56	4.23E-03	0.02	0.45	0.01	0.60	-	1.32	0.54	-	-	1.73E-03	-	37.62
Ozone depletion	kg CFC-11 eq	1.16E-05	4.85E-07	3.84E-09	3.64E-07	1.71E-09	1.63E-06	-	7.84E-06	1.24E-06	-	-	3.54E-10	-	4.72E-08
Acidification	kg SO2 eq	0.43	0.03	0.01	0.02	0.01	0.06	-	0.23	0.06	-	-	9.69E-04	-	0.01
Eutrophication	kg N eq	0.22	0.01	9.90E-04	1.10E-03	4.39E-04	0.03	-	0.14	0.02	-	-	7.84E-05	-	0.02
Smog	kg O3 eq	7.19	0.99	0.36	0.49	0.16	0.62	-	2.94	1.32	-	-	2.65E-02	-	0.27
Abiotic depletion (fossil fuel)	MJ, LHV	1438.18	117.71	28.83	46.95	12.80	206.68	-	810.37	206.48	-	-	2.65	-	5.71

Appendix H: Life Cycle Impact Assessment of WRC Decking for Minneapolis Location

Environmental impacts calculated per 1 m^2 of installed WRC decking over building life cycle (75 years)

Impact Category	Unit	Total	Resource extraction	Roundwood transport	Decking manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	kg CO2 eq	15.63	1.25	0.21	0.17	2.06	0.54	-	25.05	8.47	-	-	0.10	-	0.14
GWP100 - biogenic	kg CO2-eq	19.74	6.22E-04	0.00	0.03	0.01	0.12	-	0.93	0.32	-	-	1.08E-03	-	19.16
Ozone depletion	kg CFC-11 eq	1.02E-06	7.14E-08	3.52E-10	2.66E-08	1.03E-07	3.99E-09	-	3.55E-06	4.1E-07	-	-	1.80E-10	-	1.93E-08
Acidification	kg SO2 eq	0.09	0.01	1.17E-03	1.38E-03	0.02	0.00	-	0.12	0.05	-	-	4.92E-04	-	1.08E-03
Eutrophication	kg N eq	0.02	8.63E-04	9.07E-05	8.28E-05	1.06E-03	-8.83E-04	-	0.07	0.00	-	-	3.98E-05	-	0.01
Smog	kg O3 eq	2.32	0.15	0.03	0.04	0.46	0.02	-	1.59	1.40	-	-	0.01	-	0.03
Abiotic depletion (fossil fuel)	MJ, LHV	202.74	17.33	2.64	3.26	26.47	5.58	-	313.49	110.56	-	-	1.35	-	1.81

Appendix I: Life Cycle Impact Assessment of WRC Siding for Minneapolis Location

Environmental impacts calculated per 1 m^2 of installed WRC siding over building life cycle (75 years)

Impact Category	Unit	Total	Resource extraction	Roundwood transport	Decking manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	kg CO2 eq	11.42	0.91	0.25	0.26	1.10	1.34	-	5.57	1.93	-	-	0.02	-	0.12
GWP100 - biogenic	kg CO2-eq	4.37	4.55E-04	2.03E-03	0.05	0.01	0.06	-	0.14	0.06	-	-	1.86E-04	-	4.05
Ozone depletion	kg CFC-11 eq	1.33E-06	5.22E-08	4.14E-10	3.92E-08	5.46E-08	1.75E-07	-	8.43E-07	1.61E-07	-	-	3.81E-11	-	1.21E-08
Acidification	kg SO2 eq	0.06	0.00	1.37E-03	1.94E-03	0.01	0.01	-	0.02	0.01	-	-	1.04E-04	-	2.15E-03
Eutrophication	kg N eq	0.02	6.31E-04	1.07E-04	1.18E-04	5.63E-04	3.11E-03	-	0.02	0.00	-	-	8.44E-06	-	0.01
Smog	kg O3 eq	1.12	0.11	0.04	0.05	0.25	0.07	-	0.32	0.26	-	-	2.85E-03	-	0.07
Abiotic depletion (fossil fuel)	MJ, LHV	173.87	12.67	3.10	5.05	14.09	22.25	-	87.23	28.58	-	-	0.29	-	1.45

