Athena Sustainable Materials Institute

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The Lafarge Innovation Hub Edmonton, AB

An Environmental Building Declaration According to EN 15978 Standard

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1.0 General Information on the Assessment

This report presents an evaluation of the environmental performance of the *Lafarge Innovation Hub* (aka "the Hub"). The building has been evaluated in accordance with the requirements of the Committee for European Standardization (CEN) EN 15978[1] standard, which specifies a life cycle assessment (LCA) based calculation and reporting method for whole-buildings[2].

1.1 Purpose of the Assessment

This study was commissioned for the following purposes:

1. **To publicly declare the environmental performance of the Hub.**
   This report presents an estimate of the environmental performance of the Hub according to a standardized format in order to publicly communicate results in a transparent and comparable manner.

2. **To demonstrate an application for the Canadian Precast Prestressed Concrete Institute's (CPCI) *Sustainable Plant Program*[3] initiative.**
   This study uses plant-specific precast concrete LCI data developed with information compiled via the Sustainable Plant Program, in order to demonstrate how information gathered as part of the Program can be used for informing whole-building performance.

3. **Provide a real-world benchmark building for future analysis.**
   The Hub is composed primarily of ready-mix and precast concrete products. This structure therefore provides the study commissioner a suitable benchmark for future studies investigating how their products perform at the whole-building scale.

This report will be used for marketing and educational purposes. The intended audience of the study is primarily employees and clients of Lafarge Canada Inc., and otherwise industry stakeholders such as building design professionals, product manufacturers, and academics interested in whole-building LCA.

1.2 Identification of the Building

The Hub is a research and development facility for Lafarge West Canada construction products that was completed in April 2014. It is located within a complex that includes an existing batch plant and shop, at 22121 - 112 Avenue, in Edmonton, Alberta.

[1] EN 15978:2011 Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method

[2] While European in scope, many EN 15978 provisions (particularly those related to assessment system boundary) are quickly becoming the standardized manner in which whole-building LCA work is conducted worldwide. For this study, a North American interpretation of EN 15978 was deemed to be a suitable methodological choice to meet the study commissioner's requirement that the assessment be representative of current best-practice.

[3] The CPCI recently launched an initiative called the *Sustainable Plant Program*, which provides member plants tools to measure and improve the environmental performance of their facilities.

1.3 Other Assessment Information

Table 1 provides a summary of some pertinent assessment information.

Table 1: Assessment Information Summary

Client for assessment	Lafarge Canada Inc.
Assessor	Matt Bowick (M.A.Sc.), Senior Research Associate, Athena Sustainable Materials Institute
Assessment method	TRACI v2.1, Cumulative Energy Demand (CED)
Assessment timing	End of construction phase
Period of validity	5 years
Date of assessment	May 2014
Internal Verifier	Jamie Meil (M.Sc.), Managing Director at the Athena Sustainable Materials Institute

Statement regarding verification of this assessment:
The verifier has determined that this LCA study meets the requirements for methodology, data, and reporting in EN 15978, and is consistent with its principles.

2.0 General Information on the Object of Assessment

2.1 Functional Equivalent

EN 15978 defines a functional equivalent as "the quantified functional requirements and/or technical requirements for a building or an assembled system (part of works) for use as a basis for comparison". The functional equivalent of the Hub includes the characteristics noted in Table 2.

Table 2: Functional Equivalent

Building type	low-rise, owner-occupied laboratory
Technical and functional requirements	2006 Alberta Building Code and 1997 Model National Energy Code for Buildings
Pattern of use	research and development for 10 occupants
Required service life	75 years

2.2 Reference Study Period

The reference study period of the assessment is the same as the required service life of 75 years.

2.3 Object of Assessment Scope

The object of assessment is the Hub and only includes elements contained within the building footprint. Exterior features such as paving and landscaping are not included. The scope of building materials assessed includes envelope and structural elements, as well as interior partitions and screen glass. This scope is equivalent to Major Group Elements A1 SUBSTRUCTURE, A2 STRUCTURE, A3 EXTERIOR ENCLOSURE, B1 PARTITIONS, as defined by the Canadian Institute of Quantity Surveyors (CIQS) Elemental Format. Other building elements were not included in assessment scope due to resource constraints and/or data limitations. This assessment considers paint on gypsum board wall assemblies to be a finish and therefore it is not included in analysis.

Building operating energy and water use are not included in the assessment as there was no estimation of these aspects during the building design phase. It is anticipated that one year of operation will be measured on-site and this report be updated to include these aspects once available.

2.4 Building Description

The Hub houses a laboratory on the ground floor which is slated for use by Lafarge and other members of the construction community, including post-secondary students, associations, and local project teams.

The building (see Figure 1) has a 48.8mx18.3m rectilinear footprint in an east-west orientation, with 1470 m^2 of gross floor area on two above grade storeys (no below grade levels), and a window-to-wall ratio of approximately 0.13. Approximately 45% of the ground floor is double height space.

The roof and upper floor structures are composed of hollow-core panels that generally span from the load bearing precast concrete perimeter walls to a system of interior precast concrete beams and columns. The building's all-precast above grade structure with long spans facilitates future repurposing and disassembly. The foundation is a system of cast-in-place grade beams and pile caps supported by cast-in-place concrete piles, and interior partitions are a mix of concrete block, light gauge steel stud, and screen glass assemblies.

The Hub's precast insulated sandwich wall panels limit heat loss via thermal bridging; when combined with ground floor radiant in-floor heating, a south-facing design, and an intelligent building management system, the building delivers strong energy performance.

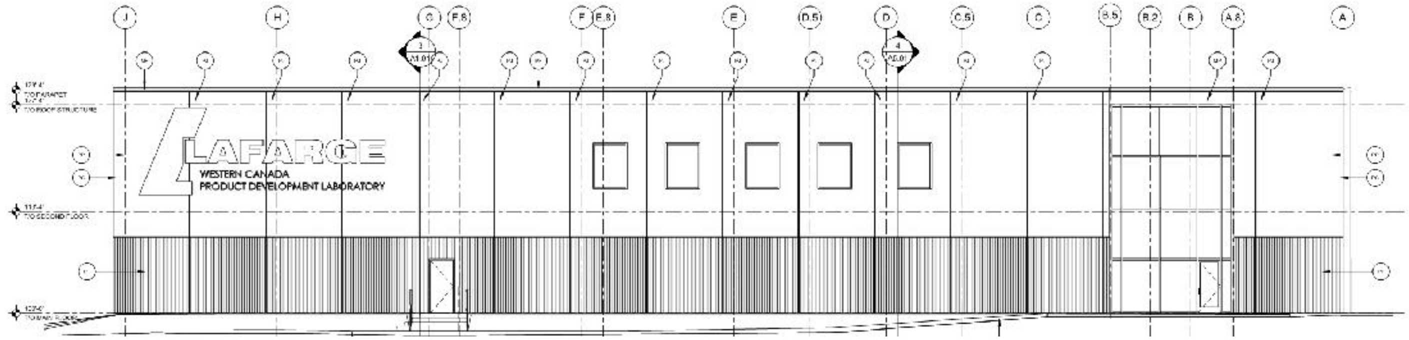
The Hub was built on a current Lafarge industrial site requiring no further development of the area. Industrial and rain water are managed across the site via a reclamation system.

See Table 3 for a more detailed description of the assemblies that make up the building and Appendix A for the resulting bill of materials calculated for the assessment.

