Athena
Sustainable Materials
Institute

Life Cycle Assessment of Log Wall and Timber Frame Systems Produced in British Columbia

Prepared for: The Cariboo-Chilcotin Beatle Action Coalition

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Abbreviations

PAH: Polycyclic aromatic hydrocarbons

PM (10/2.5): Particulate matter less than 10/2.5 micrometers in diameter

SO_2: Sulfur dioxide

TRACI: Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts

UNEP: United Nations Environment Program

US EPA: United States Environmental Protection Agency

USLCI: United States Life Cycle Inventory Database

VOCs: Volatile Organic Compounds

Glossary

Based on ISO 14040:2006- Terms and Definition Section [1].

Allocation: Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems.

Cradle to gate: A cradle-to-gate assessment considers impacts starting with extracting raw materials from the earth (the "cradle") and ending at the plant exit "gate" where the product is to be shipped to the user. In-bound transportation of input fuels and materials to the plant is included. Out-bound transportation of the product to the user is not included. The use phase, maintenance and disposal phase of the product are also not included within the scope of this study. Disposal of on-site waste at the plant and outside and transportation within the plant (if applicable) are included.

Cradle to grave: A cradle-to-gate assessment considers impacts starting with extracting raw materials from the earth (the "cradle") and ending with the end of life treatment (the "grave"). In-bound transportation of input fuels and materials to the plant is included as well as out-bound transportation of the product to the user. The use phase, maintenance and disposal phase of the product are also included within the scope of this study. Disposal of on-site waste at the plant and outside and transportation within the plant (if applicable) are similarly included.

Functional Unit: Quantified performance of a product system for use as a reference unit.

Life cycle: Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal.

Life Cycle Assessment (LCA): Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.

Life Cycle Inventory (LCI): Phase of Life Cycle Assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle.

Life Cycle Impact assessment (LCIA): Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product.

Life cycle interpretation: Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations.

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The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the information presented and do not necessarily reflect the views of the sponsors.

1. Introduction and Report Organization

1.1 Introduction

In order to quantify the environmental qualities of log and timber frame construction, the Cariboo-Chilcotin Beatle Action Coalition (CCBAC) engaged the Athena Institute to complete a life cycle assessment (LCA) of log and timber frame construction. This study was conducted in accordance with international standards on LCA, ISO 14040, ISO 14044 and ISO 21930, and the results were integrated into Athena's EcoCalculator LCA tool. The CCBAC's decision to commission the study was driven by the desire to better understand the environmental footprint of log and timber frame products and to see that information published in the EcoCalculator.

The cradle-to-grave assessment includes resource extraction, log wall and timber frame manufacturing, construction, use, and end-of-life waste treatment; transportation within and between life cycle activity stages is also included. The life cycle of three product systems were assessed in this study:

1. Handcrafted Log Wall: 100 Square Feet Installed at Construction Site in BC
2. Milled Log Wall: 100 Square Feet Installed at Construction Site in BC
3. Timber Frame: 1000 Board Feet Installed at Construction Site in BC

The functional unit is defined based on a 60-year building service life. All upstream resource and commodity material inputs were modeled in SimaPro v7.3 software using secondary LCI data from recent literature as well as the US LCI database, the Institute's proprietary databases, and the ecoinvent database. All secondary data sources were updated for this project with USLCI energy and commodity material models where possible; updates included BC-specific and regional electricity grids developed by the Athena Institute for the USLCI Database. Similarly, secondary LCI data sources were used to model life cycle effects associated with the energy requirements of construction and end-of-life processes.

The carbon sequestered in the three product systems was also assessed in this study. The net carbon balance of the source forest, the product itself, and the fate of that carbon in the landfill were all considered in the carbon balance.

The life cycle impacts of the three functional units were assessed across a set of impact indicators as per ISO 21930 using the US EPA's Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) impact characterization methodology. Cumulative energy demand (fossil, nuclear, and renewables) and weighted resource use were also calculated for the two product life cycles.

1.2 Report Organization

The remainder of this report is structured as follows:

Chapter 2 provides an overview of the LCA framework according to ISO 14040/44:2006. Those less familiar with LCA may find this section useful as a primer for understanding the complete LCA process.

Chapter 3 describes the goal and scope of the study including the study's intent, applications and target audiences. It also sets out the system boundary, functional unit, cut-off criteria, allocation methods, data quality indicators, key data sources and the life cycle impact indicators supported by the study.

Chapter 4 provides an overview of the three product systems and summarizes their respective gate-to-gate manufacturing LCI flows (materials, energy and emission to air, water and land). Chapter 4 also presents the key aspects of the remaining downstream life cycle activity stages – building construction, the use phase (periodic re-staining) and the end-of-life disposal of the wall systems in a landfill.

Chapter 5 presents the results of the carbon sequestration analysis and its relative significance compared to the rest of the life cycle.

Chapter 6 first describes the life cycle impact assessment methodology and the selected impact indicators reported throughout the study. It then goes on to report the cradle-to-manufacturing (called cradle-to-gate) LCIA results for the three component products of interest and then adds in each subsequent downstream activity stage (installation, use and end-of-life) to provide a complete 60-year cradle-to-grave profile for each of the products. The contribution of various raw material and energy inputs and processes within each activity stage is highlighted.

Chapter 7 presents the sensitivity analysis for key assumptions made in this LCA. The sensitivity analysis includes the transportation of materials to construction sites outside British Columbia, the influence of kiln-drying on the milled wall and timber frame results, and the impact of doubling the staining frequency to once every three years.

Chapter 8 brings together the LCI and LCIA results to identify significant issues in the context of the goal and scope of the study. Issues are identified via contribution and sensitivity analyses for each product system. Finally, the section presents the study's conclusions, limitations and makes some recommendations for possible next steps to extend the usefulness of the study.

2. Life Cycle Assessment Methodology

Life cycle assessment is an analytical tool used to comprehensively quantify and interpret the energy and material flows to and from the environment over the entire life cycle of a product, process, or service[1]. Environmental flows include emissions to air, water, and land, as well as the consumption of energy and material resources. By including the impacts throughout the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product and a more accurate picture of the true environmental trade-offs in product selection. Two international standards, ISO 14040:2006 and ISO 14044:20062, describe an iterative four-stage or phased methodology framework for completing an LCA, as shown in Figure 1: (1) goal and scope definition, (2) life cycle inventory, (3) life cycle impact assessment, and (4) interpretation.

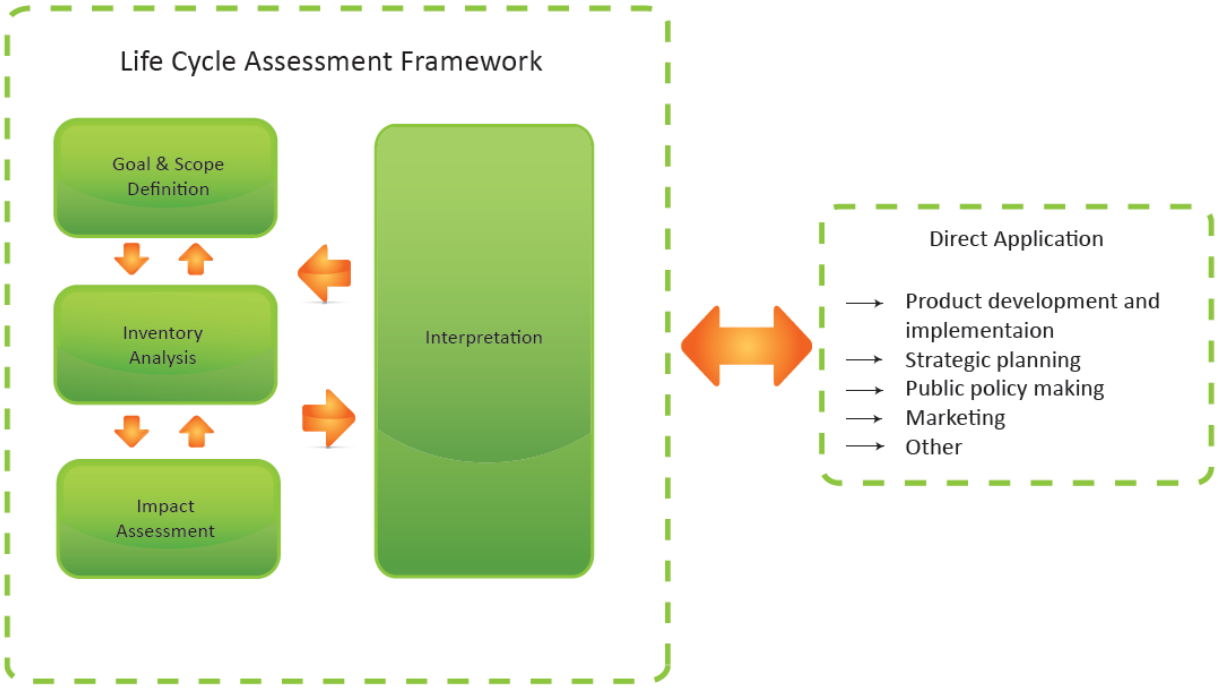

Figure 1: Stages of an LCA as per ISO 14044:2006

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; the allocation methods used, and the impact categories chosen. The goal and scope includes a definition of the context of the study, which explains how and to whom the results are to be communicated. The ISO standards require that the goal and scope of an LCA be clearly defined and consistent with the intended application. The functional unit defines what is being studied. The purpose of the functional

[1] ISO 14040:2006. Environmental Management – Life Cycle Assessment – Principles and Framework.
ISO 14044:2006. Environmental Management – Life Cycle Assessment – Requirements and guidelines.

unit is to quantify the service delivered by the product system and provide a reference to which the inputs and outputs can be related. Allocation is the method used to partition the environmental load of a process when several products or functions share the same process. In inventory analysis a flow model of the technical system is constructed using data on inputs and outputs. The flow model is often illustrated with a flow chart that includes the activities that are going to be assessed and 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 materials and energy flows, emissions to air and water, and waste generation) for all activities within the system boundary. Then, the environmental loads of the defined system are calculated and related back to the functional unit, and the flow model is finished.

Inventory analysis is followed by impact assessment, where the life cycle inventory data are characterized in terms of their potential environmental impacts; for example, resulting in acidification, ozone depletion, and global warming. The impact assessment phase of LCA is aimed at evaluating the significance of potential environmental impacts based on the LCI flow results. Classical life cycle impact assessment (LCIA) consists of the following mandatory elements: selection of impact categories, category indicators, and characterization models; and continues with the classification stage, where the inventory parameters are sorted and assigned to specific impact categories.

The categorized LCI flows are then characterized using one of many possible LCIA methodologies into common equivalence units and then are summed to provide an overall impact category total. This equivalency conversion is based on characterization factors as prescribed by the selected LCIA methodology.

In many LCAs, characterization concludes the LCIA analysis; this is also the last compulsory stage according to ISO 14044:2006. However, in addition to the mandatory LCIA elements (selection, classification, and characterization), other optional LCIA elements (normalization, grouping, and weighting) may be conducted depending on the goal and scope of the LCA study. In normalization, the results of the impact categories from the study are usually compared with the total impact in the region of interest. Grouping consists of sorting and possibly ranking of the impact categories. During weighting, the different environmental impacts are weighted against each other to get a single number for the total environmental impact. As per ISO 14044:2006, “weighting, shall not be used in LCA studies intended to be used in comparative assertions intended to be disclosed to the public”. While this study does not make explicit comparative assertions, readers and users of this study may infer a comparison and thus weighting and other optional LCIA elements are excluded to be consistent with the goal and scope of the LCA study and the ISO 14044:2006 protocol.

