Athena
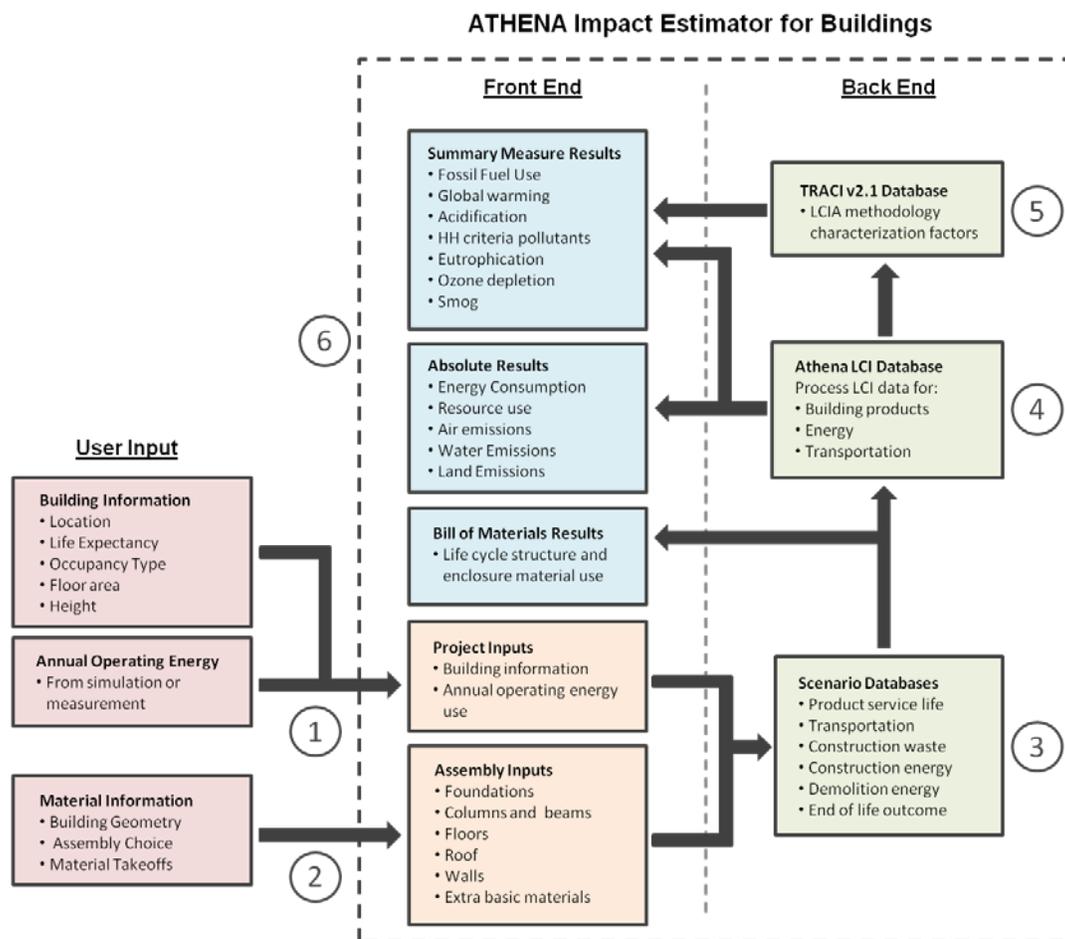# Impact Estimator
for Buildings

Athena Impact Estimator for Buildings V 4.5 Users Manual, Software and Database Overview

ATHENA Impact Estimator for Buildings

November 2013

1.0 Introduction

The goal of this document is to present an overview of the ATHENA® Impact Estimator for Buildings (IE) software and underlying databases by providing an indication of the inner workings of the tool – what it does and how it does it – and the various product and process databases it contains. It also provides information concerning the use of the software. For the latest information concerning database updates and modifications as well as "frequently asked questions" about the installation and use of the software, please visit our calculate LCA website here.