Appendix J: Life Cycle Impact Assessment of Brick Siding for New York and Seattle Locations

Environmental impacts are calculated per functional unit (100 ft^2 installed) of brick siding over 75-year building life *for New York Location*

Impact Category	Unit	Total	Resource extraction	Roundwood transport	Siding manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	kg CO_2 eq	279.23	5.54	2.38	177.66	27.44	41.34	-0	16.70	-0	-	-	3.18	-	5.00
GWP100 - biogenic	kg CO2-eq	2.65	0.01	0.02	0.23	0.20	1.47	-	0.62	-	-	-	0.03	-	0.08
Ozone depletion	kg CFC-11 eq	5.67E-06	9.19E-07	3.96E-09	1.12E-06	4.07E-08	4.88E-07	-	2.37E-06	-	-	-	5.91E-09	-	7.28E-07
Acidification	kg SO_2 eq	0.75	0.05	0.01	0.23	0.15	0.16	-	0.08	-	-	-	0.02	-	0.04
Eutrophication	kg N eq	0.05	3.39E-03	1.02E-03	0.06	0.01	-0.09	-	0.05	-	-	-	1.31E-03	-	0.02
Smog	kg O_3 eq	14.21	1.56	0.38	3.60	4.38	1.56	-	1.06	-	-	-	0.44	-	1.23
Abiotic depletion (fossil fuel)	MJ, LHV	3548.58	80.60	29.74	2371.60	343.35	403.22	-	208.99	-	-	-	44.33	-	66.74

Environmental impacts are calculated per functional unit (100 ft^2 installed) of brick siding over 75-year building life *for Seattle Location*

Impact Category	Unit	Total	Resource extraction	Roundwood transport	Siding manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	kg CO_2 eq	378.15	5.54	2.38	177.66	126.36	41.34	-	16.70	-	-	-	3.18	-	5.00
GWP100 - biogenic	kg CO2-eq	2.51	0.01	0.02	0.23	0.06	1.47	-	0.62	-	-	-	0.03	-	0.08
Ozone depletion	kg CFC-11 eq	2.63E-05	9.19E-07	3.96E-09	1.12E-06	2.07E-05	4.88E-07	-	2.37E-06	-	-	-	5.91E-09	-	7.28E-07
Acidification	kg SO_2 eq	2.12	0.05	0.01	0.23	1.52	0.16	-	0.08	-	-	-	0.02	-	0.04
Eutrophication	kg N eq	0.13	3.39E-03	1.02E-03	0.06	0.09	-0.09	-	0.05	-	-	-	1.31E-03	-	0.02
Smog	kg O_3 eq	57.95	1.56	0.38	3.60	48.11	1.56	-	1.06	-	-	-	0.44	-	1.23
Abiotic depletion (fossil fuel)	MJ, LHV	4938.67	80.60	29.74	2371.60	1733.45	403.22	-	208.99	-	-	-	44.33	-	66.74

Appendix K: Life Cycle Impact Assessment of Fiber-Cement Siding for Seattle and New York Locations

Environmental impacts are calculated per functional unit (100 ft^2 installed) of FC siding over 75-year building life *for New York Location*