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

- Identification of significant issues based on the results of the LCI and LCIA phases of LCA
- Evaluation of the study considering completeness, sensitivity, and consistency checks
- Conclusions, limitations, and recommendations.

The working procedure of LCA is iterative as illustrated by the back-and-forth arrows in Figure 1. The iteration means that information gathered in a later stage can cause effects in a former stage. When this occurs, the former stage and the following stages have to be reworked taking into account the new information. At the end, the results and conclusions of the LCA will be completely and accurately reported to the intended audience. The data, methods, assumptions, limitations, and results will be transparent and presented in sufficient detail to allow the interested parties to comprehend the complexities and trade-offs inherent in the LCA. The report will also allow the results and interpretation to be used in a manner consistent with the goals of the study.

3. Goal and Scope

This chapter sets out the intent and protocol for undertaking the full cradle-to-grave LCA study of the two log wall types and timber frame system. The goal and scope provides a roadmap for completing the life cycle inventory (LCI) data collection, its compilation, as well as its interpretation via a set of robust impact indicators.

3.1 Goals

This project was initiated and funded by the CCBAC. A life cycle assessment was proposed to consider the entire cradle-to-grave impacts of the two log wall types and timber frame system based on a common application in BC over a 60-year building service life.

The following primary reasons for carrying out this LCA study were defined.

This LCA study will be conducted –

1. To better understand the overall environmental performance of two log wall types and timber frame systems and to integrate the log wall data in Athena's EcoCalculator for Assemblies building LCA tool.

2. To better understand the contribution of various processes occurring at log and timber manufacturing facilities and hotspots elsewhere in the life cycle that may be improved by manufacturing or sourcing decisions.

3. To provide the BC LTBIA with a better understanding of the environmental footprint their members' products so the life cycle impacts of their products may be effectively communicated in relation to their thermal performance.

3.1.2 Intended Audience

The intended audience for the results of this LCA study is both internal (identification of hotspots and opportunities for improvement) and external (energy code developers, architectural, engineering, and specifying professionals).

3.1.3 Comparative Assertions

This LCA does not include or infer any comparative assertion across the three products or other building materials or systems.

3.2 Scope of Considered System

3.2.1 Definition of the Functional Unit

The functional unit serves as the starting point for defining the scope of the study that will seek to consider its environmental impacts. The *functional unit* is defined in ISO 14040:2006 as the quantified performance of a product system for use as a reference unit.

The three functional units subject to analysis in this LCA are defined as follows:

1. Handcrafted Log Wall: Cradle-to-grave life cycle of 100 square feet handcrafted log walls (18 inch diameter); manufactured and installed at construction site in BC and then maintained for a service period of 60-years.
2. Milled Log Wall: Cradle-to-grave life cycle of 100 square feet milled profile log walls (8 inch diameter); manufactured and installed at construction site in BC and then maintained for a service period of 60-years.
3. Timber Frame: 1000 board feet heavy timbers; manufactured and installed at construction site in BC and then maintained for a service period of 60-years.

3.2.2 System Boundaries

This cradle-to-grave life cycle assessment considers impacts starting with extracting raw materials from the earth (the "cradle") and ending with the treatment of waste at the end of the service life. Transportation of materials and energy inputs within and between all activity stages is included within the receiving life stage. The use phase, maintenance and disposal of the product systems are also included within the scope of this study. Disposal of on-site waste from product manufacture, on-site construction and periodic maintenance of the products are included in the system boundary. Table 1 lists the inclusions and exclusions from the system boundaries considered in this study.

Table 1: General overview of the System Boundaries for this LCA study

INCLUDED	**EXCLUDED**
• Input raw materials, energy, and fuel • Transportation throughout life cycle • On-site installation material and energy use • Service life requirements (staining) • Removal at the end of service life • Special treatment after service life • Landfilling of waste materials	• Fixed capital equipment and facilities • Hygiene related water use • Transportation of employees • Land use

3.2.3 Multiple-output Allocation

The study was completed using an attributional methodology, where average manufacturing data is employed throughout the value chain. In the attributional approach, the elementary flows and potential environmental impacts are assigned to a specific product system as an account of the history of the product. This differs from the consequential method, which seeks to model a cause-and-effect chain by using marginal data in the value chain. Allocation, where necessary, was conducted following ISO14040/44:2006 methodologies.

Multi-functionality has been identified as a significant methodological issue in LCA. The general situation is that most processes that constitute part of a product system are multi-functional: (1) they produce more than one product (co-production), (2) treat two or more waste inputs (combined waste treatment), (3) treat one waste input and produce one valuable output (open- or close-loop recycling) or (4) serve three or more valuable functions from both input and output (Heijungs and Suh, 2002).

In such cases the materials and energy flows, as well as associated environmental releases, shall be allocated to the different products according to clearly stated procedures (ISO 14044, Section 4.3.4). As per ISO 14044, allocation means partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems. The guidance provided by (ISO) recognizes the variety of approaches which can be applied dealing with multifunctional processes. ISO suggests a generic step-wise framework to address allocation issues in LCA (ISO 14044, 2006).

The following three steps are required:

1. Wherever possible allocation should be avoided by (1) dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes, or (2) expanding the product system to include additional functions related to the co-products, taking into account the requirements of ISO 14044, Section 2.2.1.

2. Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products and functions in a way that reflects the underlying physical relations between them; that is, they should reflect that inputs and outputs are changed by quantitative changes in the products or functions delivered by the system.

3. Where physical relationships alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them. For example, input and output data might be allocated between co-products in relation the economic value of the products.

ISO requirements and recommendations were followed in this LCA study for allocation procedures in general (4.3.4.2) and allocation procedures for reuse and recycling (4.3.4.3). The study also followed the recommendations of the UNEP-SETAC life cycle initiative, life cycle

inventory program, Task Force 3: Methodological consistency, Inventory methods in LCA: towards consistency and improvement.

3.2.4 Cut-off Criteria

The cut-off criteria for input flows to be considered within each system boundary are given in Table 2 below:

Table 2: Cut-off Criteria

CUT-OFF CRITERIA	THRESHOLD
Mass	If a flow is less than 1% of the total mass input of the product system being modeled it may be excluded, providing its environmental relevance is minor
Energy	If a flow is less than 1% of the total product system's energy inputs it may be excluded, providing its environmental relevance is minor
Environmental relevance	If an input 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

The sum of the neglected input flows must not exceed 3% of the total mass, energy or environmental relevance. Similar cut-off criteria were also used to identify which outputs should be traced to the environment; for example, by including waste treatment processes.

The primary LCI data for this study was collected from 6 BC facilities, representing the various product types, for the reference year 2011. Plant personnel provided allocated data for each of the gate-to-gate product systems considered in the scope of the system.

For other ancillary or process materials, such as the production of chemical inputs, fuels and power, secondary data from commercially available LCI databases were deemed acceptable during the goal and scope development for the project (e.g., US LCI Database, North American adjusted Ecoinvent database, etc.).

3.2.5 Data Quality

This section documents the achieved data quality requirements relative to ISO 14044 requirements. Data quality is judged by its precision (measured, calculated or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied on a study serving as a data source) and representativeness (geographical, temporal, and technological).

Precision and Completeness
Primary data on raw materials, energy, and emissions were provided by log and timber frame manufacturers based on 2011 annual purchases, production output, and reported process emissions. Some of the reported transportation distance data are estimates due to the complexity of each facility's supply chains. All upstream and downstream secondary data is consistently applied with sometimes unknown, but similar precision. See appendix A for secondary data sources.

All components of the final product were modeled and all raw material inputs, energy flows and emissions were included. Some small inconsistencies in the mass balance were noted due to imprecise calculations of material weight and/or inconsistency in tracking waste sent externally. All inventory flows were modeled and at no time were data excluded due to application of the study's cut-off criteria.

Consistency and Reproducibility
To ensure consistency, only primary data as provided by the survey respondents were used to model gate-to-gate processes. All other secondary data (upstream and downstream) were consistently applied across the three product systems of interest. At various points in the study (data collection and modeling) a quality and consistency check was performed. The objective of these checks was to ensure that the data collection, the development of the LCI model, and the final results remained consistent with the scope of the study, and that the study delivered the required information. The quality check process included a review of the precision and completeness of the collected primary data (e.g. mass and energy balance was performed), applicability of LCI datasets used, general model structure, and results plausibility (e.g. comparison to other similar reports and the Athena Impact Estimator for Buildings database). The data was found to be within acceptable ranges compared to internally and publically available information.

Reproducibility by third parties is possible using the aggregated inventory data and background LCIs documented in Appendix A. Due to the diverse nature of background LCI datasets used in completing the project a statistical analysis of uncertainty was not possible.

Temporal Coverage
Primary data collected from the manufacturing facilities for their operational activities related to the three product processes of interest are representative for the year 2011 (reference year). Additional data necessary to model base material production and energy use, etc. was adapted from various secondary databases (US LCI database, ecoinvent, etc.) and their use is described in Appendix A.

Geographical Coverage
The geographical coverage for this study is based on North American (NA) system boundaries for all processes and products. Whenever North American background data was not readily available, European data (adjusted for N. American system boundaries) was used as a proxy (see Appendix A).

4. BC Log and Timber Products Manufacture Life Cycle Inventory

Log and timber manufacturing data was collected from manufacturers of the two log wall types and heavy timber frame materials in BC. Appendix 2 presents the LCI data collection questionnaires developed for the two various product types represented in this study.

All upstream resource and commodity material inputs were modeled using secondary LCI data from literature, including the US LCI database, the Institute's proprietary database, and ecoinvent. All secondary data sources were updated for this project with USLCI energy and commodity material models where possible; updates included BC-specific, regional, and North American electricity grids developed by Athena for the USLCI. The source data used to model each technosphere flow in SimaPro is listed in Appendix 1.

4.1 Handcrafted Log Wall LCI

Handcrafted log wall manufacture begins with the delivery of raw logs that are air dried until they are dimensionally stable. The logs are then hand-hewn with a draw knife and the joinery is cut into the logs with chainsaws. The logs are then hand-fitted at the manufacturer's site and a hoist is used to erect the structure which when complete it is broken down and loaded onto a truck to be delivered to the construction site. The life cycle inventory for handcrafted log walls is presented in Table 3.

Table 3: Gate-to-gate Life Cycle Inventory for Handcrafted Log Wall Manufacture

	PRODUCT	UNIT	AMOUNT
OUTPUTS	100 Sq. Ft. Handcrafted Wall	odkg	1389.26
	WASTE		
	Wood Waste	odkg	161.54
INPUTS	**WOOD MATERIAL**		
	Cedar Roundwood	m3	3.05
	Pine Roundwood	m3	0.44
	Spruce Roundwood	m3	0.11
	ENERGY		
	Electricity	kWh	86.21
	Diesel	L	13.27
	Gasoline	L	9.00
	Delivery of Materials by Truck	tkm	62.21
	OPERATING CONSUMABLES		
	Hydraulic Fluid	L	0.08
	Lubricants	L	0.65
	Antifreeze	L	0.05
	Shrinkwrap	kg	0.08

For the survey respondents in this study, Western Red Cedar was the primary species that was used, with lesser amounts of pine and spruce also used. The hand-hewing and joining results in roughly 10% wood waste that is primarily used as biomass energy. Since this waste is removed without revenue or cost, it was assumed to leave the system boundary without burden or impacts attributed to it.

4.2 Milled Profile Log Wall LCI

Milled profile log walls differ from handcrafted walls in that the raw log is first milled into a standardized cant, which is a rough sawn timber, before the piece is profiled to create the desired finish and fit. Milled profile log walls are available in a variety of shapes, with one or both sides flat or rounded. The functional unit in this study assumes an 8 inch diameter round finish. In this study, a majority of the production utilized pre-milled cants while the remainder milled the cants themselves. This is reflected in the life cycle inventory that includes log and cant inputs presented in Table 4.