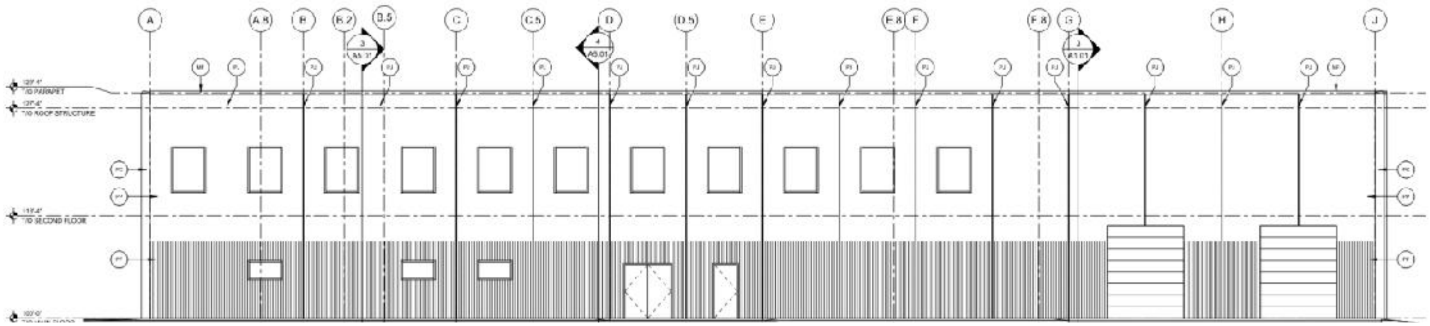
Table 3: Construction Assembly Summary

CIQS Element		Description
A1 SUBSTRUCTURE	A11 Foundations	• 305x 510, 305x610, 305x915 CC grade beams • 760x915 CC pile caps • 610ϕ CC piles
	A12 Basement Excavation	• not include in scope
A2 STRUCTURE	A21 Lowest Floor Construction	• 200 CC slab on grade with vapor retarder • areas with in-floor heating have 75 extruded polystyrene
	A22 Upper Floor Construction	▪ 200 PC hollow-core panels ▪ 355x760 PC beams ▪ 355x355 PC columns ▪ PC stairs ▪ some hollow structural steel framing
	A23 Roof Construction	▪ 200, 250 PC hollow-core panels ▪ 355x760 PC beams ▪ 355x355 PC columns ▪ some HSS framing ▪ metal deck at main entrance
A3 EXTERIOR ENCLOSURE	A31 Walls Below Grade	▪ none
	A32 Walls Above Grade	▪ 305 insulated PC wall panel with 100 extruded polystyrene insulation ▪ double glazed curtain wall at main entrance
	A33 Windows & Entrances	▪ double glazed, aluminum frame windows ▪ steel doors
	A34 Roof Covering	▪ modified bitumen roof membrane, 25 protection board, 100 polyisocyanurate insulation + sloped insulation, air/vapor retarder
	A35 Projections	▪ PC wall panel parapet ▪ 90 steel stud @400c/c parapet with aluminum composite panel cladding at main entrance
B1 PARTITIONS & DOORS	B11 Partitions	Mix of: ▪ 200, 150 reinforced concrete block ▪ 90, 150 light gauge steel stud @400c/c, gypsum board ▪ wire glass, steel frame interior glazing ▪ tempered glass, aluminum frame interior glazing
	B12 Doors	▪ steel doors ▪ aluminum glazed doors

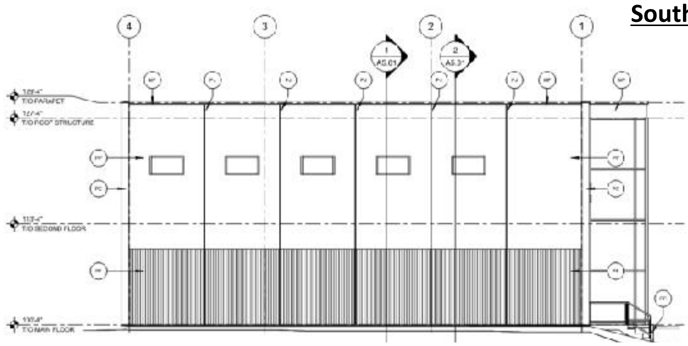
Table Notes:
All dimensions are millimeters
CC = reinforced cast-in-place concrete
PC = reinforced precast concrete



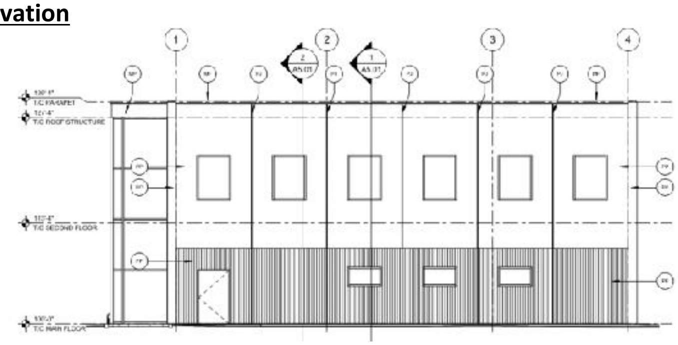
North Elevation



South Elevation



East Elevation



West Elevation

Figure 1: The Hub Building Elevations

3.0 Statement of Boundaries and Scenarios Used

3.1 System Boundary

EN 15978 defines the system boundary of a building life cycle according to the format shown in Figure 2, which provides a consistent and transparent reporting format for building assessments and is consistent with the structure of environmental product declarations (EPDs) produced in conformance with the standard EN 15804:2012[4].

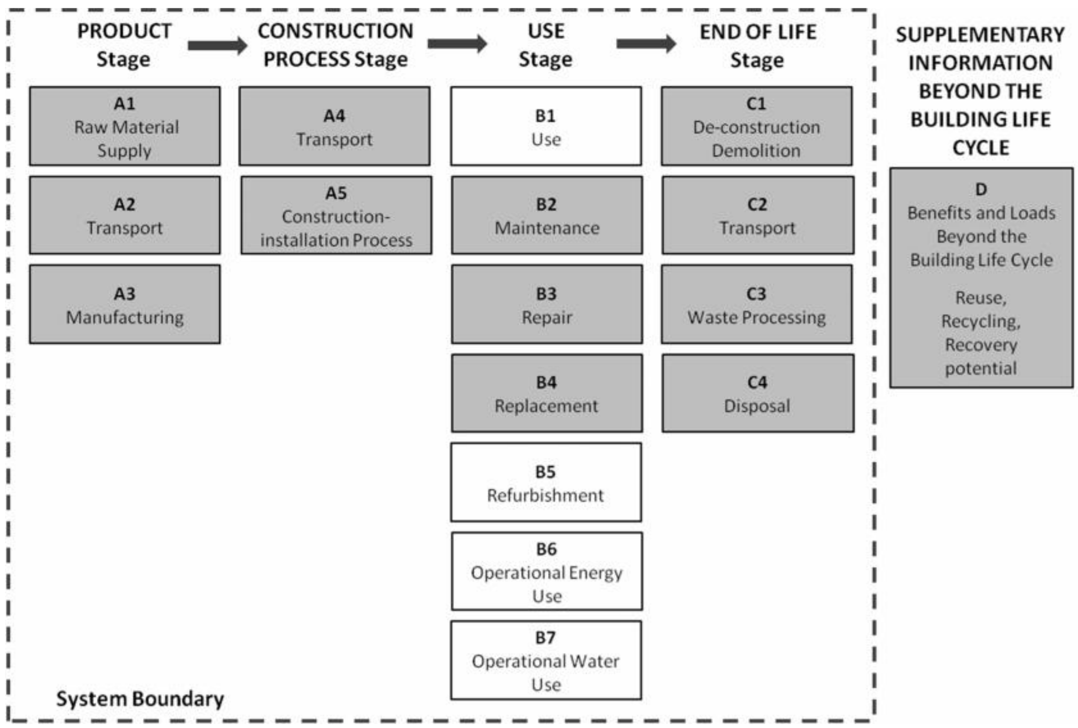


Figure 2: EN 15978 Building LCA Life Cycle Stages and Modules (study scope shown grey)

The system boundary according to EN 15978 is structured by the temporal flow of the building life cycle, i.e. *Product*, *Construction Process*, *Use*, and *End of Life* stages. Each stage is comprised of *information modules*[5] labeled with alpha-numeric designations "A1" through "C4".