Impact Category	Unit	Total	Resource extraction	Roundwood transport	Siding manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	kg CO_2 eq	224.01	91.83	2.17	3.94	8.68	7.39	-	51.75	57.00	-	-	0.63	-	0.63
GWP100 - biogenic	kg CO2-eq	4.55	1.92	0.02	0.01	0.07	0.13	-	1.32	1.08	-	-	5.71E-03	-	6.30E-04
Ozone depletion	kg CFC-11 eq	1.22E-05	1.80E-06	3.60E-09	5.24E-08	1.44E-08	9.63E-07	-	7.84E-06	1.42E-06	-	-	1.16E-09	-	1.09E-07
Acidification	kg SO_2 eq	1.02	0.42	0.01	0.01	0.05	0.03	-	0.23	0.26	-	-	3.19E-03	-	0.01
Eutrophication	kg N eq	0.35	0.06	9.28E-04	3.05E-03	3.72E-03	0.01	-	0.14	0.04	-	-	2.58E-04	-	0.08
Smog	kg O_3 eq	14.38	5.30	0.34	0.10	1.37	0.36	-	2.94	3.73	-	-	0.09	-	0.16
Abiotic depletion (fossil fuel)	MJ, LHV	1987.01	460.60	27.04	51.35	108.35	125.43	-	810.37	386.38	-	-	8.74	-	8.74

Environmental impacts are calculated per functional unit (100 ft² installed) of FC siding over 75-year building life *for Seattle Location*

Impact Category	Unit	Total	Resource extraction	Roundwood transport	Siding manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	kg CO_2 eq	270.66	91.83	2.17	3.94	39.78	7.39	-	51.75	72.55	-	-	0.63	-	0.63
GWP100 - biogenic	kg CO2-eq	4.93	1.92	0.02	0.01	0.32	0.13	-	1.32	1.20	-	-	5.71E-03	-	6.30E-04
Ozone depletion	kg CFC-11 eq	1.23E-05	1.80E-06	3.60E-09	5.24E-08	6.62E-08	9.63E-07	-	7.84E-06	1.44E-06	-	-	1.16E-09	-	1.09E-07
Acidification	kg SO_2 eq	1.28	0.42	0.01	0.01	0.22	0.03	-	0.23	0.35	-	-	3.19E-03	-	0.01
Eutrophication	kg N eq	0.37	0.06	9.28E-04	3.05E-03	0.02	0.01	-	0.14	0.05	-	-	2.58E-04	-	0.08
Smog	kg O_3 eq	21.75	5.30	0.34	0.10	6.28	0.36	-	2.94	6.19	-	-	0.09	-	0.16
Abiotic depletion (fossil fuel)	MJ, LHV	2569.37	460.60	27.04	51.35	496.58	125.43	-	810.37	580.50	-	-	8.74	-	8.74

Appendix L: Life Cycle Impact Assessment of Vinyl Siding for Seattle and New York Locations

Environmental impacts are calculated per functional unit (100 ft^2 installed) of vinyl siding over 75-year building life *for New York Location*

Impact Category	Unit	Total	Resource extraction	Roundwood transport	Decking manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement t	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	kg CO_2 eq	120.14	45.30	3.80	3.09	0.92	1.82	-	25.05	27.46	-	-	0.09	-	12.61
GWP100 - biogenic	kg CO2-eq	3.03	0.94	0.03	0.08	0.01	0.27	-	0.93	0.67	-	-	8.22E-04	-	1.02E-01
Ozone depletion	kg CFC-11 eq	7.80E-06	2.54E-06	6.33E-09	1.14E-07	1.52E-09	7.64E-09	-	3.55E-06	1.33E-06	-	-	1.68E-10	-	2.42E-07
Acidification	kg SO_2 eq	0.49	0.18	0.03	0.01	0.01	0.01	-	0.12	0.12	-	-	4.59E-04	-	0.02
Eutrophication	kg N eq	0.17	0.05	2.11E-03	0.01	3.92E-04	1.36E-03	-	0.07	0.03	-	-	3.72E-05	-	0.01
Smog	kg O_3 eq	6.53	1.94	0.87	0.10	0.14	0.08	-	1.59	1.57	-	-	0.01	-	0.22
Abiotic depletion (fossil fuel)	MJ, LHV	1849.16	882.05	47.48	36.62	11.43	17.18	-	313.49	497.38	-	-	1.26	-	42.27

Environmental impacts are calculated per functional unit (100 ft^2 installed) of vinyl siding over 75-year building life *for Seattle Location*