Table 4: Gate-to-gate Life Cycle Inventory for Milled Profile Log Wall Manufacture

	PRODUCT	UNIT	AMOUNT
OUTPUTS	100 Sq. Ft. Milled Profile Wall	odkg	617.45
	WASTE		
	Wood Waste	odkg	293.57
INPUTS	**WOOD MATERIALS**		
	Douglas Fir Roundwood	m3	0.80
	Pine/Spruce Roundwood	m3	0.07
	Douglas Fir Cants	mbfm	0.91
	ENERGY		
	Electricity	kWh	258.96
	Diesel	L	31.50
	Gasoline	L	2.97
	Propane	L	0.81
	Delivery of Materials by Truck	tkm	100.62
	OPERATING CONSUMABLES		
	Hydraulic Fluid	L	0.38
	Lubricants	L	1.01
	Antifreeze	L	0.16
	Shrinkwrap	kg	1.72

After milling and shaping, the logs are then stacked similarly to handcrafted log walls to erect the structure which when complete is broken down and loaded onto a truck to be delivered to the construction site. Milled profile log walls may be either air-dried or kiln-dried. In this study, the material was assumed to be air-dried, which includes the use of standing dead timber. The sensitivity of the results to kiln-drying is presented in Chapter 7.

4.3 Heavy Timber Manufacture LCI

Similar to the milled wall manufacturing described in Section 4.2, a majority of the timber production utilized pre-milled rough timbers while the remainder milled the timbers from logs themselves. This is reflected in the life cycle inventory that includes log and rough lumber inputs. Also similar to the milled profile walls, the timbers may be either air-dried or kiln-dried. In this study, the material was assumed to be air-dried. The sensitivity of the results to kiln-drying is presented in Chapter 7. The life cycle inventory for the timber frame milling is presented in Table 5.

Table 5: Gate-to-gate Life Cycle Inventory for Heavy Timber Manufacture

	PRODUCT	UNIT	AMOUNT
OUTPUTS	1000 Board Feet Timbers	odkg	664.76
	WASTE		
	Wood Waste	odkg	287.34
INPUTS	**WOOD MATERIALS**		
	Douglas Fir Roundwood	m3	0.79
	Pine/Spruce Roundwood	m3	0.07
	Rough Douglas Fir Lumber	mbfm	0.89
	ENERGY		
	Electricity	kWh	237.53
	Diesel	L	21.79
	Gasoline	L	2.67
	Delivery of Materials by Truck	tkm	98.48
	OPERATING CONSUMABLES		
	Hydraulic Fluid	L	0.37
	Lubricants	L	0.99
	Antifreeze	L	0.16
	Shrinkwrap	kg	1.68

4.4 Delivery and Construction

The three products are trucked to construction sites where they are installed through the use of a crane. The baseline scenario is that the building is constructed in BC, and since the log wall manufacturers are located throughout the province, the log walls are assumed to be transported 200 km to the construction site.

At the construction site, a diesel crane is used to stack the log walls and raise the timber frame. The crane idles through much of the construction process, with acceleration of the engine occurring when the load is lifted. It was estimated that a typical crane consumes 75 liters of diesel fuel to lift one 50 m3 truckload of logs.

During the log wall construction process, steel bolts are inserted into pre-drilled holes spaced every 4 feet to provide greater rigidity of the finished wall. Two layers of low density polyethylene (LDPE) gasket are inserted into the channel at the bottom of each log to provide a weather proof seal. The delivery transportation, diesel used by the crane, and LDPE gasket use for 100 square feet of log wall are presented in Table 6. The variation in steel and insulation between the handcrafted and milled profile walls is a result of the greater diameter of the handcrafted logs which means fewer layers of logs are used (and gasket and bolts between them). Wool insulation is also sometimes placed between the gaskets but is excluded in this study because it is assumed not required and is assumed to be of negligible impact.

Table 6: Delivery and Construction Inputs

	ENERGY INPUTS	**UNIT**	**AMOUNT**
HANDCRAFTED LOG WALL	Diesel Truck Delivery	tkm	277.85
	Diesel Crane	l	4.84
	MATERIAL INPUTS		
	Steel Bolts	kg	7.36
	PVC Gasket	kg	1.16
	ENERGY INPUTS	**UNIT**	**AMOUNT**
MILLED LOG WALL	Diesel Truck Delivery	tkm	123.49
	Diesel Crane	l	2.22
	MATERIAL INPUTS		
	Steel Bolts	kg	9.08
	PVC Gasket	kg	2.62
	ENERGY INPUTS	**UNIT**	**AMOUNT**
TIMBER FRAME	Diesel Truck Delivery	tkm	132.95
	Diesel Crane	l	2.39

4.5 Periodic Staining

The exterior side of the log walls are stained at the point of construction, and periodically throughout the service life. A variety of stains are available to the log home owner. In this study, we assumed 1.5 gallons use of a water-based acrylic stain (which is the amount required for the recommended three coats) applied every 6 years throughout the 60 year service life. While this assumption is a conservative one with many homeowners likely not applying 3 coats during each stain, the sensitivity of additional staining is addressed in Chapter 7.

The interior side may be stained, treated with oil, and in some instances varnished or painted. The interior finishing was excluded in this analysis because no interior finishing is required to provide the log wall function. Additionally, when the interior is finished, the substance that is used varies and is insignificant compared to the exterior portion that is finished 10 times during the service life.

Similar to the interior log wall surface, the timber frame may or may not be finished with stain, oil, or polyurethane. The variety of potential finishes and the fact that no finishing is required for the performance of the product led to the exclusion of finishing for the timber frame.

4.6 End of Life

The end of life demolition and municipal waste treatment is included in the analysis for all three products and is based on Athena's internal models for these processes (which are typically of negligible impact).The influence of biogenic carbon emissions from the landfill is discussed in greater detail in Chapter 5 in relation to the over-all biogenic carbon balance of the product.

5. Biogenic Carbon Accounting

5.1 Background Rationale for Biogenic Carbon Accounting

The primary reason for including product carbon storage in LCA accounting is that sustainably managed forests are net carbon neutral over the long term - meaning that the carbon sequestered in a forest may rise and fall with growth and disturbance (burning for instance) but is neither increasing nor decreasing in carbon content in the long term. This stems from the fact that unlogged forests eventually reach a state of maturity where they no longer remove any carbon from the atmosphere - and means that any storage of carbon in products is additional to the storage in the forest.

Researchers at CORRIM[2], the Consortium for Research on Renewable Industrial Materials, presented the graphic shown in Figure 2 that shows carbon storage by forest age and illustrates that sequestration levels off after year 80.

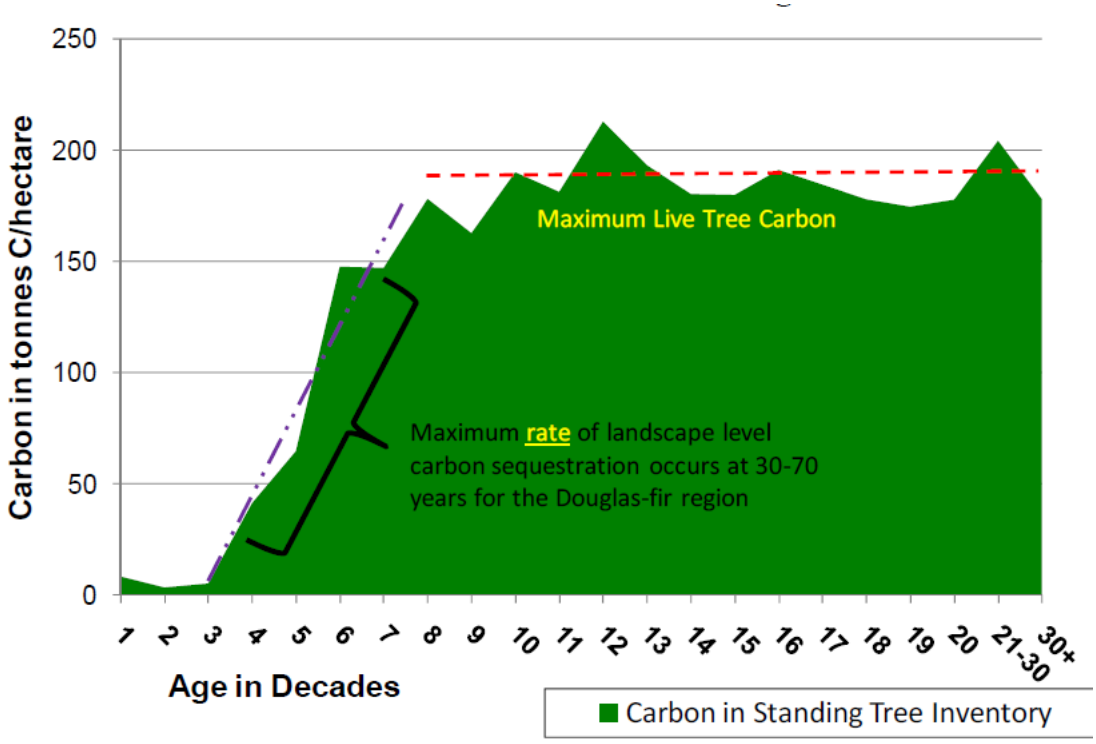

Figure 2: Carbon Balance by Age Class of Forest in Western Washington

It follows that logging a forest late in its growth phase prevents the forest from reaching the mature steady-state, and instead causes the forest to re-enter the highest growth phase that occurs in year 30-70 during the life cycle of the wood product.

[2] http://www.corrim.org/pubs/reports/2010/biomass_vs_fossil/BiomassVSFossilEmissionsNov2010.pdf

Forests only reach decline if they are not subjected to natural disturbance. In Canada, while the area of forests logged has remained relatively constant (around 1 million hectares annually), the area subjected to natural disturbance has varied from 47-243 million hectares (Shown in Figure 3). This means that in Canada, wood left unlogged is much more likely to be emitted by fire or insect than to be logged at a later date. This gives further credence to the notion that sequestering carbon in a product shelters the carbon from natural disturbance and replaces a high carbon risk mature forest with a younger forest that sequesters additional carbon as it regrows.

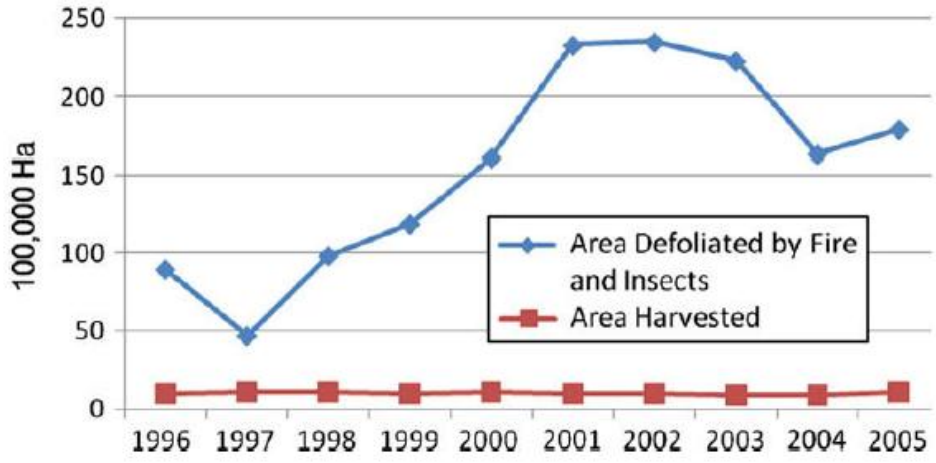

Figure 3: Source of Forest Disturbance in Canada from 1996-2005

When incorporating carbon sequestration in wood products LCA accounting, we must remind ourselves that the flow of carbon out of the atmosphere and into the forest only occurs while the forest is growing and not after the forest reaches maturity. We must also note that a durable wood product is typically still in service after 70-80 years, at which point the forest from which it came has regenerated and itself has reached maturity. The alternative baseline condition is a forest that in 80 years has either reached maturity and is no longer sequestering carbon or has been lost to disturbance.