The Impact Estimator is a whole building, environmental life cycle based decision support tool for use by building design teams primarily at the conceptual design stage of a project. The tool focuses on the conceptual stage because this is when key decisions are first made about the shape and material make-up of a building's structure and envelope. The IE takes comprehensive life cycle inventory information and makes it easily accessible so the design team can make more holistic and informed environmental decisions about the design and material make-up of a proposed building. For teams farther along the design process or wishing to produce a retrospective environmental footprint assessment, the software is also able to import a "bill of materials" for a said design (from CAD/BIM based tools) and based on this information provides a detailed environmental footprint for the building (see section 3.3 for more on this software capability).

This document starts with a high level description of the tool's use and capabilities. It illustrates the relationships between building materials, components and assemblies, how they were arrived at, and how they are called upon in the software. It also outlines the various life cycle stages the software supports and the methods used to derive a complete building environmental life cycle inventory and impact assessment profile. The software's embedded material and energy carrier LCI databases are also explained, highlighting their use within the tool.

Throughout this document, various database and model workings are described by way of example to provide the reader a more illustrative understanding of the tool's inner workings and the process of entering their building designs. The software comes with a detailed "help file" and users are urged to call upon the help menu for details, assumptions and limitations concerning inputs to the model.

The software itself has undergone various incarnations. It first started as a spreadsheet model (2000) and was then migrated to a C++ object oriented software design platform (2005). In 2007, it was completely re-written in C#. From time to time, this report touches upon new features and capabilities that have been added to the newest version.

A "Reports & Publications" tab is available on our website. These reports typically relate to the underlying ISO 14040/44 LCI data used in the software.

2.0 High Level Description

The Impact Estimator (IE) for Buildings software is a decision support tool, not a scoring or rating system. The software indicates the environmental implications of different material mixes or design choices and the user can then consider the trade-offs among the various environmental effects. In fact, the essence of the software's decision support role is its ability to compare up to five design scenarios across a set of selected environmental impact summary measures. When using the software, a user may have two or more building designs already in mind or they may start with a baseline design and then look at various ways of improving that design's environmental performance.

The model provides a cradle-to-grave Life Cycle Inventory (LCI) profile for a whole building over a user-selected building service life. The inventory results comprise a long list of highly speciated flows from and to nature in the form of energy and raw material flows as well as emissions to air, water and land. The IE supports the following life cycle impact assessment measures based on the US EPA Tool for Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI v2.1 (2012)) and in accordance with ISO 21930/31:

- ➢ Global Warming Potential -CO_2 equivalent mass
- ➢ Acidification (Air) Potential - SO_2 equivalent mass
- ➢ Human Health Criteria –PM 2.5 equivalent mass
- ➢ Eutrophication (air & water) Potential - N equivalent mass
- ➢ Smog (air) Potential – O_3 equivalent mass
- ➢ Ozone Depletion (air) Potential – CFC 11 equivalent
- ➢ Fossil Fuel Consumption GJ – Total fossil fuel energy

All of these impact measures are either internationally accepted or are referenced measures in various international standards documents related to buildings and their evaluation (e.g., ISO 21930 & ISO 21931 and the International Green Construction Code). The software and its database is North American specific.

As the user inputs information, a component bill of materials is determined, at which point the software applies the Institute's regionalized LCI databases for product extraction and manufacturing, transportation, on-site construction and ongoing maintenance and replacement. It also takes into account building system demolition and end-of-life disposition of materials.

3.0 Software Inner Workings

3.1 Overview

Depending upon user-supplied information, the software is able to perform a variety of calculations. For instance, when the project's location is selected from a list of 16 supported N.A. locations/regions, the software activates appropriate electricity grids, transportation modes and distances and even product manufacturing technologies applicable to the product mix for the selected region. The choice of expected service life, type of building and, where relevant, whether the building is owner occupied or rental, turns on effects specific to the maintenance and replacement for envelope materials such as roofing, cladding and window systems.

The IE also allows the user the option to input[1] the building's estimated annual operating energy by fuel type. It is then able to calculate primary operating energy, including pre-combustion energy (the energy used to extract, refine and deliver energy) and the related emissions to air, water and land over the life cycle of the building. The software can subsequently compare and contrast the life cycle operating and embodied energy and other environmental effects of the building design, thus allowing the user to better understand the inherent trade-offs associated with adding more envelope materials (e.g., insulation) with reductions in operating energy use.

The model accepts user input on either an imperial or metric basis, but all calculations and results are reported in metric (SI) units.