Impact Category	Unit	Total	Resource extraction	Roundwood transport	Decking manufacturing	Transport to Customer	Installation	Use	Maintenance	Replacement	Operational water use	Dismantling	Waste Transport	Sorting	Disposal
			A1	A2	A3	A4	A5	B1,	B2	B4	B7	C1	C2	C3	C4
GWP100 - fossil	kg CO_2 eq	125.63	45.30	3.80	3.09	4.58	1.82	-	25.05	29.29	-	-	0.09	-	12.61
GWP100 - biogenic	kg CO2-eq	3.09	0.94	0.03	0.08	0.04	0.27	-	0.93	0.68	-	-	8.22E-04	-	1.02E-01
Ozone depletion	kg CFC-11 eq	7.81E-06	2.54E-06	6.33E-09	1.14E-07	7.61E-09	7.64E-09	-	3.55E-06	1.34E-06	-	-	1.68E-10	-	2.42E-07
Acidification	kg SO_2 eq	0.53	0.18	0.03	0.01	0.03	0.01	-	0.12	0.13	-	-	4.59E-04	-	0.02
Eutrophication	kg N eq	0.17	0.05	2.11E-03	0.01	1.96E-03	1.36E-03	-	0.07	0.03	-	-	3.72E-05	-	0.01
Smog	kg O_3 eq	7.40	1.94	0.87	0.10	0.72	0.08	-	1.59	1.86	-	-	0.01	-	0.22
Abiotic depletion (fossil fuel)	MJ, LHV	1,917.72	882.05	47.48	36.62	57.13	17.18	-	313.49	520.23	-	-	1.26	-	42.27

Appendix M: Flow Level Data Quality Assessment

Table below shows results from the data quality assessment conducted for resource extraction and manufacturing flows of alternative decking and siding products included in the comparative assessment. Note that data quality criteria were assessed qualitatively by ranking the quality (i.e., high, medium and low).

Inputs from technosphere, materials	Source	Data quality criteria		
		Temporal	Geographical	Technological
WPC decking				
Wood flour	Huidong Meixin Plastic Lumber Products Manufacturing Co., Ltd., 2021. Environmental Product Declaration NewTechWood Wood Plastic Composite. https://www.newtechwood.ca/wp-content/uploads/Environmental-Product-Declaration-2.pdf. (2021)	High (<10 years)	Low (manufacturing operations in China)	Low
HDPE				
Lubricants - polyester				
Maleic Anhydride				
Gear box oil	Amount required for Twin Screw Extruder (Milacron Inc., 2024)	High (<10 years)	High (north American)	High
Electricity	Operation of hammermills for producing wood flour (calculated based on Rajendran, et.al., 2018)	High (<10 years)	Low (South Korea)	Low
Electricity	PE shredding (calculated based on Vecoplan, 2018)	High (<10 years)	High (USA)	High (USA)
Electricity	Amount required for Twin Screw Extruder (Milacron Inc., 2024)	High (<10 years)	High (USA)	High (USA)
Electricity	LDED, 2005	Low (>10 years)	Low (Europe)	Low (Europe)
Brick siding – clay extraction				
Motor oil	ASMI, 2008	Low (>10 years)	High (Canada)	High (Canada)
Greases				
Hydraulic fluids				
Fuel Oil				
Diesel Fuel				
Electricity				
Brick manufacturing				

Clay and shale	The Brick Industry Association, 2020	High (<10 years)	High (USA)	High (USA)
Secondary material (ash, grog, etc.)				
Pigments				
Additives				
Water				
Transportation	Kneifel, et. al., 2021	High (< 10 years)	High (USA)	High (USA)
Natural gas				
Electricity				
Air Emissions	ASMI, 2008	Low (< 10 years)	High (Canada)	High (Canada)
FC siding				
Portland Cement	Kneifel, et. al., 2021	High (< 10 years)	High (USA)	High (USA)
Fly ash				
Silica sand				
Cellulose pulp				
Primer				
Natural gas				
Diesel Fuel				
Gasoline				
Propane				
Electricity				
Vinyl siding				
PVC resin	Sustainable Solutions Corporation, 2016; Kneifel et. al., 2021	High (< 10 years)	High (USA)	High (USA)
ASA				
Filler (calcium carbonate)				
Impact Modifier (acrylic or chlorinated PET)				
Titanium Dioxide				
Tin Stabilizer (organo-tin mercaptide)				
Process aid				
Lubricant (paraffin/calcium stearate)				