5.2 Carbon Sequestration Product Baseline

The three functional units in this study are each primarily comprised of wood. The carbon sequestered in that wood is found by first converting from dry mass to carbon content by multiplying by 0.5, the carbon content in a kg of dry wood. Next, the carbon dioxide equivalent (which is the basis for greenhouse gas accounting) is found by multiplying by 44/12 which is the ratio of the molecular weight of carbon dioxide relative to carbon. The carbon dioxide equivalents sequestered in the three functional units are as follows:

1. Handcrafted Log Wall: 1389 odkg wood = 2547 kg CO_2eq.
2. Milled Log Wall: 617 odkg wood = 1132 kg CO_2eq.
3. Timber Frame: 665 odkg wood = 1219 kg CO_2eq.

5.3 Carbon Dynamics at End of Life

The following end of life carbon dynamics description was adapted from an Athena Institute authored journal article *Prospects for Carbon Neutral Housing: The Influence of Greater Wood Use on the Carbon Footprint of a Single-Family Residence*; the reference to which is found in the references section.

The carbon that is sequestered in the wood products is subject to some decay once the wood product reaches the end of its service life and the material is taken to a landfill. Wood's lignin content and imperfect conditions for anaerobic microbacteria that exist in landfills cause the majority of carbon in wood to remain intact while 24% is converted equally to carbon dioxide and methane. A portion of the methane that is produced, about 10%, is oxidized within the landfill before it reaches the surface. Thus, the composition of landfill gas (LFG) is 55% CO2, 45% CH4 (on a molar basis) when it reaches the surface. Landfill gas capture systems operate at varying efficiencies. The USEPA estimates that the average landfill gas capture technology in landfills where solid wood products are disposed results in the capture of about 90% of emitted landfill gas. Of the 90% that is captured, only 70% is combusted in an industrial turbine to produce electricity. The remaining 30% is flared to eliminate methane but without energy recovery. The result of these carbon flows is three distinct sources of greenhouse gasses:

- Direct Emissions: Non-captured landfill gas that includes methane and carbon dioxide
- Emissions from Flaring: Carbon dioxide emissions released from flaring landfill gas
- Emissions from Energy Recovery: Carbon dioxide emissions released from burning landfill gas with energy recovery

The LFG that is utilized as fuel has a heating value of 15.8 MJ/kg and reduces demand for equivalent amounts of natural gas that would have otherwise been consumed as a fuel. This energy surplus causes a negative emission of the equivalent combustion of natural gas heat. The overall biogenic carbon emissions (and prevented emissions) for the three functional units are given in Table 7.

Table 7: Carbon Sequestration Balance for Log and Timber Products

	Biogenic Flows per ODKG (kg CO2e)	100 Sq. Ft. Handcrafted Log Wall (kg CO2e)	100 Sq. Ft. Milled Profile Log Wall (kg CO2e)	1000 Board Feet Timbers (kg CO2e)
Baseline Sequestration	-1.83	-2546.98	-1131.99	-1218.73
Direct Emissions	0.20	283.69	126.08	135.74
Emissions from flaring	0.12	165.04	73.35	78.97
Emissions from energy recovery	0.28	385.10	171.16	184.27
Prevented nat. gas emissions	-0.18	-243.79	-108.35	-116.65
Net Carbon Sequestration	-1.41	-1956.93	-869.75	-936.39

6. Life Cycle Impact Assessment

6.1 LCIA Methodology

The impact categories and assessment methods are the mid-point indicators from the U.S. EPA Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI). The TRACI methodologies were developed specifically for the US using input parameters consistent with US locations and consistent with ISO 21930, *Sustainability in building construction – Environmental declaration of building products*. They include primary energy (fossil fuel depletion), global warming, ozone depletion, photochemical oxidants (smog), eutrophication, and acidification potential.

It should be noted that while LCI enjoys a fairly consistent methodology, the life cycle impact assessment (LCIA) phase is very much a "work in progress" and there is no overall agreement on which LCIA categories should be included in a LCA or a single accepted methodology for calculating all of the impact categories to be included. Typically, LCIA is completed in isolation of the LCI, that is, the LCI requests a complete mass and energy balance for each unit process or product system under consideration and once completed the LCI is sifted through various LCIA indicator categories to determine possible impacts. For this study, we have relied on ISO 21930[3] to identify the various impact categories to be included in the LCIA and TRACI as the LCIA methodology. ISO 21930 provides an internationally accepted scope for decisions as to which LCIA categories should be supported for building sustainability metric analysis, while the TRACI LCIA methodology provides a North American context for the actual measures to be supported. ISO21930 stipulates a number of mid-point LCIA characterization measures to be supported and while not opposing end-point measures, dissuades their use until they are more internationally accepted. The measures advocated by ISO 21930 include:

1. Use of Resources and Energy
    a. Depletion of non-renewable primary energy
    b. Use of renewable primary energy
2. Climate change
3. Destruction of the ozone layer
4. Formation of photochemical oxidants
5. Acidification of land and water sources
6. Eutrophication

3 ISO 21930:2007 – Building and Construction Assets – Sustainability in building constructions – Environmental declaration of building products.

Optional end-point LCIA measures listed in ISO 21930 include human toxicity and ecotoxicity; however, their uncertainty increases with movement from mid-point to end-point measures. Therefore we do not recommend using or reporting end-point measures. It is important to note that the impacts described by an LCA are estimates of relative and potential impacts, rather than direct measurements of real impacts, with limitations as described in the ISO international standards series 14040:2006. Table 20 sets out the impact categories supported by TRACI (2.0) and their inherent impact potential.

Table 8: Impact categories in Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI)

IMPACT CATEGORY	NATURAL ENVIRONMENT	HUMAN HEALTH	RESOURCES
Global warming	♦		
Acidification	♦	♦	
Ozone depletion	♦	♦	
Eutrophication	♦	♦	
Photochemical Smog	♦	♦	
Ecotoxicity	♦		
Human health: criteria air		♦	
Human health: cancer		♦	
Human health: non-cancer		♦	
Fossil fuel			♦

While TRACI supports fossil fuel depletion (on a global scale), it does not readily report primary energy use. For purposes of this study the total primary energy use was tabulated and summarized as an impact indicator directly from the LCI results. Further, the study adopts the "Cumulative Energy Demand" method to organize and report primary energy resource use[4]. Total primary energy is the sum of all energy sources drawn directly from the earth, such as natural gas, oil, coal, biomass or hydropower energy. The total primary energy can be further broken down into categories. For this reason, the study provides a measure of total primary energy derived from the direct LCI flows broken down into renewable and non-renewable energy sources. Higher heating value (HHV) of primary energy carriers is used to calculate the primary energy values reported in the study.

With respect to the other LCIA measures, the following TRACI impact categories (IC) and characterization factors (CF)[5] were calculated and reported (also see Table 21).

[4] R. Frischknecht and N. Jungbluth (Editors), *Implementation of Life Cycle Impact Assessment Methods*, DataV1.1, Ecoinvent Report No. 3, 2004.

[5] Characterization factor is a factor derived from a characterization model which is applied to convert an assigned life cycle inventory analysis result to the common unit of the category indicator. The common unit allows calculation of the category indicator result [ISO 14040:2006].

a. **Global warming (IC) -** TRACI uses global warming potentials (CF), a midpoint metric proposed by the International Panel on Climate Change (IPCC), for the calculation of the potency of greenhouse gases relative to CO2. The 100-year time horizons recommended by the IPCC and used by the United States for policy making and reporting are adopted within TRACI. Global warming potential (GWP) – the methodology and science behind the GWP calculation can be considered one of the most accepted LCIA categories. GWP_{100} will be expressed on equivalency basis relative to CO_2 – i.e., equivalent CO_2 mass basis.

b. **Acidification (IC) -** As per TRACI, acidification comprises processes that increase the acidity (hydrogen ion concentration, [H+]) of water and soil systems. Acidification is a more regional rather than global impact effecting fresh water and forests as well as human health when high concentrations of SO_2 are attained. The Acidification potential (CF) of an air emission is calculated on the basis of the number of H+ ions which can be produced and therefore is expressed as potential H+ equivalents on a mass basis.

c. **Ozone depletion (IC) -** Stratospheric ozone depletion is the reduction of the protective ozone within the stratosphere caused by emissions of ozone-depleting substances. International consensus exists on the use of Ozone Depletion Potentials (CF), a metric proposed by the World Meteorological Organization for calculating the relative importance of CFCs, hydrochlorofluorocarbons (HFCs), and halons expected to contribute significantly to the breakdown of the ozone layer. TRACI is using the ozone depletion potentials published in the Handbook for the International Treaties for the Protection of the Ozone Layer (UNEP-SETAC 2000), where chemicals are characterized relative to CFC-11.

d. **Eutrophication (IC) -** In TRACI, eutrophication is defined as the fertilization of surface waters by nutrients that were previously scarce. This measure encompasses the release of mineral salts and their nutrient enrichment effects on waters – typically made up of phosphorous and nitrogen compounds and organic matter flowing into waterways. The result is expressed on an equivalent mass of nitrogen (N) basis. The characterization factors estimate the eutrophication potential of a release of chemicals containing N or P to air or water, per kilogram of chemical released, relative to 1 kg N discharged directly to surface freshwater.

e. **Photochemical smog (IC) -** *Photochemical ozone formation potential (CF)* – Under certain climatic conditions, air emissions from industry and transportation can be trapped at ground level where, in the presence of sunlight, they produce photochemical smog, a symptom of photochemical ozone creation potential (POCP). While ozone is not emitted directly, it is a product of interactions of volatile organic compounds (VOCs) and nitrogen oxides (NO_x). The “smog” indicator is expressed on a mass of equivalent ozone (O_3) basis.

f. **Total primary energy (IC) –** Total primary energy is the sum of all energy sources which are drawn directly from the earth, such as natural gas, oil, coal, biomass or hydropower energy. The total primary energy contains further categories namely non-renewable and renewable energy, and fuel and feedstock energy. *Non-renewable energy* includes all fossil and mineral primary energy sources, such as natural gas, oil, coal and nuclear energy. *Renewable energy*

includes all other primary energy sources, such as hydropower and biomass. *Feedstock energy* is that part of the primary energy entering the system which is not consumed and/or is available as fuel energy and for use outside the system boundary. Total Primary Energy is expressed in MJ.

g. **Respiratory effects (IC)** – The midpoint level selected by TRACI will be used based on exposure to elevated particulate matter (PM) less than 10 micrometers in diameter. Particulate matter is the term for particles found in the air, including dust, dirt, soot, smoke, and liquid droplets. Particles can be suspended in the air for long periods of time. Some particles are large or dark enough to be seen as soot or smoke. Others are so small that individually they can only be detected with an electron microscope. Many manmade and natural sources emit PM directly or emit other pollutants that react in the atmosphere to form PM. These solid and liquid particles come in a wide range of sizes. Particles less than 10 micrometers in diameter (PM10) pose a health concern because they can be inhaled into and accumulate in the respiratory system. Particles less than 2.5 micrometers in diameter (PM2.5) are referred to as "fine" particles and are believed to pose the greatest health risks. Because of their small size (approximately 1/30th the average width of a human hair), fine particles can lodge deeply into the lungs.

h. **Weighted resource use (IC)** - Raw resource use can be measured in common units such as tonnes, but a unit of one resource like iron ore is not at all comparable to a unit of another resource like timber or coal when it comes to environmental implications of extracting resources. Since the varied effects of resource extraction, (e.g., effects on bio-diversity, ground water quality and wildlife habitat, etc.) are a primary concern, it is important to ensure they are taken into account. While these ecological carrying capacity effects are as important, they are much harder to incorporate for a number of reasons, especially their highly site-specific nature.