Accounting for the life cycle of a building is complete when all its constituent materials are either disposed of via landfill or incineration, or reach a state where they are no longer considered waste (e.g. a steel framing member ready for reuse). This allocation methodology is also known as the *Polluter Pays* principle. The benefit potential of materials and energy leaving the system boundary is optionally accounted in module "D".
Table 4 is a summary of which information modules are included in the assessment, along with a brief description of the activities included in the assessment. The modules included in scope are additionally shown infilled grey in Figure 2.

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[4] EN 15804:2012 Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products

[5] *Information modules* are groups of processes that are similar in nature, e.g. material transport

Table 4: Assessment System Boundary and Scope Summary

Information Module	Name	Included?	Processes Included
A1	Raw material supply	Y	primary resource harvesting and mining
A2	Transport	Y	all transportation up to manufacturing plant gate
A3	Manufacturing	Y	manufacture of raw materials into products
A4	Transport	Y	transportation of materials and construction equipment to site
A5	Construction-installation process	Y	construction equipment energy use, and production, transportation and waste management of material lost during construction
B1	Installed product in use	N	n/a
B2	Maintenance	Y	all product, construction process, and end of life related activities related to maintaining building components during use
B3	Repair	Y	all product, construction process, and end of life related activities related to repairing building components during use
B4	Replacement	Y	all product, construction process, and end of life related activities related to replacing building components during use
B5	Refurbishment	N	n/a
B6	Operational energy use	N	n/a
B7	Operational water use	N	n/a
C1	De-construction demolition	Y	demolition equipment energy use
C2	Transport	Y	transportation of recovered materials from site to waste processing plant and waste to disposal facility
C3	Waste Processing	Y	waste sorting facility
C4	Disposal	Y	disposal facility equipment energy use and site effects
D	Benefits and loads beyond the system boundary	Y	avoided emissions due to recovered materials used in lieu of conventional sources

Four of the modules were not assessed for the following reasons:

- **B1:** there is currently insufficient consensus in terms of methodology and data to practically quantify these effects for all products used in the building.
- **B6, B7:** there was no operating energy and water estimation of operating energy and water consumption during the design phase of the building, and such estimates are beyond the scope of the study work.
- **B5:** there is no planned refurbishment for the building at this time and no available scenario information on typical refurbishment activities for this type of building.

3.2 Scenarios for Defining the Building Life Cycle

Due to the fact that not all information is practically available to the assessor and buildings have long and uncertain services lives, scenarios (i.e. assumptions) are required to provide a complete description of the building. For the purpose of this assessment, a scenario is defined as information generally required to calculate inputs for the process-based environmental data used. For example, transportation distances for materials are required to calculate the tonne*km input for transportation life cycle inventory data (LCI) used in the assessment.

This section describes the scenarios assumed that are relevant to the object of assessment and its system boundary, and are based on current practice.

3.2.1 Construction Process Stage

The assumed plant-to-site materials transportation scenarios are presented in Table 5. Ready-mix concrete was supplied by the Lafarge mixing plant located on-site and therefore its transportation distance was assumed to be zero. Precast concrete products were supplied by the Lafarge precast plant located in Edmonton and shipped to site by truck. All other materials transportation information noted in Table 5 are estimates from the *Athena Transportation Database* for the Calgary location.

On-site construction waste due to cut-offs, or unused, lost, or damaged materials require greater quantities of materials to be purchased than what is specifically required in the final building. The assessment accounts for these additional quantities by multiplying materials required by the building at initial construction, and during maintenance, repair and replacement, by *Construction Waste Factors*. The assumed scenarios shown in Table 5 are estimates from the *Athena Construction Waste Factor Database*.

The assumed energy and water use required on-site for construction (module A5, Construction-installation Process) are presented in Table 6. These estimates were provided by the project Contractor.

3.2.2 Use Stage

The required service life of the building is 75 years as per the building owner.

Maintenance, repair and replacement activities (information modules B2, B3, B4, respectively) typically involve periodic tasks (i.e. material replacements) to ensure the continued functional performance of the building. This assessment calculates the number of times a task occurs over the lifetime of the building according to equation (1), which is the methodology used by the Athena *Impact Estimator for Buildings* (IE4B) software.

$$N_x = (S - F_x) / F_x \quad (1)$$

where,

N_x	is the number of times task x occurs
S	is the building service life (years)
F_x	is the task frequency for task x (years)

This methodology typically results in only a percentage of the final task being allotted to the building. For example, if the service life of a building is 65 years and the replacement frequency of a window unit is 15 years, only 33% of the window replacement occurring at year 60 (5 years/15 years) is allotted to the building.

Table 5: Construction Process Stage Scenarios

Material	Distance Transported to Site (km) (module A4)				Construction Waste Factor (module A5)
	Rail, diesel	Road, diesel	Barge, diesel/ residual fuel oil	Ocean, diesel/ residual fuel oil	
1/2" Moisture Resistant Gypsum Board	300	265	0	0	1.1
5/8" Regular Gypsum Board	300	265	0	0	1.1
6 mil Polyethylene	0	3585	0	0	1.02
Aluminum	0	810	0	0	1.00
Ballast (aggregate stone)	0	60	0	0	1.05
Cold Rolled Sheet	3088	60	0	0	1.01
Concrete 20 MPa (fly ash avg)	0	0	0	0	1.05
Concrete 30 MPa (fly ash avg)	0	0	0	0	1.05
Concrete Blocks	0	60	0	0	1.05
Double Glazed Soft Coated Argon	0	500	0	0	1.00
EPDM membrane (black, 60 mil)	0	3610	0	0	1.03
Expanded Polystyrene	0	100	0	0	1.05
Extruded Polystyrene	0	391	0	0	1.05
Galvanized Decking	3088	60	0	0	1.01
Galvanized Sheet	3088	60	0	0	1.01
Galvanized Studs	3088	60	0	0	1.01
Glass Fibre	0	359	0	0	1.05
Glazing Panel	0	500	0	0	1.00
Hollow Structural Steel	3088	60	0	0	1.01
Joint Compound	300	274	0	0	1.07
Modified Bitumen membrane	0	960	0	0	1.03
Mortar	0	60	0	0	1.15
MW Batt R20	0	746	0	0	1.05
Nails	0	60	0	0	1.03
Paper Tape	300	274	0	0	1.05
Polyiso Foam Board (unfaced)	0	2440	0	0	1.05
Polypropylene Scrim Kraft Vapour Retarder Cloth	0	3585	0	0	1.02
Precast Concrete	0	26	0	0	1.00
Rebar, Rod, Light Sections	0	60	0	0	1.01
Screws Nuts & Bolts	0	60	0	0	1.03
Softwood Plywood	1148	60	0	0	1.05
Solvent Based Alkyd Paint	0	950	0	0	1.02
Welded Wire Mesh / Ladder Wire	3088	60	0	0	1.02
Wide Flange Sections	3088	60	0	0	1.01

Table 6: Construction-installation Process Resource Use Estimates

Resource Use (module A5)	Quantity
Grid electricity	1,000 kWh
Diesel	8,500 L
Propane	82,900 L
Natural gas	75 m^3
Water	20 m^3

Equation (1) deviates from the methodology outlined in EN 15978. The standard requires that [1] only whole replacements to be considered and [2] if the remaining service life of the building is short in proportion to the estimated service of a product, the actual likelihood of the task shall take into account the required technical and functional performance for the product. In other words, the assessor may have to make value judgments as to whether the final task occurs. It is the opinion of the Institute that this causes inconsistency between assessments.