3.2 Assembly and Material Considerations

The user defines the building assemblies for a project in terms of their geometry and material make-up or composition from both a structural and envelope perspective. The software is capable of modeling well over 1500 structural and envelope assembly combinations and is generally applicable to more than 90% of the typical North American residential and non-residential building stock.

To add an assembly, the user starts with one of the basic structural systems listed below and can then build up a complete assembly system by adding cladding, insulation, barriers or other materials. Unlike previous versions of the software, the user now has more flexibility to develop different assemblies with the same basic structural system, for example by having different cladding materials for different walls of the same type (e.g., multiple claddings on similar structural wall types). Similarly, the IE also allows the user flexibility in choosing different performing windows types for different wall types. The IE's column & beam structural system has been reconfigured to facilitate modeling of columns

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[1] Annual operating energy quantities by fuel type are entered in the General project dialogue box

on the perimeter of the building or having the exterior wall provide the perimeter support instead of perimeter columns and five more column options are now available that were not supported in Version 3. Version 4 also now delineates floor from roof assemblies separately, instead of under the same sub-group as was the case in version 3.

The software has detailed LCI information for individual basic materials as well as for component products such as trusses that are typically manufactured off-site.

Assemblies are currently disaggregated into groups and types — foundations, walls, floors, roofs, and columns and beams. A set of assembly types is represented within each assembly grouping (e.g., steel HSS columns with steel wide flange beams in columns & beams, and wood stud walls or steel stud walls within the wall assembly group).

Below is a list of the basic structural assemblies supported by the model; each of which can have many envelope configurations depending on information entered by the user via the input dialogue boxes.

Foundations
Concrete footings – perimeter and/or column
Concrete slab on grade

Walls (Exterior infill, load bearing and Interior non-load bearing)
Wood stud walls with or without plywood or OSB sheathing
Steel stud walls with or without plywood or OSB sheathing
Concrete block
Concrete cast-in-place
Curtain wall
Concrete tilt-up
Insulated concrete form
Metal Building System Walls
Structural Insulated Panels

Beams and Columns
Wood Column
Hollow Structural Steel column
Cast-in-place Concrete beam and/or column
Precast Concrete beam and/or column
Glulam beam and/or column
LVL/PSL beam and/or column
Wide flange beam and/or column
Wide flange beam and/or column (Gerber)

Mixed column and beam – mixed material system (e.g., LVL beam on concrete column)
Metal Building Systems – Primary frames

<u>Floors</u>
Composite Metal
Concrete suspended slab
Concrete parking garage – drop panel system
Concrete hollow core
Concrete pre-cast double ”T”
Open web steel joist with "Q" deck
Steel joists with structural wood sheathing (decking)
Composite metal floor system
Glulam joists and solid wood decking
Wood “I” joists with structural wood sheathing (decking)
Light frame wood trusses (parallel) with structural wood sheathing (decking)
Wood trusses with steel web and structural wood sheathing (decking)
Solid wood joists with structural wood sheathing (decking)

<u>Roofs</u>
Composite Metal
Concrete suspended slab
Concrete parking garage – drop panel system
Concrete hollow core
Concrete pre-cast double ”T”
Open web steel joist with "Q" deck
Composite metal roof system
Steel joists with structural wood sheathing (decking)
Glulam joists and solid wood decking
Wood “I” joists with structural wood sheathing (decking)
Light frame wood trusses (parallel or pitched) with structural wood sheathing (decking)
Metal Building System Roof
Wood trusses with steel web and structural wood sheathing (decking)
Solid wood joists with structural wood sheathing (decking)