   The approach adopted by the Athena Institute was to survey a number of resource extraction and environmental specialists across Canada to develop subjective scores of the relative effects of different resource extraction activities. The scores reflect the expert panel ranking of the effects of extraction activities relative to each other for each of several impact dimensions. The scores were combined into a set of resource-specific index numbers, which are as weights to the amounts of raw resources used to manufacture each building product. The Weighted Resource Use values reported by the Impact Estimator are the sum of the weighted resource requirements for all products used in each of the designs. They can be thought of as "ecologically weighted pounds or kilograms", where the weights reflect expert opinion about the relative ecological carrying capacity effects of extracting resources.

Table 9: Selected Impact Indicators

IMPACT CATEGORY	UNIT	SOURCE METHOD	LEVEL OF SITE SPECIFICITY
Global warming	kg CO2 eq	TRACI	Global
Smog	kg O3 eq	TRACI	North America
Acidification	mol H+ eq	TRACI	North America
Resp. effects	kg PM10 eq	TRACI	North America
Ozone depletion	kg CFC-11 eq	TRACI	North America
Eutrophication	kg N eq	TRACI	North America
Weighted Resource	kg	Athena	North America
Total energy	MJ eq	CED – Adapted	Global
*Fossil energy**	MJ eq	CED – Adapted	Global
*Nuclear energy**	MJ eq	CED – Adapted	Global
*Renewables***	MJ eq	CED – Adapted	Global

* Fossil energy, Nuclear energy, and Renewables are subsets of Total energy

** Renewables includes hydro, solar, biomass, and geothermal energy

6.2 LCIA Results for Handcrafted Log Wall

The life cycle impact assessment results of handcrafted log walls are presented in Table 10 on an absolute basis, in Table 11 on a percentage contribution basis, and graphically in Figure 4.

Table 10: LCIA Results for 100 Square Feet Handcrafted Log Wall Manufactured and Constructed in British Columbia – Absolute Basis

	Units	Total	Logging	Manufacture	Delivery and Construction	Bolts and Gasket	Stain	End of Life
Global warming	kg CO2 eq.	183.35	14.95	73.53	40.78	13.16	40.67	0.26
Acidification	H+ moles eq.	72.01	2.32	24.57	10.67	4.64	29.75	0.07
Respiratory effects	kg PM2.5 eq.	0.21	0.00	0.04	0.01	0.03	0.13	0.00
Eutrophication	kg N eq.	0.05	0.00	0.02	0.01	0.01	0.01	0.00
Smog	kg NOx eq.	0.79	0.03	0.47	0.20	0.02	0.08	0.00
Ozone Depletion	kg CFC 11 eq	6.50E-09	6.09E-10	3.06E-09	1.59E-09	1.07E-10	1.12E-09	1.09E-11
Weighted Resource	kg	2,259.99	2,097.00	28.52	15.58	28.64	90.14	0.09
Total energy	MJ eq	4,138.93	224.70	1,484.78	580.00	210.82	1,518.70	119.94
Fossil energy	MJ eq	3,739.64	222.00	1,160.81	574.26	178.67	1,483.96	119.94
Nuclear energy	MJ eq	54.14	2.20	9.66	4.89	6.20	31.19	0.01
Renewable energy	MJ eq	345.15	0.50	314.30	0.84	25.95	3.55	0.00

Table 11: LCIA Results for 100 Square Feet Handcrafted Log Wall Manufactured and Constructed in British Columbia – Percentage Basis

	Logging	Manufacture	Delivery and Construction	Bolts and Gasket	Stain	End of Life
Global warming	8.16%	40.10%	22.24%	7.18%	22.18%	0.14%
Acidification	3.22%	34.12%	14.81%	6.44%	41.31%	0.10%
Respiratory effects	1.65%	17.80%	6.89%	12.43%	61.18%	0.04%
Eutrophication	3.75%	46.75%	20.67%	17.27%	11.41%	0.15%
Smog	3.64%	59.09%	25.17%	2.32%	9.57%	0.21%
Ozone Depletion	9.37%	47.13%	24.43%	1.65%	17.25%	0.17%
Weighted Resource	92.79%	1.26%	0.69%	1.27%	3.99%	0.00%
Total energy	5.43%	35.87%	14.01%	5.09%	36.69%	2.90%
Fossil energy	5.94%	31.04%	15.36%	4.78%	39.68%	3.21%
Nuclear energy	4.07%	17.84%	9.04%	11.45%	57.60%	0.01%
Renewable energy	0.14%	91.06%	0.24%	7.52%	1.03%	0.00%

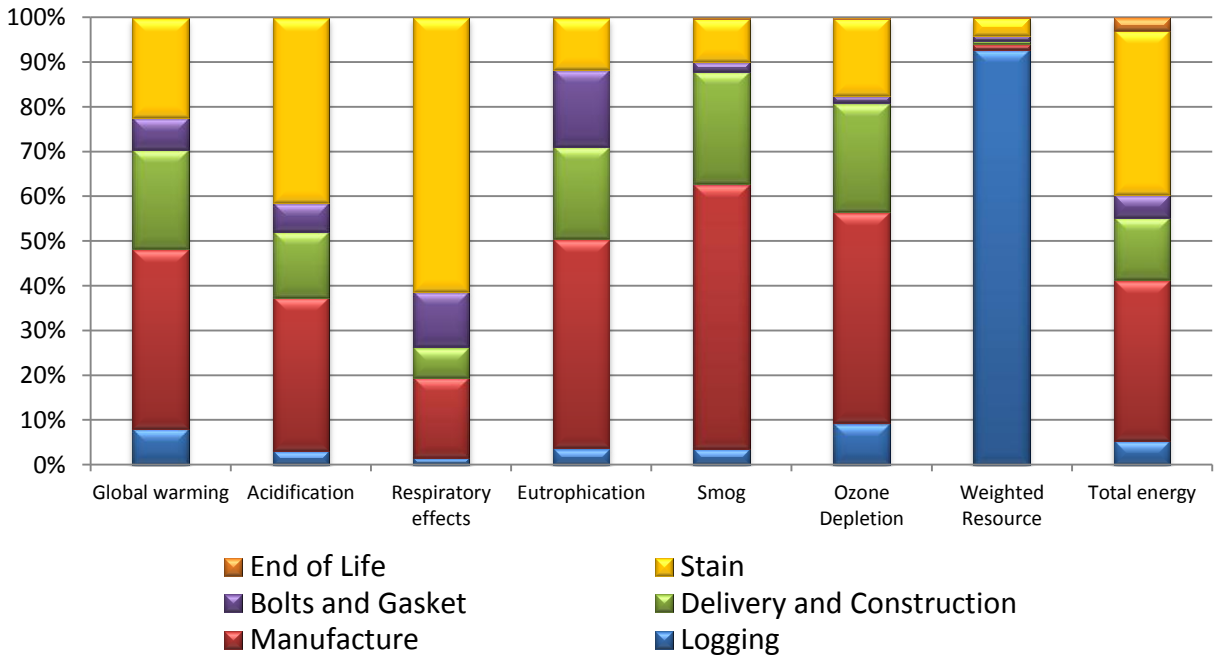

Figure 4: LCIA Results for 100 Square Feet Handcrafted Log Wall Manufactured and Constructed in British Columbia – Percentage Basis

The results indicate that the manufacturing portion of the life cycle is the greatest contributor to impacts in all categories except weighted resource use and respiratory effects. The logging process consumes the greatest resources because this process is the point in the life cycle where wood resources are extracted from the environment. The respiratory effects in the

staining portion of the life cycle is caused by nitrogen oxide emissions generated in propylene manufacture, which is a precursor to the acrylic portion of the stain.

Besides weighted resource use, the logging portion of the life cycle is a small contributor to impacts in all categories. The steel fasteners and gaskets, as well as the end of life processing, are similarly small overall contributors to the life cycle impacts.

The delivery and construction of the log walls accounts for roughly 20% of the life cycle global warming impacts. This amount is somewhat higher than is typical in residential construction due to the massive nature of the log walls that requires significant transportation burdens and the use of a crane to hoist the logs into place at the construction site.

6.3 LCIA Results for Milled Profile Log Wall

The life cycle impact assessment results of milled profile log walls are presented in Table 12 on an absolute basis, in Table 13 on a percentage contribution basis, and graphically in Figure 5.

Table 12: LCIA Results for 100 Square Feet Milled Profile Log Wall Manufactured and Constructed in British Columbia – Absolute Basis

	Units	Total	Logging	Cant Milling and Manufacture	Delivery and Construction	Bolts and Gasket	Stain	End of Life
Global warming	kg CO2 eq.	218.08	6.96	129.56	23.05	17.72	40.67	0.12
Acidification	H+ moles eq.	75.37	1.55	30.02	6.40	7.62	29.75	0.03
Respiratory effects	kg PM2.5 eq.	0.26	0.02	0.06	0.01	0.04	0.13	0.00
Eutrophication	kg N eq.	0.04	0.00	0.02	0.01	0.01	0.01	0.00
Smog	kg NOx eq.	0.62	0.01	0.38	0.12	0.03	0.08	0.00
Ozone Depletion	kg CFC 11 eq	7.49E-09	2.22E-10	5.07E-09	8.92E-10	1.84E-10	1.12E-09	4.85E-12
Weighted Resource	kg	1,120.89	933.66	50.63	8.52	37.90	90.14	0.04
Total energy	MJ eq	5,484.40	182.67	3,050.95	325.89	352.89	1,518.70	53.31
Fossil energy	MJ eq	4,371.66	108.13	2,091.51	322.67	312.10	1,483.96	53.31
Nuclear energy	MJ eq	61.08	0.86	17.52	2.75	8.76	31.19	0.00
Renewable energy	MJ eq	1,051.65	73.68	941.91	0.47	32.03	3.55	0.00

Table 13: LCIA Results for 100 Square Feet Milled Profile Log Wall Manufactured and Constructed in British Columbia – Percentage Basis

	Logging	Cant Milling and Manufacture	Delivery and Construction	Bolts and Gasket	Stain	End of Life
Global warming	3.19%	59.41%	10.57%	8.13%	18.65%	0.05%
Acidification	2.05%	39.83%	8.49%	10.11%	39.47%	0.04%
Respiratory effects	9.01%	23.61%	3.27%	15.42%	48.67%	0.02%
Eutrophication	1.79%	47.70%	13.81%	24.09%	12.53%	0.07%
Smog	2.16%	61.50%	19.76%	4.26%	12.21%	0.12%
Ozone Depletion	2.96%	67.67%	11.90%	2.45%	14.95%	0.06%
Weighted Resource	83.30%	4.52%	0.76%	3.38%	8.04%	0.00%
Total energy	3.33%	55.63%	5.94%	6.43%	27.69%	0.97%
Fossil energy	2.47%	47.84%	7.38%	7.14%	33.94%	1.22%
Nuclear energy	1.42%	28.69%	4.50%	14.34%	51.05%	0.00%
Renewable energy	7.01%	89.57%	0.04%	3.05%	0.34%	0.00%