Equation (2) was used to calculate the total material quantities being replaced over the building lifetime:

$$Q_{x,y} = N_x \; M_y \, P_{x,y} \qquad (2)$$

where,

$Q_{x,y}$	is the total quantity of material y replaced due to task x
N_x	is the number of times task x occurs
M_y	is the total quantity of material y in the assembly
$P_{x,y}$	is the percent of M_y replaced due to task x

Table 7 summarizes the Repair and Replacement module scenarios assumed. It was determined that no appreciable material replacement occurs due to maintenance activities. Therefore, there are no scenarios for module B2 Maintenance and its effects are assumed to be zero.

The reporting format and calculation methodology of the sourced task frequencies (F_x) and material use %'s ($P_{x,y}$) are not compliant with ISO standards 15686-1[6] and 15686-8[7], as required by EN 15978. Nevertheless, it is the opinion of the Institute that until service life planning is a more established practice in North America, the sources from which the scenarios were developed are of sufficient quality for this building assessment.

3.2.3 End of Life Stage

EN 15978 stipulates that the environmental burdens of a particular material are no longer attributed to the building once it has reached a state where it is no longer considered waste. This assessment assumes that once the material is either [1] separated for recycling, reuse, or energy recovery purposes or [2] disposed of (i.e. either via landfilled or incinerated), it has reached its end-of-waste state.

For the purpose of this assessment it is assumed that:

- 98% of structural steel, 70% of reinforcing steel, 95% of aluminum and 100% of concrete products are sorted on-site to be recycled; the building is not allotted any additional burdens (modules C2, C3, or C4) for these waste fractions. The concrete that is crushed on-site is assumed to be used as aggregate at the ready-mix concrete plant located on-site.
- The remaining waste fractions are transported 29 km to the *Edmonton Waste Management Centre* (module C2), and processed (i.e. sorted) at its *Construction and Demolition Recycling Facility* (module C3). After the materials have been sorted:
    - 100% of roof membrane and insulation materials are disposed of at the facility landfill (module C4);
    - 60% of other materials are recovered for recycling and the building is not allotted any additional burdens (module C4) for these waste fractions. The remaining 40% of materials are disposed of at the facility landfill (module C4).

The on-site material recycling rates are estimates taken from the *Athena End of Life Database*, whereas assumptions related to the Edmonton Waste Management Centre come from its website[8].

[6] ISO 15686-1:2011 Buildings and constructed assets - Service life planning - General principles and framework
[7] ISO 15686-8:2008 Buildings and constructed assets - Service life planning - Reference service life and service-life estimation
[8] http://www.edmonton.ca/for_residents/garbage_recycling/edmonton-waste-management-centre.aspx

Table 7: Use Stage Scenarios

Assembly/ Building Element	Replaced Materials	Task Frequency (F_x)	Material Use % ($P_{x,y}$)	Data Source
Repair (module B3)				
Slab on grade	Concrete 20 MPa (flyash av)	15	2	1
	Welded Wire Mesh / Ladder Wire	15	2	1
	Rebar, Rod, Light Sections	15	2	1
	6 mil Polyethylene	15	2	1
	Extruded Polystyrene	15	2	1
Gypsum wallboard	5/8" Fire-Rated Type X Gypsum Board	20	2	1
	Joint Compound	20	2	1
	Paper Tape	20	2	1
Windows	Double Glazed Soft Coated Argon	1	3	2
Curtain wall	EPDM membrane (black, 60 mil)	35	10	2
	Glazing Panel	1	3	2
	Screws Nuts & Bolts	35	10	2
Roof envelope	Galvanized Sheet	1	1.5	2
	Modified Bitumen membrane	1	1.5	2
	1/2" Moisture Resistant Gypsum Board	1	1.5	2
	Glass Fibre	1	1.5	2
	Polyiso Foam Board (unfaced)	1	1.5	2
	Polypropylene Scrim Kraft Vapour Retarder Cloth	1	1.5	2
Replacement (module B4)				
Windows	Aluminum	35	100	2
	Double Glazed Soft Coated Argon	35	100	2
	EPDM membrane (black, 60 mil)	35	100	2
	Nails	35	100	2
Roof envelope	Galvanized Sheet	15	100	2
	Modified Bitumen membrane	15	100	2
	1/2" Moisture Resistant Gypsum Board	15	100	2
	Glass Fibre	15	100	2
	Polyiso Foam Board (unfaced)	15	80	2
	Polypropylene Scrim Kraft Vapour Retarder Cloth	15	100	2
ACM panel	Aluminum	60	100	1
	6 mil Polyethylene	60	100	1

Data Sources
1 - Whitestone Research's *Maintenance and Repair Cost Database*
2- ASMI report *Maintenance, Repair, and Replacement Effects for Building Envelope Materials*

3.2.4 Benefits Beyond the System Boundary

Module D quantifies the future potential net benefit or load of materials and energy sources recovered from the building and exiting the system boundary. These output flows are assumed to substitute materials or energy production from existing technologies and/or current practice.

This assessment estimates the potential benefits and/or loads from the fraction of concrete and steel products that are recovered for recycling, which account for 88% of the building's life cycle material use on a mass basis.

According to EN 15804/15978 standards, a material leaves the system boundary of a building product or constructed work when it has been disposed of, or otherwise reached an "end-of-waste" state. The analyses included in this assessment assume that materials substituting primary products or energy in another life cycle reach an end-of-waste state once they have been deconstructed and separated on-site.

Module D substitution effects were calculated according to Equation (3):

$$LCI_D = NF * PY * (lci_1 - lci_2) \quad (3)$$

where,

LCI_D	is the module D substitution effects LCI of the secondary material/fuel
NF	is the net output flow of the secondary material/fuel
PY	is the process yield of the recycling, reuse, or energy recovery process (e.g. >1kg scrap is required to produce 1kg steel)
lci_1	is the unit process LCI (e.g. per-kg-product) for producing the material/ energy that is substituted
lci_2	is the unit process LCI for producing the materials/energy from secondary sources which substitutes primary production

The net output flow (NF) is the difference between the recovered secondary material/fuel leaving the product system and the secondary material/fuel that was used by the system, for all information modules included in the life cycle of the object of assessment. It represents the net amount of secondary material/fuel made added to or removed from, the technosphere. The assumed net output flows presented in Table 8 were calculated with recycled content and recovery rate information from Athena databases.