Figure 1 below provides an example of the input dialogue box for a wood stud wall. Here a user firsts assigns a name to the wall assembly, inputs its length and height, and chooses the wall type from the available assembly components. In the figure the user selected a single wood stud wall, the user could have equally chosen the assembly twice of reflect a double stud wall in their design.
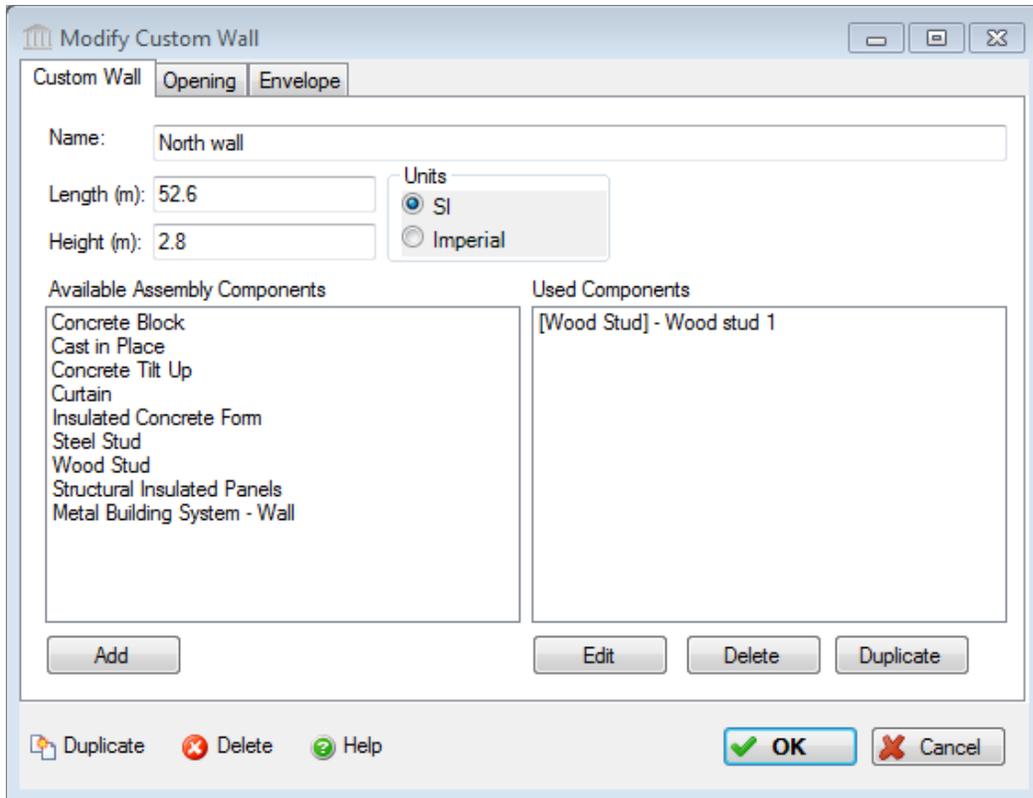
Figure 1

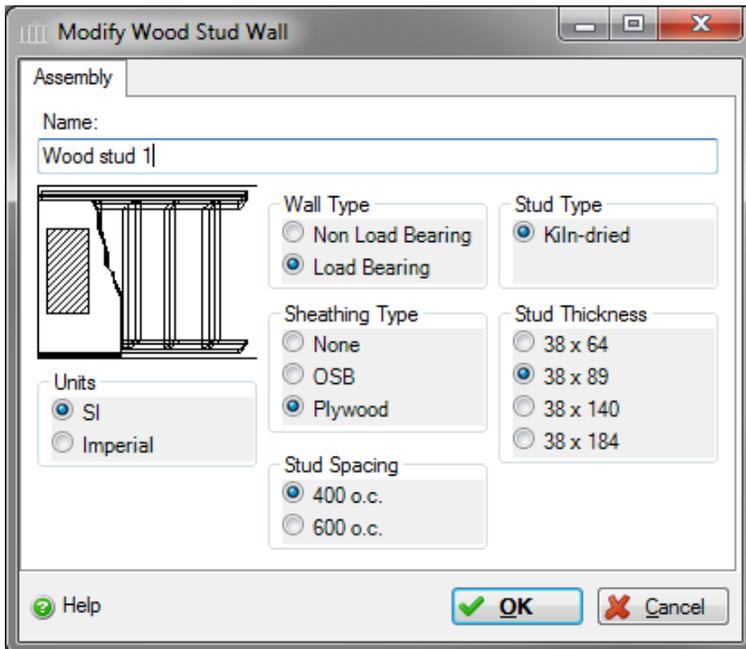Figure 2 below allows user to specify the details of the wall assembly