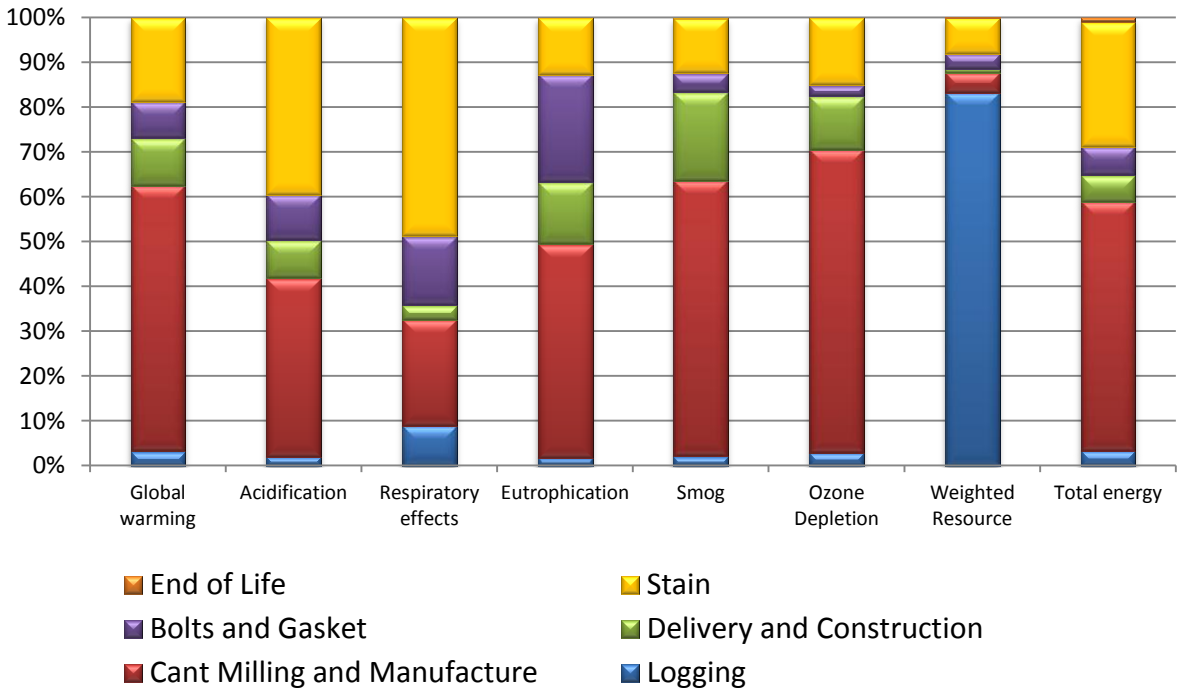

Figure 5: LCIA Results for 100 Square Feet Milled Profile Log Wall Manufactured and Constructed in British Columbia – Percentage Basis

The results for the milled profile wall are similar to the handcrafted wall. Again, the cant milling and manufacturing portion of the life cycle is the greatest overall contributor to life cycle impacts, with the exception of the respiratory effects of the stain and the resource use attributed to the logging process.

The logging, delivery, and construction portions of the life cycle cause less impacts in the milled profile log wall life cycle than in the life cycle of the handcrafted log wall. This is due to the fact that the milled profile log wall consumes less raw material and weighs less than half as much as the handcrafted wall. The additional electricity consumed in the manufacturing portion of the life cycle as compared to the manufacturing of the handcrafted wall is inconsequential since the grid in BC is based entirely on hydro power which is a minor contributor to the reported environmental impacts.

6.4 LCIA Results for Timber Frame System

The life cycle impact assessment results of heavy timbers are presented in Table 14 on an absolute basis, in Table 15 on a percentage contribution basis, and graphically in Figure 6.

Table 14: LCIA Results for 1000 Board Feet Heavy Timbers Manufactured and Constructed in British Columbia – Absolute Basis

	Units	Total	Logging	Timber Milling	Delivery and Construction	End of Life
Global warming	kg CO2 eq.	123.49	6.82	95.45	21.10	0.13
Acidification	H+ moles eq.	31.46	1.51	24.28	5.63	0.04
Respiratory effects	kg PM2.5 eq.	0.08	0.02	0.05	0.01	0.00
Eutrophication	kg N eq.	0.02	0.00	0.02	0.01	0.00
Smog	kg NOx eq.	0.43	0.01	0.31	0.11	0.00
Ozone Depletion	kg CFC 11 eq	4.75E-09	2.17E-10	3.71E-09	8.19E-10	5.23E-12
Weighted Resource	kg	1,051.02	1,004.47	38.53	7.97	0.04
Total energy	MJ eq	2,996.37	178.79	2,460.74	299.45	57.39
Fossil energy	MJ eq	2,043.75	105.83	1,584.04	296.49	57.39
Nuclear energy	MJ eq	16.62	0.85	13.24	2.53	0.00
Renewable energy	MJ eq	936.00	72.11	863.45	0.43	0.00

Table 15: LCIA Results for 1000 Board Feet Heavy Timbers Manufactured and Constructed in British Columbia – Percentage Basis

	Logging	Timber Milling	Delivery and Construction	End of Life
Global warming	5.52%	77.30%	17.08%	0.10%
Acidification	4.81%	77.17%	17.90%	0.11%
Respiratory effects	27.75%	63.11%	9.09%	0.05%
Eutrophication	3.39%	73.19%	23.26%	0.15%
Smog	3.07%	71.97%	24.78%	0.18%
Ozone Depletion	4.57%	78.07%	17.25%	0.11%
Weighted Resource	95.57%	3.67%	0.76%	0.00%
Total energy	5.97%	82.12%	9.99%	1.92%
Fossil energy	5.18%	77.51%	14.51%	2.81%
Nuclear energy	5.09%	79.69%	15.20%	0.02%
Renewable energy	7.70%	92.25%	0.05%	0.00%

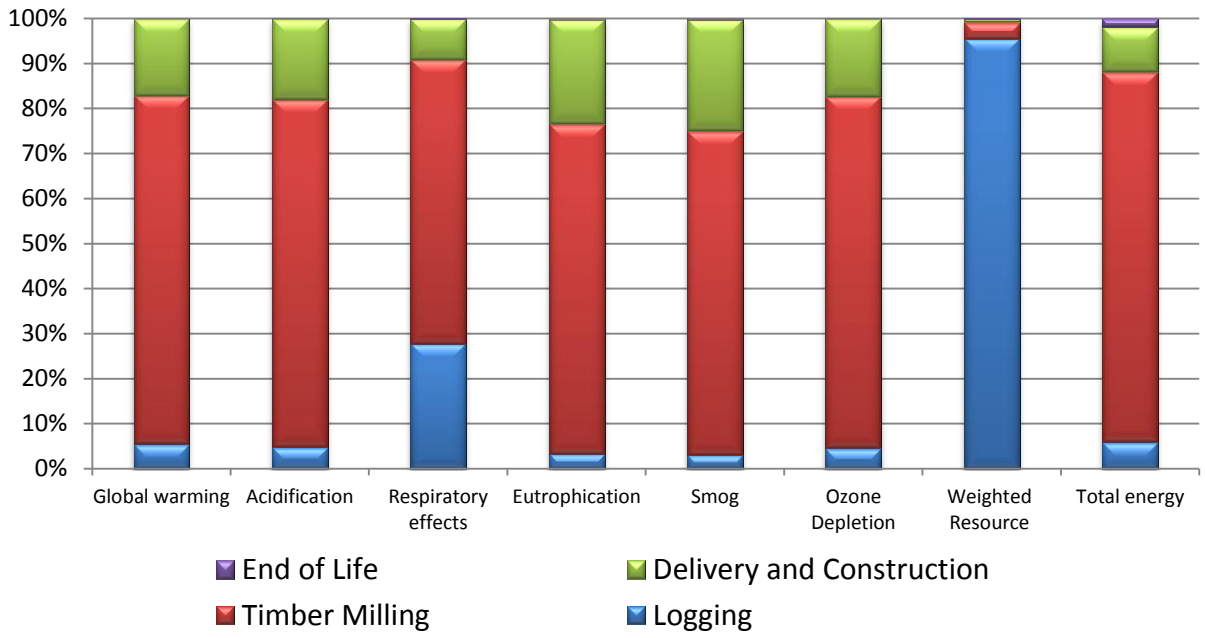

Figure 6: LCIA Results for 1000 Board Feet Heavy Timbers Manufactured and Constructed in British Columbia – Percentage Basis

The timber milling process is the greatest cause of impacts in the life cycle, with the logging causing less than 10% of impacts in all categories except weighted resource use. It should be noted that while the focus of this LCA was not to identify the overall scale of environmental impacts since no comparisons are involved, the overall impacts of all three products, and particularly the heavy timbers, is quite low across the board.

7. Sensitivity Analysis

7.1 Transportation to Construction Sites Outside BC

The functional unit in this study was based on the construction of the log walls and timber frames in British Columbia. The results may be translated to other locations by considering the impacts of transporting the various products to construction sites across North America, Asia, and Europe. These transportation scenarios may be derived by the transportation impacts presented in this section. Tables 15, 16, and 17 present the impacts of transporting the handcrafted walls, milled profile wall, and timber frame via truck, train, and shipping freighter.

Table 16: Transportation Sensitivity Analysis for Handcrafted Log Walls

	Units	Baseline Total	1000 km Truck	1000 km Truck % Increase	1000 km Train	1000 km Train % Increase	1000 km Ship	1000 km Ship % Increase
Global warming	kg CO2 eq.	183.35	124.64	68%	29.58	16%	24.88	14%
Acidification	H+ moles eq.	72.01	41.62	58%	29.99	42%	29.20	41%
Respiratory effects	kg PM2.5 eq.	0.21	0.05	26%	0.04	18%	0.03	16%
Eutrophication	kg N eq.	0.05	0.04	85%	0.03	68%	0.03	59%
Smog	kg NOx eq.	0.79	0.85	108%	0.70	88%	0.62	79%
Ozone Depletion	kg CFC 11 eq	6.50E-09	4.72E-09	73%	1.12E-09	17%	9.29E-10	14%
Weighted Resource	kg	2259.99	40.53	2%	9.65	0%	7.98	0%
Total energy	MJ eq	4138.93	1724.46	42%	410.59	10%	339.64	8%
Fossil energy	MJ eq	3739.64	1707.43	46%	406.54	11%	336.28	9%
Nuclear energy	MJ eq	54.14	14.53	27%	3.46	6%	2.86	5%
Renewable energy	MJ eq	345.15	2.50	1%	0.60	0%	0.49	0%

Table 17: Transportation Sensitivity Analysis for Milled Profile Log Walls

	Units	Baseline Total	1000 km Truck	1000 km Truck % Increase	1000 km Train	1000 km Train % Increase	1000 km Ship	1000 km Ship % Increase
Global warming	kg CO2 eq.	218.08	80.39	37%	19.08	9%	16.05	7%
Acidification	H+ moles eq.	75.37	26.84	36%	19.35	26%	18.83	25%
Respiratory effects	kg PM2.5 eq.	0.26	0.04	14%	0.02	9%	0.02	8%
Eutrophication	kg N eq.	0.04	0.03	60%	0.02	48%	0.02	42%
Smog	kg NOx eq.	0.62	0.55	89%	0.45	73%	0.40	65%
Ozone Depletion	kg CFC 11 eq	7.49E-09	3.04E-09	41%	7.25E-10	10%	5.99E-10	8%
Weighted Resource	kg	1120.89	26.14	2%	6.22	1%	5.15	0%
Total energy	MJ eq	5484.40	1112.23	20%	264.82	5%	219.06	4%
Fossil energy	MJ eq	4371.66	1101.25	25%	262.21	6%	216.89	5%
Nuclear energy	MJ eq	61.08	9.37	15%	2.23	4%	1.85	3%
Renewable energy	MJ eq	1051.65	1.61	0%	0.38	0%	0.32	0%