Table 8: Module D Scenarios (kg secondary material per kg product used)

Flow Type	Steel Products					Concrete Products
	Structural Steel	Rebar	Sheet	Screws etc.	Nails	
Recycled Content	0.838	1	0.439	1	1	0
Effective Recovery Rate	0.992	0.88	0.992	0.88	0.6	1
Net Output Flow[1]	0.154	-0.12	0.553	-0.12	-0.4	1

[1] a negative value indicates that the system is a net consumer of secondary material/fuel

PY (lci1 - lci2) is the net value of producing materials/energy via secondary vs. primary production, per unit net output flow. This assessment assumes the following:

- **Recycled steel** materials substitute for primary metal production. PY (lci1 - lci2) is therefore the difference between primary and secondary metals production (i.e. the "scrap value").
- **Recycled concrete** materials are crushed on-site and substitute for aggregate. PY (lci1 - lci2) is therefore the difference between the effects primary aggregate production (i.e. quarrying, crushing, transporting) and crushing of concrete.

4.0 Environmental Data

4.1 Data Sources

Whole-building LCA typically draws on environmental product declaration (EPD) and/or life cycle inventory (LCI) environmental data sources. The assessment does not draw on EPDs as a source of data since [1] currently few building product EPDs exist in North America, [2] there is a general lack of consistency between EPDs of different product categories.

For these reasons, the assessment draws exclusively on three LCI data sources:

- the Athena LCI Database (http://www.athenasmi.org/our-software-data/lca-databases/)
- the US LCI Database (http://www.nrel.gov/lci/)
- the Ecoinvent LCI Database (http://www.ecoinvent.ch/)

Table 9 presents a summary of which LCI data sources were used for the various information modules considered in the assessment. In general, the Athena LCI Database is the source for process data; this database in turn draws on the US LCI Database for energy combustion and pre-combustion processes, including those related to electricity generation and transportation. The Ecoinvent LCI Database was used for processes not available in either Athena or US LCI databases, in particular waste processing and landfill effects. Since Ecoinvent data is European in context, the datasets used were adjusted to better reflect a Canadian context, as outlined in Section 4.2. Table 10 summarizes the assumed concrete mix designs, which are generic mixes taken from the Athena LCI database.

Table 9: Data Sources Summary

LCI Data	Information Modules	Source	Time Frame	Geographical Representativeness	Technological Representativeness
Common fossil fuels (including pre-combustion)	All	US LCI Database	2004-2008	Canada	Average
Electricity generation and delivery	All	US LCI Database	2007	Canada and Alberta	Average
Transportation	A2, A4, A5, B2, B3, B4, C2	US LCI Database	2004-2008	Canada	Average
Portland cement	A1, A3	Athena LCI Database (PCA)	2006-2008	Canada and Alberta	Average
Ready-mix concrete plant	A3	Athena LCI Database (PCA)	2006-2008	Canada and Alberta	Average
Precast concrete plant	A3	Athena LCI Database (CPCI)	2011, 2012	Canada, Edmonton plant	Average
Steel products	A1, A3	Athena LCI Database (WSA, AISI)	2011, 2013	North America	Average
Other building products	A1, A3, B2, B3, B4	Athena LCI	2003-2013	Canada and Alberta	Average
Demolition	C1	Athena LCI Database	2003	Canada	Average
Waste sorting facility	C3	Ecoinvent LCI Database	2003	Switzerland, adjusted to Canada and Alberta	Average
Landfill	C4	Ecoinvent LCI Database	2003	Switzerland, adjusted to Canada and Alberta	Average

4.2 Data Adjustments and Substitutions

In order to improve geographic representativeness and data consistency, the following adjustments were made to Ecoinvent LCI Database processes used in the assessment:

- European energy use profiles were substituted with data from the US LCI;
- Material processes were substituted with data from the US LCI, if available;
- Infrastructure effects were removed from the processes in order to remain consistent with current North American LCA practice.

Table 10: Assumed Concrete Mix Designs

Concrete Mix, kg per m³	Precast Concrete - hollow-core	Precast Concrete - wall panel, columns, beams	Ready-mix Concrete - 30 MPa	Ready-mix Concrete - 20 MPa	Concrete Block	Cement Mortar
Portland Cement	326	354	297	204	189	307
Fine Aggregate - natural sand	961	943	722	925	1191	785
Coarse Aggregate - crushed	979	759	1092	1009	510	0
Fly Ash	53	79	53	36	0	0
Chemical Admixtures	0.365	2.966	-	-	-	-
Water	126	166	160	160	53	185
Total	**2446**	**2305**	**2324**	**2334**	**1943**	**1277**

Adjustments were additionally made to the precast plant operations LCI data to better reflect the Lafarge plant (in Edmonton) the Hub sourced precast elements from. To this end, the following adjustments were made to the Athena LCI Database weighted-average precast plant operations profile:

- Operating energy use, wash water, and inbound transportation data was substituted with survey information from the Edmonton plant's 2013 CPCI *Sustainable Plant Tracking Tool* for 2013[9].
- Plant grid electricity was adjusted to be representative of Alberta.

LCI data for some of the building materials was unavailable. In order to include these materials in the scope of assessment, materials from the Athena LCI Database deemed to most closely estimate their environmental profile was substituted. In some cases, the resulting estimates required a combination of more than one LCI profile. Some of the substitutions also required scaling the material takeoff to adjust for differences between the products. For example, the aluminum composite panel (ACM) includes a 2mm polyethylene core that was modeled using 6mil polyethylene sheet (0.15mm). The appropriate amount of 6mil polyethylene sheet to be modeled as a proxy for the core was determined by scaling the area of coverage by a factor of 2mm/0.15mm = 13. Table 11 is a summary of materials that were substituted.

Table 11: LCI Data Substitutions

Material	Athena LCI Database Substitution(s)
Backer rod	6 mil Polyethylene
1" Protection board	1/2" Moisture resistant Gypsum Board, Glass Fibre
ACM panel	Aluminum, 6 mil Polyethylene

4.3 Data Quality

Precision: all LCI data sources used were compiled in accordance with ISO 14040/14044 procedures and requirements. The data adjustments and substitutions noted in Section 4.2 introduce inaccuracies..

Completeness: all relevant, specific processes, including inputs (raw materials, energy, water) and outputs (emissions and production volume) are considered and modeled to represent the object of assessment (the building).

[9] The *Sustainable Plant Tracking Tool*, is an Excel-based survey tool used track a precast plant's product output, use of materials and energy, and water, and transportation of inbound materials.

Consistency: the assessment draws primarily on a single LCI database (Athena LCI) with consistent system boundary and scope. Ecoinvent processes were modified to align with Athena/US LCI Database system boundaries.

Reproducibility: the data used is available in the LCI databases noted; the report specifies the adjustments and substitutions made to data such that they are generally reproducible.

Representativeness:

- Time related coverage **-** validation of data is not older than 10 years, as required by EN 15978.
- Geographical coverage **-** at minimum Canada and representative of the region (Alberta) where the building is located
- Technological coverage - average, reflecting the physical reality of the products found in the building.

5.0 List of Indicators Used

A list of the environmental indicator results required by EN 15978, along with those included in the assessment, is presented in Table 12. Indicators excluded from the assessment were not evaluated because the underlying LCI datasets used do not sufficiently support them. The environmental impacts considered were evaluated according the EPA's TRACI v2.1[10] life cycle impact assessment (LCIA) methodology. TRACI provides a North American context for the supported measures and results in some of the indicator units being different than those required by EN 15978. This has been deemed acceptable for this study since North American adoption of a standard like EN 15978 would presumably be structured on the use of TRACI as LCIA methodology.