Chlorinated polyethylene				
Sealant				
Calcium stearate				
Pigments				
Electricity				
Natural Gas				
Propane				
Gasoline				
Water use				
Air emissions				
Dichloroethane				
Vinyl chloride				
Waste				
Landfill				
Incineration				

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Appendix N: THIRD PARTY ATTESTATION

June 25, 2025

Critical Review by Panel of External Experts

The Critical Review Panel was charged with reviewing and commenting on the "Life Cycle Assessment of Western Red Cedar Decking, Siding and Competing Products". The study was conducted by FPInnovations for the Western Red Cedar Lumber Association (WRCLA). The study involved comparing the environmental performance of western red cedar siding and decking with competing alternatives, namely, WRC, clay brick, vinyl and fiber cement (FC) siding products, and WRC and composite wood/plastic decking with varying levels of recycled content. LCAs were developed for each of these products and then comparisons were provided. The objectives of the study were to compare and contrast the life cycle environmental impact of WRC decking and siding with alternative decking and siding products such as composite wood-plastic decking and vinyl, clay brick, and FC siding products used in residential applications. The following is the final review statement by the external review panel based on the June 2025 report version.

Panel Members

Thomas P. Gloria, Ph.D.,
Industrial Ecology Consultants (Review Panel Chair)

Charles Thibodeau, Ph.D.
CT Consultant (Panelist)

James Salazar,
WAP Sustainability Consulting (Panelist)

Critical Review Tasks & Objectives
The review process involved the primary task of reviewing to the International Organization of Standardization (ISO) 14044:2006(E) *Environmental management – Life cycle assessment – Requirements and guidelines*, the critical review process included the following objectives to ensure conformance with applicable standards:

- The methods used to carry out the LCA were consistent with the applicable international standards
- The methods used to carry out the LCA were scientifically and technically valid
- The data used were appropriate and reasonable in relation to the goal of the study
- The interpretations reflected the limitations identified and the goal of the study, and
- The study report was transparent and consistent.

Review Results
The overall review was conducted in an equitable and constructive manner. All comments were addressed, and all open issues resolved. There were no dissenting opinions held by the reviewers or the commissioner upon finalization of the review.

The study's main limitations include:

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- The study findings are limited due to no firsthand industry average data available in the literature for WPC decking, brick and FC siding types, and missing vinyl siding packaging and manufacturing waste treatment data,
- Missing vinyl LCI flows, due to lack of an available proxy,
- Inability to validate the material and energy consumption data obtained from the literature for WPC, brick and FC,
- Reviewers did not have access to raw material inventory data for wood products, due to confidentiality reasons,
- Limited ability to conduct uncertainty analysis due to small sample size of WRC siding and descriptive statistics of secondary data sets,
- Use of tertiary data based, ecoinvent, that is based primarily on European conditions, and
- Imprecise service lives of siding and decking products,

The reviewers agree with the LCA practitioner that caution should be exercised in drawing strong conclusions from the comparative assertion, especially when the selected alternative products outperform WRC siding by a narrow margin.

After three rounds of review of comments and responses by the panel members and FPInnovations, based on the goals set forth to review this study, the review panel concludes that the study conforms to ISO 14044:2006 as a comparative assertion study that may be disclosed to the public. In this case, ISO 14044, section 5.2 requires that a third-party report be made available to any third parties to whom the communication is made. The third-party report as well as the detailed review comments and the responses of the practitioner will be available from FPInnovations. Confidential content may be removed from the report before sharing it with third parties.

Respectfully,

Thomas P. Gloria, Critical Review Panel Chair

25 June 2025
Newton, Massachusetts