Table 18: Transportation Sensitivity Analysis for Heavy Timbers

	Units	Baseline Total	1000 km Truck	1000 km Truck % Increase	1000 km Train	1000 km Train % Increase	1000 km Ship	1000 km Ship % Increase
Global warming	kg CO2 eq.	123.49	67.56	55%	16.04	13%	13.49	11%
Acidification	H+ moles eq.	31.46	22.56	72%	16.26	52%	15.83	50%
Respiratory effects	kg PM2.5 eq.	0.08	0.03	36%	0.02	25%	0.02	22%
Eutrophication	kg N eq.	0.02	0.02	98%	0.02	78%	0.01	68%
Smog	kg NOx eq.	0.43	0.46	108%	0.38	89%	0.34	79%
Ozone Depletion	kg CFC 11 eq	4.75E-09	2.56E-09	54%	6.09E-10	13%	5.04E-10	11%
Weighted Resource	kg	1051.02	21.97	2%	5.23	0%	4.33	0%
Total energy	MJ eq	2996.37	934.74	31%	222.56	7%	184.10	6%
Fossil energy	MJ eq	2043.75	925.52	45%	220.36	11%	182.28	9%
Nuclear energy	MJ eq	16.62	7.87	47%	1.87	11%	1.55	9%
Renewable energy	MJ eq	936.00	1.35	0%	0.32	0%	0.27	0%

The transportation impacts are significant in terms of the overall life cycle impacts. Transporting the log walls 1000 km by truck increases the global warming impacts between 37% and 68% for the various products. Considering the fact that the Rocky Mountain region of the United States is a significant market for BC log and timber products, this means that shipping a log wall from Vancouver to Denver (2,400 km) via truck more than doubles the global warming impacts of all three products. Similarly, a train shipment across the continent to the east coast (4,500 km) or a trans-atlantic shipment (5,500 km) would increase impacts by greater than 50% and by as much as 100%. It should be noted that these transportation impacts are only calculated in relation to the overall impacts of the rest of the life cycle which are generally quite low and any consideration between alternative materials should similarly include shipping as a portion of the life cycle.

7.2 Kiln Drying of Milled Profile Wall and Timber Frame

The baseline case in the analysis excluded kiln-drying as the industry's standard practice is to use air-dried material – often from standing dead timber. The handcrafted log walls almost exclusively use air-dried material due to the difficulty of kiln drying whole logs, but the milled profile log walls and timbers are often sold as kiln-dried. The sensitivity analysis presented in Table 19 shows the relative impacts of the kiln drying process in relation to the life cycle impacts.

Table 19: Kiln Drying Sensitivity Analysis for Milled Profile Log Walls and Timbers

	Units	Milled Profile Baseline Wall	Kiln Drying	Kiln Drying % Increase		Timber Frame Baseline	Kiln Drying	Kiln Drying % Increase
Global warming	kg CO2 eq.	218.08	15.88	7%		123.49	19.84	16%
Acidification	H+ moles eq.	75.37	9.07	12%		31.46	11.34	36%
Respiratory effects	kg PM2.5 eq.	0.26	0.05	18%		0.08	0.06	72%
Eutrophication	kg N eq.	0.04	0.00	10%		0.02	0.01	24%
Smog	kg NOx eq.	0.62	0.31	50%		0.43	0.39	91%
Ozone Depletion	kg CFC 11 eq	7.49E-09	1.26E-10	2%		4.75E-09	1.58E-10	3%
Weighted Resource	kg	1120.89	334.23	30%		1051.02	417.79	40%
Total energy	MJ eq	5484.40	299.36	5%		2996.37	374.20	12%
Fossil energy	MJ eq	4371.66	4.29	0%		2043.75	5.37	0%
Nuclear energy	MJ eq	61.08	30.58	50%		16.62	38.22	230%
Renewable energy	MJ eq	1051.65	0.00	0%		936.00	0.00	0%

The kiln drying process modestly increases the impacts of the milled log walls and timber products. Additional smog and weighted resource use are caused by the use of wood fuel in the drying process that causes additional nitrogen oxide emissions and wood resource consumption.

7.3 Staining Frequency

The baseline scenario assumed staining every 6 years whereas a fastidious log home owner may choose to stain more often than this. Doubling this frequency to once every 3 years causes the increased impacts presented in Table 20.

Table 20: Staining Sensitivity for Handcrafted and Milled Profile Log Walls

	Units	Handcraft Baseline Wall	Additional Stain	Additional Stain % Increase		Milled Profile Baseline Wall	Additional Stain	Additional Stain % Increase
Global warming	kg CO2 eq.	183.35	40.67	22%		218.08	40.67	19%
Acidification	H+ moles eq.	72.01	29.75	41%		75.37	29.75	39%
Respiratory effects	kg PM2.5 eq.	0.21	0.13	61%		0.26	0.13	49%
Eutrophication	kg N eq.	0.05	0.01	11%		0.04	0.01	13%
Smog	kg NOx eq.	0.79	0.08	10%		0.62	0.08	12%
Ozone Depletion	kg CFC 11 eq	6.50E-09	1.12E-09	17%		7.49E-09	1.12E-09	15%
Weighted Resource	kg	2259.99	90.14	4%		1120.89	90.14	8%
Total energy	MJ eq	4138.93	1518.70	37%		5484.40	1518.70	28%
Fossil energy	MJ eq	3739.64	1483.96	40%		4371.66	1483.96	34%
Nuclear energy	MJ eq	54.14	31.19	58%		61.08	31.19	51%
Renewable energy	MJ eq	345.15	3.55	1%		1051.65	3.55	0%

The increased stain frequency doubles the contribution of this portion of the life cycle, adding roughly 20% in additional global warming impacts. This is noteworthy for portions of the log home and construction sites that are subject to above-average weathering conditions. It may similarly be concluded that a less maintenance-conscious home owner, and one in a less demanding climate, may stain less than once every 6 years and with less than 3 coats each time and subsequently reduce impacts (although potentially causing greater replacement and repair frequency).

8. Interpretation and Conclusions

8.1 Conclusions

The impacts of the three products are generally driven by the manufacturing portion of the life cycle. The stain is also a significant driver of impacts, accounting for roughly 20% of global warming impacts in the two log wall life cycles. The logging, construction, steel and gasket use, and end of life processing are less significant in terms of overall impacts.

The sensitivity analysis revealed that the results are highly sensitive to the transportation distance and mode of transportation. Shipping the products via truck to a Rocky Mountain US city such as Denver roughly doubles the global warming impacts, as does shipping the materials via train across the continent or via ship to Asia or Europe. The kiln drying and staining frequency, while significant, were less influential to overall impacts.

The final consideration of this analysis is to compare the carbon sequestration as presented in Chapter 5 with the life cycle impacts presented in Chapter 6. Table 21 shows the net carbon footprint of the three products that includes both the net carbon sequestration as shown in Table 7 and the greenhouse gasses from the rest of the life cycle. This result is also shown graphically in Figure 8.

It is clear that the overall carbon sequestration benefits of the three products far outweigh the greenhouse gas emissions caused by the rest of the life cycle. In the case of the handcrafted log walls that cause very little impacts relative to the mass of the product, the carbon sequestered in the wood is greater than 10 times the greenhouse gas emissions from the rest of the life cycle.

Table 21: Net Carbon Balance for Log and Timber Products

	100 Sq. Ft. Handcrafted Log Wall (kg CO2e)	100 Sq. Ft. Milled Profile Log Wall (kg CO2e)	1000 Board Feet Timbers (kg CO2e)
Life Cycle Greenhouse Gas Emissions	183.35	218.08	123.49
Net Carbon Sequestration	-1956.93	-869.75	-936.39
Net Carbon Balance	-1773.59	-651.66	-812.90

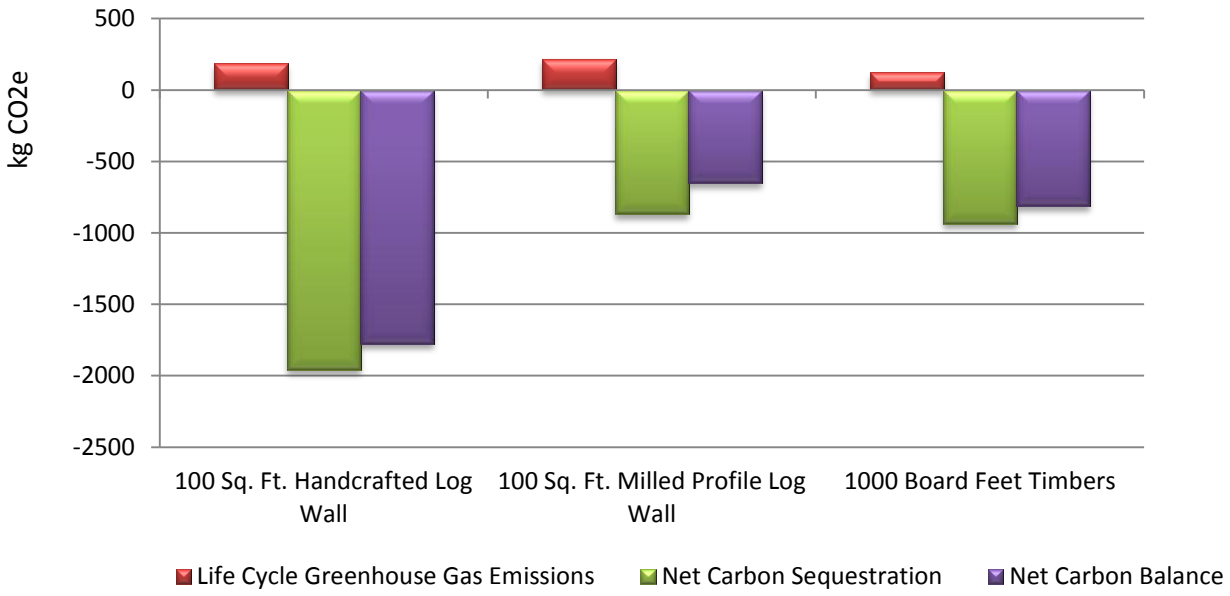

Figure 7: Net Carbon Balance for Log and Timber Products

8.2 Limitations

The sensitivity analysis revealed several areas of uncertainty in the study. First, the construction sites were limited to the BC region and assumed that the materials were transported 200 km to the construction site. To expand the analysis to the rest of the BC log and timber industry's sales regions throughout the world, the mode of transportation would first need to be established and the impacts recalculated. The underlying data to derive these balances are available in the sensitivity analysis which identified this as a major area of sensitivity in the model.

The stain and kiln-drying are also sources of uncertainty in the model. The kiln-drying is less influential to overall impacts, but the stain frequency is a significant source of uncertainty as it is reliant on the tendencies of individual home owners and other burdens that may be site specific and even vary within a building depending on orientation.

8.3 Recommendations

The overall impacts are quite low for all of the products that were assessed in this LCA as the life cycle draws heavily on BC electricity which is generated by low impact hydropower. The carbon balance that includes carbon sequestration also identifies that the log walls have the potential to be well beyond carbon neutral and result in an overall carbon sink. This gives the

BC LTBIA significant leverage to push for the incorporation of life cycle impacts as a justification for alternative compliance or exceptions with regards to thermal performance based standards and building codes. We would recommend that these results be combined with ongoing energy research to gain a full understanding of the sustainability of log and timber building to put both sets of results into perspective.

We would also like to suggest that the industry consider LCA-based declarations of their products, such as an ISO 14025 compliant environmental product declaration. Such a declaration, which is fairly well established in European markets and is increasingly being sought in North America, would firmly put the industry in a position of proactive disclosure – and would allow the industry to emphasize the positive attributes of their products as demonstrated in this LCA.