Energy resource use was evaluated according to Cumulative Energy Demand (CED) methodology. All other indicators considered were evaluated by summing elementary (e.g. water use) or intermediate LCI flows (e.g. water use) or material usage (e.g. materials for recycling) over the building life cycle.

Please note the following:

- Information modules and environmental indicators not assessed have been denoted with "xx".
- *Net use of fresh water is* a summation of primary fresh water withdrawals, including water consumed and water discharged after withdrawal.
- *Use of secondary material* is a summation of the use of recycled, reused materials in products that make up the building.
- *Non-hazardous waste disposed* is a summation of the final waste flows landfilled.
- *Output Flows Leaving the System* indicators include only flows that are downstream from the building, i.e. they do not include upstream flows leaving the system such as during product manufacturing.

[10] http://www.epa.gov/nrmrl/std/traci/traci.html

Table 12: Reported Environmental Indicators

EN 15978 Environmental Indicator	Methodology	Unit
Environmental Impacts		
Global warming potential	TRACI v2.1	kg CO_2 eq.
Depletion of the stratospheric ozone layer	TRACI v2.1	kg CFC-11 eq.
Acidification potential of land and water	TRACI v2.1	kg SO_2 eq.
Eutrophication potential	TRACI v2.1	kg N eq.
Formation potential of tropospheric ozone photochemical oxidants	TRACI v2.1	kg O_3 eq.
Abiotic resource depletion potential for elements	*not in scope*	
Abiotic resource depletion potential of fossil fuels	TRACI v2.1	MJ surplus
Resource Use		
Renewable primary energy excluding energy resources used as raw material	CED	MJ
Renewable primary energy resources used as raw material	CED	MJ
Non-renewable primary energy excluding resources used as raw material	CED	MJ
Non-renewable primary energy resources used as raw material	CED	MJ
Secondary material	Sum of LCI flows	kg
Renewable secondary fuels	*not in scope*	
Non-renewable secondary fuels	*not in scope*	
Net use of fresh water	Sum of LCI flows	m^3
Waste Categories		
Non-hazardous waste disposed	Sum of LCI flows	kg
Hazardous waste disposed	*not in scope*	
Radioactive waste disposed	*not in scope*	
Output Flows Leaving the System		
Components for re-use	Sum of LCI flows	kg
Materials for recycling	Sum of LCI flows	kg
Materials for energy recovery (not being waste incineration)	Sum of LCI flows	kg
Exported energy	Sum of LCI flows	MJ

6.0 Communication of Assessment Results

6.1 Life Cycle Results

Table 13 presents 75-year life cycle results for the Hub, along with results normalized per-m^2 gross floor area, per-year, and per-m^2-year basis.

6.2 Contribution Analysis

Tables 14 and 15, and Figures 3 and 4 show the contributions of the various information modules to the total life cycle results.

6.3 Sensitivity Analysis

EN 15978 requires that "the significance of the influence of the data chosen for the building assessment shall be determined (e.g. through a sensitivity analysis) and reported". For the most part, the assessment uses data from a single source (Athena LCI Database) which has a high degree of methodological consistency. The most notable choice of data to investigate is precast concrete, since it makes up a significant share of the building's structure and the assessment uses Athena LCI data that has been adjusted using survey information from the product manufacturer.

The following two sensitivity analyses were conducted for precast concrete products:

- **Scenario 1:** in order to investigate the influence and sensitivity of precast operations at the building scale, the Edmonton plant operating energy and wash water were increased by 10%.
- **Scenario 2:** in order to investigate the influence of the assumed concrete mixes at the building scale, the amount of fly ash substituting portland cement in the precast concrete mixes was increased by 10 kg/m3; from a % fly ash of 14.1% to 16.7 % for hollow-core, and 18.2% to 20.5% for wall, beam, and column mixes.

Table 16 presents the percent change of the Hub results to the two scenarios.

Table 13: The Hub Life Cycle Results

Environmental Indicator	Unit	75-year Total	75-year, per-m²	Total, per-year	per-m²-year
TRACI v2.1 Environmental Impacts					
Global warming potential	kg CO_2 eq.	1.15E+06	7.84E+02	1.54E+04	1.05E+01
Depletion potential of the stratospheric ozone layer	kg CFC-11 eq.	4.42E-03	3.01E-06	5.90E-05	4.01E-08
Acidification potential of land and water	kg SO_2 eq.	7.24E+03	4.93E+00	9.65E+01	6.57E-02
Eutrophication potential	kg N eq.	2.80E+02	1.90E-01	3.73E+00	2.54E-03
Formation potential of tropospheric ozone photochemical oxidants	kg O_3 eq.	1.10E+05	7.52E+01	1.47E+03	1.00E+00
Abiotic resource depletion potential for elements	n/a	xx	xx	xx	xx
Abiotic resource depletion potential of fossil fuels	MJ surplus	1.83E+06	1.24E+03	2.44E+04	1.66E+01
Resource Use					
Renewable primary energy excluding energy resources used as raw material	MJ	2.62E+05	1.78E+02	3.49E+03	2.38E+00
Renewable primary energy resources used as raw material	MJ	5.34E+04	3.63E+01	7.12E+02	4.85E-01
Non-renewable primary energy excluding resources used as raw material	MJ	2.07E+07	1.41E+04	2.76E+05	1.88E+02
Non-renewable primary energy resources used as raw material	MJ	1.99E+06	1.35E+03	2.65E+04	1.80E+01
Secondary material	kg	1.28E+05	8.74E+01	1.71E+03	1.17E+00
Renewable secondary fuels	n/a	xx	xx	xx	xx
Non-renewable secondary fuels	n/a	xx	xx	xx	xx
Net use of fresh water	m^3	2.14E+03	1.46E+00	2.86E+01	1.94E-02
Waste Categories					
Non-hazardous waste disposed	kg	3.17E+05	2.16E+02	4.23E+03	2.87E+00
Hazardous waste disposed	n/a	xx	xx	xx	xx
Radioactive waste disposed	n/a	xx	xx	xx	xx
Output Flows					
Components for re-use	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Materials for recycling	kg	3.30E+06	2.24E+03	4.40E+04	2.99E+01
Materials for energy recovery (not being waste incineration)	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Exported energy	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 14: 75-year Total Life Cycle Results, by information module