Figure 2

The user can also specify opening types (window and door) configurations for their wall as shown in Figure 3.
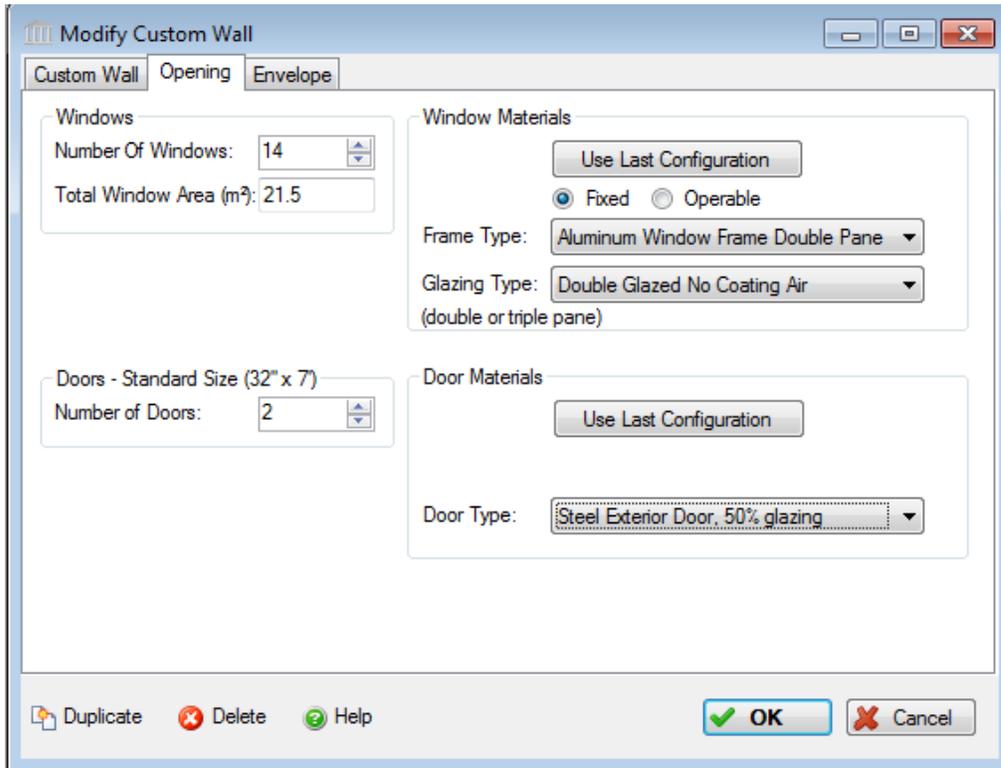

Figure 3

Non-structural, envelope materials are based primarily on the surface area of the specific assembly to which they are to be applied. For example, both insulation and gypsum board materials are added to an assembly on the basis of type and thickness and the IE determines the amount based on the area of the assembly. Windows, on the other hand, are determined based on the total area of openings as well as the number of openings indicated by the user for the assembly *(Figure 3)*. For windows, the software determines the total frame perimeter for each window (either as a fixed or operating frame), and the hardware and net glazing (double or triple lite) required for the type of window selected. Over 30 window configurations are supported in the software. Data for doors has been developed and included since version 4 on a similar basis. Doors are all considered to be a standard size (32"x84"), and there are 8 different door types available for different interior and exterior applications. As openings are specified the structural framing requirements of the wall automatically change (addition of studs and headers) to accommodate the opening.

3.3 Bill of Materials

When the user selects an assembly the software determines the associated bill of materials. As more assemblies are selected, the software aggregates the bill

of materials to the whole building level. For example, a user enters a "wood stud wall" assembly by specifying its geometry (length and width) and its attributes – e.g., sheathing type and stud spacing (see *Figure 2)* as well as windows and doors

The model then calculates the amount of materials used and aggregates them to determine a "bill of materials" report (Figure 4) for each assembly included in a design project. The "bill of materials" is dynamically updated as you modify and add more assemblies and materials to your project.