9. References

1. ISO 14040:2006. Environmental Management – Life Cycle Assessment – Principles and Framework.

2. ISO 14044:2006. Environmental Management – Life Cycle Assessment – Requirements and guidelines.

3. ISO 21930:2007. Sustainability in Building Construction – Environmental Declaration of Building Products.

4. Bare, Jane C, and others. 2003. TRACI- The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts, Journal of Industrial Ecology, Volume 6, Number 3

5. Bare, Jane C (2011) TRACI 2.0: the tool for the reduction and assessment of chemical and other environmental impacts 2.0. Clean Techn. Envion. Policy 13:687-696

6. Frischknecht, R. and N. Jungbluth (editors). 2004 Implementation of Life Cycle Impact Assessment Methods. Ecoinvent Report No. 34. Data V1.1. Dübendorf, Switzerland: Ecoinvent.

7. Leiden University. Guide on Environmental Life Cycle Assessment. Part 2B Operation Annex. 2001. Leiden, Netherlands: Leiden University.

8. Lundie, Sven, Andreas Ciroth, and Gjalt Huppes. 2007. Inventory Methods in LCA: Towards Consistency and Improvement. 135 pages. UNEP-SETAC Life Cycle Initiative, Life Cycle Inventory Program, Task Force 3: Methodological Consistency.

9. Salazar, J. and J. Meil (2009) *Prospects for carbon neutral housing: The influence of greater wood use on the carbon footprint of a single family residence.* Journal of Cleaner Production: 17(17): 1563-1571.

10. U.S. LCI Database. Maintained by National Renewable Energy Laboratory. http://www.nrel.gov/lci/.

Appendix 1: Life Cycle Inventory Secondary Data Sources

Technosphere Input	LCI Data Source
Cedar Roundwood	CIPEC (LCA by Athena/Forintek)data for logs at roadside
Diesel	USLCI data for diesel combusted in equipment; pre-combustion dummy processes corrected
Diesel Crane	USLCI data for diesel combusted in equipment; pre-combustion dummy processes corrected
Diesel Truck Delivery	USLCI data for diesel transport, combination truck, diesel powered; pre-combustion dummy processes corrected
Douglas Fir Roundwood	CIPEC (LCA by Athena/Forintek)data for logs at roadside
Douglas Fir Lumber	CIPEC (LCA by Athena/Forintek)data for rough cut green lumber; includes logging
Electricity	Athena data for % electricity source and line loss, USLCI data for combustion processes
Gasoline	USLCI data for gasoline combusted in equipment; pre-combustion dummy processes corrected
Hydraulic Fluid	USLCI data for gasoline production; pre-combustion dummy processes corrected
LDPE Gasket	USLCI data for low density polyethylene resin
Lubricants	USLCI data for gasoline production; pre-combustion dummy processes corrected
Natural gas	USLCI data for natural gas combusted in boiler; pre-combustion dummy processes corrected
Pine Roundwood	CIPEC (LCA by Athena/Forintek)data for logs at roadside
Propane	USLCI data for propane combusted in equipment; pre-combustion dummy processes corrected
Shrinkwrap	USLCI data for low density polyethylene resin
Spruce Roundwood	CIPEC (LCA by Athena/Forintek)data for rough cut green lumber; includes logging
Steel Bolts	Athena data for screws, nuts, bolts; based on World Steel data

Appendix 2: Data Collection Questionnaires

Please provide as much detail as possible for all questions. Units of measure are specified for some materials, but if you have other units that are easier to report, please replace our units and add yours.

We have provided lists of inputs, waste, and emissions as placeholders. Please replace these lists with ones that you maintain in-house. We have also provided emissions reporting templates that you may use or simply insert your existing emissions tables into the Air Emissions and Water Emissions worksheets.

All responses you provide should be for production in the reporting year 2010 or if based on a different year noted by that response.

For production inputs and outputs, we prefer responses that incorporate changes to inventory levels between year beginning and end. Otherwise, these may be reported as amount purchased in that time period and an estimation given as to whether inventory was roughly the same at year beginning and end. The preferred response is to includes changes to inventory in the reported year for both purchased and produced materials based on the following formula:

Quantity Produced = Sold + (Inventory $_{\text{year end}}$ - Inventory $_{\text{year beginning}}$)
Quantity Consumed = Purchased +(Inventory $_{\text{year beginning}}$ - Inventory $_{\text{year end}}$)

Add comments or clarifications directly on the questionnaire if needed.

Thank you for your valuable time and careful effort to fill in all the blanks.

Please contact James Salazar (phone: 250.306.0638, email: james.salazar@athenasmi.org) at the Athena Institute with any questions.

ATHENA INSTITUTE LCI PROCESS DATA WORKSHEET

General Information

Please complete this worksheet based on 2010 year production

If basis other than 2010 calendar year production, describe here:

PARTICIPANT INFORMATION

Prepared by:		Contact Phone Number:	
Position:		Email:	
Facility Location:		Date Prepared:	

ATHENA: Optional Section

DATA COLLECTION METHOD

Please check the boxes for the data collection methods used to fill out this survey.

	Material In	Energy In	Product Out	Waste Out	Emissions
Inventory Records					
Accounting Records					
Equipment spec's					
Engineering estimates					
Other (describe)					

TOTAL PRODUCTION

	Amount	Units
Log Wall System:		Sq. Ft Walls (avg. Thickness)
Heavy Timbers		mbfm
Milled Log Wall System:		Sq. Ft Walls (avg. thickness)
Other Products (Estimated by Category):		
Other Products (Estimated by Category):		
Other Products (Estimated by Category):		
Other Products (Estimated by Category):		
Other Products (Estimated by Category):		
Other Products (Estimated by Category):		

Add Rows if Necessary

ATHENA: Units to with those used in keeping - these un need to get with t

ATHENA INSTITUTE LCI PROCESS DATA WORKSHEET

Handcrafted Log Wall Manufacture

PRODUCT INFORMATION

Average Log Wall Thickness:		log diameter (inches)
Total Log Wall Production in 2010		sqft wall

ATHENA: This section to be revised entirely if records not available on wall area basis

PRIMARY PRODUCT OUTPUT IN 2010

	Amount	Units	Log Diameter	Species
Log Wall Type 1				
Log Wall Type 2				
Log Wall Type 3				
Log Wall Type 4				
Log Wall Type 5				
Other				
Other				
Other				
Other				
Other				

Add Rows if Necessary

ATHENA: Only provide data for log wall portion of porduction in this section

PRIMARY MATERIAL INPUTS IN 2010

	Amount	Units	Species	Distance to Supplier (miles)	Mode of Transport		
					% Road	% Rail	% Ship
Raw Unpeeled Log (Species 1)							
Raw Unpeeled Log (Species 2)							
Raw Unpeeled Log (Species 3)							
Raw Unpeeled Log (Species 4)							
Raw Unpeeled Log (Species 5)							
Other							
Other							
Other							
Other							
Other							

Add Rows if Necessary

LOG WALL SPECIFIC WASTE IN 2010

ATHENA: To be given as % of inputs if total waste not tracked

	Amount	Units	% of Inputs (if known)	Disposal Method		
				Municipal Waste	Recycle	Other Treatment
Bark		kg				
Shavings						
Chips						
Sawdust						
Other						
Other						
Other						
Other						

Add Rows if Necessary

ATHENA INSTITUTE LCI PROCESS DATA WORKSHEET

Handcrafted Log Wall Manufacture

PRODUCT INFORMATION

Average Log Wall Thickness:		log diameter (inches)
Total Log Wall Production in 2010		sqft wall

PRIMARY PRODUCT OUTPUT IN 2010

	Amount	Units	Wall Thickness	Flat or Rounded
Log Wall Type 1				
Log Wall Type 2				
Log Wall Type 3				
Log Wall Type 4				
Log Wall Type 5				
Other				
Other				
Other				
Other				
Other				

Add Rows if Necessary

PRIMARY M

ATHENA: Only provide data for log wall portion of production in this section

ATHENA: Please feel free to change these if glulam, roundwood, or other inputs are used

	Amount	Units	Dimensions	Moisture Content	Species	Distance to Supplier (miles)	Mode of Transport % Road	% Rail	% Ship
Timber Input 1									
Timber Input 2									
Timber Input 3									
Timber Input 4									
Timber Input 5									
Other									
Other									
Other									
Other									
Other									

Add Rows if Necessary

LOG WALL SPECIFIC WASTE IN 2010

	Amount	Units	% of Inputs (if known)	Disposal Method: Municipal Waste	Recycle	Other Treatment
Bark						
Shavings						
Chips						
Sawdust						
Other						
Other						
Other						
Other						

Add Rows if Necessary

ATHENA INSTITUTE LCI PROCESS DATA WORKSHEET

Heavy Timber Manufacture

PRODUCT INFORMATION

Total Timber Production in 2010: _____ mbfm

PRIMARY PRODUCT OUTPUT IN 2010

	Amount	Units	Dimensions	Species
Timber Product 1				
Timber Product 2				
Timber Product 3				
Timber Product 4				
Timber Product 5				
Other				
Other				
Other				
Other				
Other				

Add Rows if Necessary

PRIMARY MATERIAL INPUTS IN 2010

ATHENA: Only provide data for heavy timber portion of production in this section

ATHENA: Please change these inputs to reflect what you purchase - i.e. rough or planed timbers, glulam, etc. Please provide dimensions of inputs

	Amount	Units	Species	Distance to Supplier (miles)	Mode of Transport % Road	% Rail	% Ship
Raw Unpeeled Log (Species 1)							
Raw Unpeeled Log (Species 2)							
Raw Unpeeled Log (Species 3)							
Raw Unpeeled Log (Species 4)							
Raw Unpeeled Log (Species 5)							
Other							
Other							
Other							
Other							
Other							

Add Rows if Necessary

HEAVY TIMBER SPECIFIC WASTE IN 2010

	Amount	Units	% of Inputs (if known)	Disposal Method: Municipal Waste	Recycle	Other Treatment
Bark		kg				
Shavings						
Chips						
Sawdust						
Other						
Other						
Other						
Other						

Add Rows if Necessary

ATHENA INSTITUTE LCI PROCESS DATA WORKSHEET

Facility Energy Use

ATHENA: In this section please make your best estimate as to the portion of energy used to manufacture the different products

FACILITY ENERGY INPUTS IN 2010

	Amount	Units	Energy Use by Product: % Milled Wall Production	% Heavy Timber Production	% Handcrafted Wall Production	% Other
Purchased Elect.		kWh				
Natural gas		m3				
Diesel fuel		liters				
Gasoline		liters				
Propane		liters				
Other (specify)						
Other (specify)						
Other (specify)						

Add Rows if Necessary

ATHENA INSTITUTE LCI PROCESS DATA WORKSHEET

Facility Anciliary Materials

ANCILIARY MATERIAL "INPUTS" IN 2010

	Amount	Units	Distance to Supplier (miles)	Material Use by Product: % Milled Wall Production	% Heavy Timber Production	% Handcrafted Wall Production	% Other
Hydraulic fluid		liters					
Lubricants		liters					
Antifreeze		liters					
Shrink wrap		kg					
Pallets (not reused)		#					
Cardboard		kg					
Other							
Other							

Add Rows if Necessary

ANCILIARY MATERIAL "WASTE" IN 2010

	Amount	Units	% of Inputs (if known)	Disposal Method: Municipal Waste	Recycle	Other Treatment
Hydraulic fluid		liters				
Lubricants		liters				
Antifreeze		liters				
Shrink wrap		kg				
Pallets (not reused)		#				
Cardboard		kg				
Other						
Other						

Add Rows if Necessary