Environmental Indicator	Unit	PRODUCT stage		CONSTRUCTION PROCESS stage		USE stage						
		Raw Material Supply and Manufacturing	Transport	Transport	Construction Installation Process	Use of Products	Maintenance	Repair	Replacement	Refurbishment	Operational Energy Use	Operational Water Use
		A1/A3	A2	A4	A5	B1	B2	B3	B4	B5	B6	B7
TRACI v2.1 Environmental Impacts												
Global warming potential	kg CO_2 eq.	6.55E+05	4.17E+04	1.04E+04	2.10E+05	xx	0.00E+00	9.88E+04	1.02E+05	xx	xx	xx
Depletion potential of the stratospheric ozone layer	kg CFC-11 eq.	1.99E-03	1.61E-06	4.11E-07	5.29E-05	xx	0.00E+00	9.34E-04	1.39E-03	xx	xx	xx
Acidification potential of land and water	kg SO_2 eq.	4.34E+03	2.40E+02	5.58E+01	9.26E+02	xx	0.00E+00	6.22E+02	7.19E+02	xx	xx	xx
Eutrophication potential	kg N eq.	1.23E+02	1.42E+01	3.71E+00	5.00E+01	xx	0.00E+00	2.75E+01	3.23E+01	xx	xx	xx
Formation potential of tropospheric ozone photochemical oxidants	kg O_3 eq.	5.38E+04	7.00E+03	1.84E+03	2.25E+04	xx	0.00E+00	7.58E+03	6.12E+03	xx	xx	xx
Abiotic resource depletion potential for elements	n/a	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Abiotic resource depletion potential of fossil fuels	MJ surplus	7.39E+05	8.35E+04	2.47E+04	3.94E+05	xx	0.00E+00	1.91E+05	3.17E+05	xx	xx	xx
Resource Use												
Renewable primary energy excluding energy resources used as raw material	MJ	1.89E+05	6.10E+01	4.34E+01	1.81E+03	xx	0.00E+00	9.14E+03	6.13E+04	xx	xx	xx
Renewable primary energy resources used as raw material	MJ	5.08E+04	0.00E+00	0.00E+00	2.66E+03	xx	0.00E+00	6.26E+00	0.00E+00	xx	xx	xx
Non-renewable primary energy excluding resources used as raw material	MJ	1.20E+07	5.70E+05	1.48E+05	2.88E+06	xx	0.00E+00	1.11E+06	3.60E+06	xx	xx	xx
Non-renewable primary energy resources used as raw material	MJ	7.97E+05	0.00E+00	0.00E+00	2.17E+04	xx	0.00E+00	4.06E+05	7.61E+05	xx	xx	xx
Secondary material	kg	1.25E+05	0.00E+00	0.00E+00	1.43E+03	xx	0.00E+00	1.45E+03	4.91E+02	xx	xx	xx
Renewable secondary fuels	n/a	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Non-renewable secondary fuels	n/a	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Net use of fresh water	m^3	1.67E+03	0.00E+00	0.00E+00	4.89E+01	xx	0.00E+00	1.62E+02	2.64E+02	xx	xx	xx
Waste Categories												
Non-hazardous waste disposed	kg	8.43E+04	9.84E+01	7.02E+01	9.04E+03		0.00E+00	4.27E+04	6.92E+04	xx	xx	xx
Hazardous waste disposed	n/a	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Radioactive waste disposed	n/a	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Output Flows												
Components for re-use	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	xx	0.00E+00	0.00E+00	0.00E+00	xx	xx	xx
Materials for recycling	kg	0.00E+00	0.00E+00	0.00E+00	1.01E+05	xx	0.00E+00	5.87E+04	3.20E+04	xx	xx	xx
Materials for energy recovery (not being waste incineration)	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	xx	0.00E+00	0.00E+00	0.00E+00	xx	xx	xx
Exported energy	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	xx	0.00E+00	0.00E+00	0.00E+00	xx	xx	xx

Table 15: 75-year Total Life Cycle Results, by information module (cont.)

Environmental Indicator	Unit	END OF LIFE stage				Life Cycle Total	Benefits and loads beyond the system boundary
		De-construction and Demolition	Transport	Waste Processing	Disposal		
		C1	C2	C3	C4		D
TRACI v2.1 Environmental Impacts							
Global warming potential	kg CO_2 eq.	2.08E+04	9.35E+03	1.32E+03	3.00E+03	1.15E+06	-2.29E+04
Depletion potential of the stratospheric ozone layer	kg CFC-11 eq.	9.08E-07	3.72E-07	1.64E-06	5.09E-05	4.42E-03	-8.25E-07
Acidification potential of land and water	kg SO_2 eq.	2.79E+02	4.32E+01	1.21E+01	4.15E+00	7.24E+03	-1.53E+02
Eutrophication potential	kg N eq.	1.86E+01	3.12E+00	3.46E-01	7.22E+00	2.80E+02	-6.14E+00
Formation potential of tropospheric ozone photochemical oxidants	kg O_3 eq.	9.88E+03	1.53E+03	1.79E+02	9.91E+01	1.10E+05	-2.96E+03
Abiotic resource depletion potential for elements	n/a	xx	xx	xx	xx	xx	0.00E+00
Abiotic resource depletion potential of fossil fuels	MJ surplus	5.50E+04	2.16E+04	1.01E+03	6.78E+02	1.83E+06	-3.85E+04
Resource Use							
Renewable primary energy excluding energy resources used as raw material	MJ	1.31E+02	5.38E+01	2.67E+02	1.16E+02	2.62E+05	-3.17E+03
Renewable primary energy resources used as raw material	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.34E+04	0.00E+00
Non-renewable primary energy excluding resources used as raw material	MJ	3.09E+05	1.22E+05	1.86E+04	5.40E+03	2.07E+07	-3.43E+05
Non-renewable primary energy resources used as raw material	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.99E+06	0.00E+00
Secondary material	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.28E+05	0.00E+00
Renewable secondary fuels	n/a	xx	xx	xx	xx	xx	xx
Non-renewable secondary fuels	n/a	xx	xx	xx	xx	xx	xx
Net use of fresh water	m^3	0.00E+00	0.00E+00	2.27E-02	6.45E-01	2.14E+03	1.31E+01
Waste Categories							
Non-hazardous waste disposed	kg	2.11E+02	8.69E+01	4.91E+01	1.11E+05	3.17E+05	1.58E+03
Hazardous waste disposed	n/a	xx	xx	xx	xx	xx	xx
Radioactive waste disposed	n/a	xx	xx	xx	xx	xx	xx
Output Flows							
Components for re-use	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Materials for recycling	kg	2.97E+06	0.00E+00	1.34E+05	0.00E+00	3.30E+06	0.00E+00
Materials for energy recovery (not being waste incineration)	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Exported energy	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Figure 3: Information Module Contributions to Life Cycle Environmental Impacts

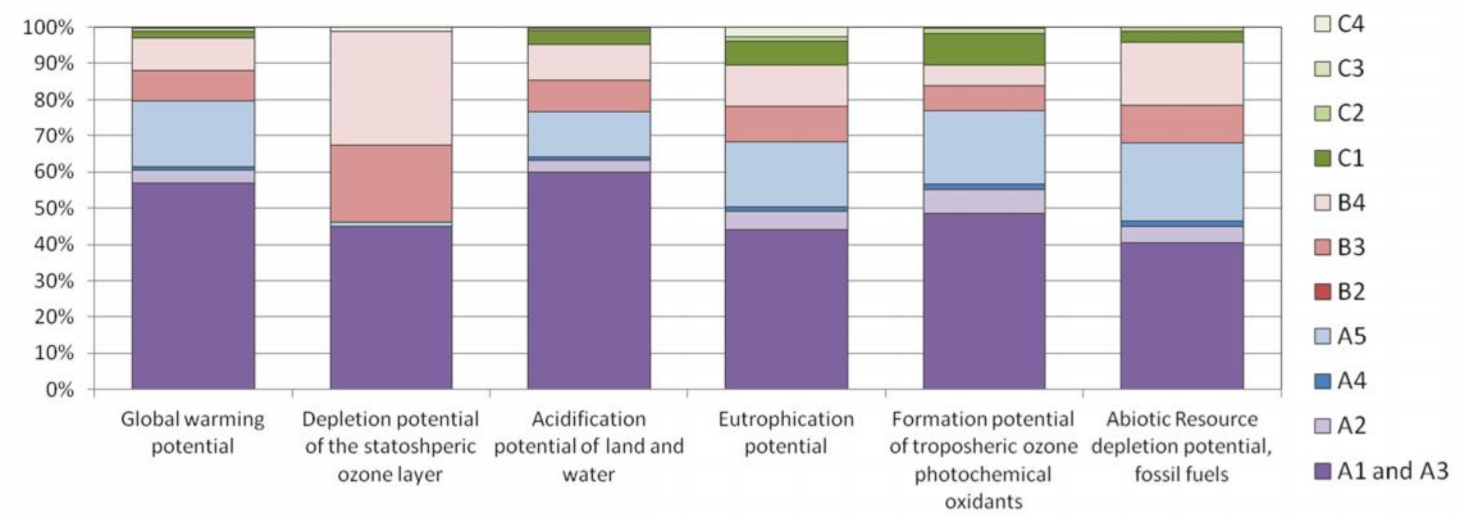

Figure 4: Information Module Contributions to Life Cycle Resource Use, Waste Categories, and Output Flows

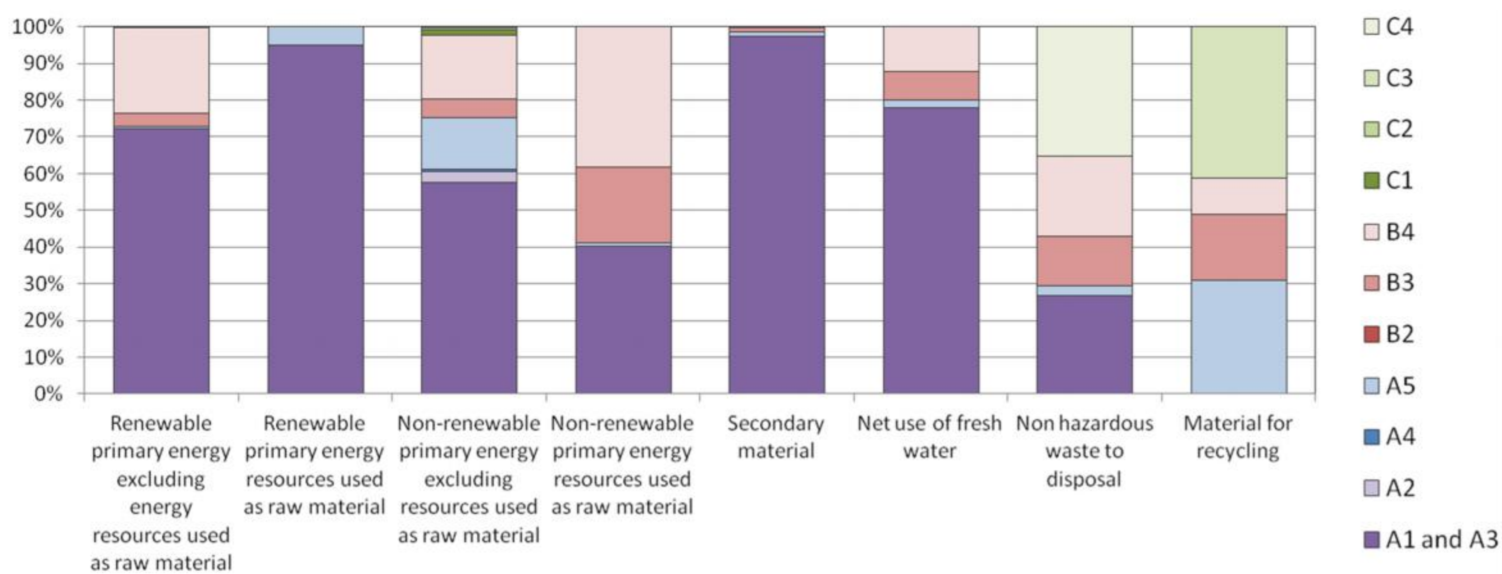

Table 16: Percent Change of Results to Changes in LCI Data

Environmental Indicator	Scenario 1	Scenario 2
TRACI v2.1 Environmental Impacts		
Global warming potential	0.70%	-0.46%
Depletion potential of the stratospheric ozone layer	0.02%	0.00%
Acidification potential of land and water	1.00%	-0.35%
Eutrophication potential	0.54%	-0.25%
Formation potential of tropospheric ozone photochemical oxidants	0.53%	-0.25%
Abiotic resource depletion potential for elements	xx	xx
Abiotic resource depletion potential of fossil fuels	0.95%	-0.10%
Resource Use		
Renewable primary energy excluding energy resources used as raw material	0.08%	-0.08%
Renewable primary energy resources used as raw material	0.00%	0.00%
Non-renewable primary energy excluding resources used as raw material	0.65%	-0.11%
Non-renewable primary energy resources used as raw material	0.00%	0.00%
Secondary material	0.00%	3.81%
Renewable secondary fuels	xx	xx
Non-renewable secondary fuels	xx	xx
Net use of fresh water	0.01%	-0.22%
Waste Categories		
Non-hazardous waste disposed	0.01%	-0.02%
Hazardous waste disposed	xx	xx
Radioactive waste disposed	xx	xx
Output Flows		
Components for re-use	0.00%	0.00%
Materials for recycling	0.00%	0.00%
Materials for energy recovery (not being waste incineration)	0.00%	0.00%
Exported energy	0.00%	0.00%

Appendix A: Bill of Materials

Table 17 summarizes the quantities of materials that were calculated to be in the object of assessment. Precast product material quantities were provided by Lafarge and Athena calculated all other materials. The bill of materials includes only materials that make up the building at initial construction, i.e. material use during building occupancy is not included.

Table 17: Bill of Materials

Material	Initial	Unit
1/2" Moisture Resistant Gypsum Board	1.79E+03	m^2
5/8" Regular Gypsum Board	4.37E+02	m^2
6 mil Polyethylene	1.11E+03	m^2
Aluminum	3.71E+00	Tonnes
Ballast (aggregate stone)	3.10E+05	kg
Cold Rolled Sheet	2.94E-01	Tonnes
Concrete 20 MPa (fly ash avg)	1.82E+02	m^3
Concrete 30 MPa (fly ash avg)	3.65E+02	m^3
Concrete Blocks	1.26E+04	Blocks
Double Glazed Soft Coated Argon	6.66E+01	m^2
EPDM membrane (black, 60 mil)	1.76E+02	kg
Expanded Polystyrene	3.80E+02	m^2 (25mm)
Extruded Polystyrene	6.03E+03	m^2 (25mm)
Galvanized Decking	1.83E-02	Tonnes
Galvanized Sheet	5.89E+00	Tonnes
Galvanized Studs	8.55E-01	Tonnes
Glass Fibre	8.87E+02	kg
Glazing Panel	7.52E+00	Tonnes
Hollow Structural Steel	5.54E+00	Tonnes
Joint Compound	4.50E-01	Tonnes
Modified Bitumen membrane	9.55E+03	kg
Mortar	3.19E+01	m^3
MW Batt R20	3.45E+01	m^2 (25mm)
Nails	2.99E-01	Tonnes
Paper Tape	5.42E-03	Tonnes
Polyiso Foam Board (unfaced)	5.82E+03	m^2 (25mm)
Polypropylene Scrim Kraft Vapour Retarder Cloth	8.96E+02	m^2
Precast Concrete	5.00E+02	m^3
Rebar, Rod, Light Sections	5.36E+01	Tonnes
Screws Nuts & Bolts	3.93E-01	Tonnes
Silicone Sealant	1.39E+02	kg
Softwood Plywood	4.91E+02	m^2 (9mm)
Solvent Based Alkyd Paint	2.36E+03	L
Welded Wire Mesh / Ladder Wire	2.03E+00	Tonnes
Wide Flange Sections	2.02E+00	Tonnes