Bill Of Materials Report

Units: ◉ SI ○ Imperial

Project : Wood Stud Wall

Material	Quantity	Unit	Mass Value	Mass Unit
Aluminum Window Frame	185.2749	kg	0.1853	Tonnes
Double Glazed No Coating Air	78.4919	m2	1.2710	Tonnes
Expanded Polystyrene	7.9800	m2 (25mm)	0.0057	Tonnes
Galvanized Sheet	0.1879	Tonnes	0.1879	Tonnes
Glazing Panel	0.0960	Tonnes	0.0960	Tonnes
Nails	0.0217	Tonnes	0.0217	Tonnes
Small Dimension Softwood Lumber, kiln-dried	1.9892	m3	0.8859	Tonnes
Softwood Plywood	170.8096	m2 (9mm)	0.8069	Tonnes
Solvent Based Alkyd Paint	0.7244	L	0.0005	Tonnes

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Figure 4

The user defines envelope material layers applicable to the assembly (e.g., gypsum board, vapor barrier and insulation by type and thickness as in *Figure 5*). At any time a user can "save" a set of envelope materials as a predefined envelope system by giving it a name (e.g., my favorite wall envelope system) and then can simply reapply it again to another wall by selecting it from the predefined envelope system pull down menu list.
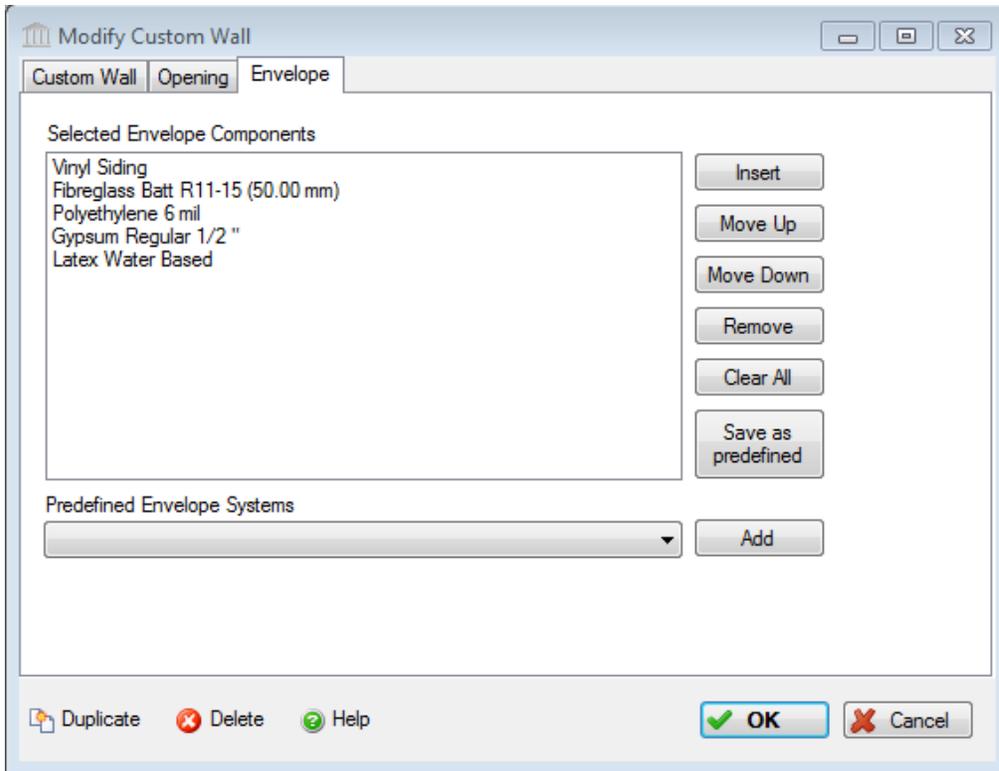
Figure 5

The model then estimates the quantities of these "envelope" or non-structural materials using the previously defined assembly geometry and adds these materials to the bill of materials *(Figure 6)*. We refer to this type of bill of material calculation as a "prescriptive" quantity take-off – the user prescribes a set of elements comprising the assembly instead of the model completing any "engineered" quantity take-off calculations.

Figure 6

We refer to a second kind of quantity take-off or bill of materials calculation as a "deterministic" method. An example of this method would apply to intermediate floors, roofs, and column and beam systems. In these cases the user specifies supported spans, bay sizes and live loads and the model determines the depth or size of a building element (structural floor element, supported slab, beam and column, etc.) to satisfy the selected assembly design parameters. *(Figure 7 below)*
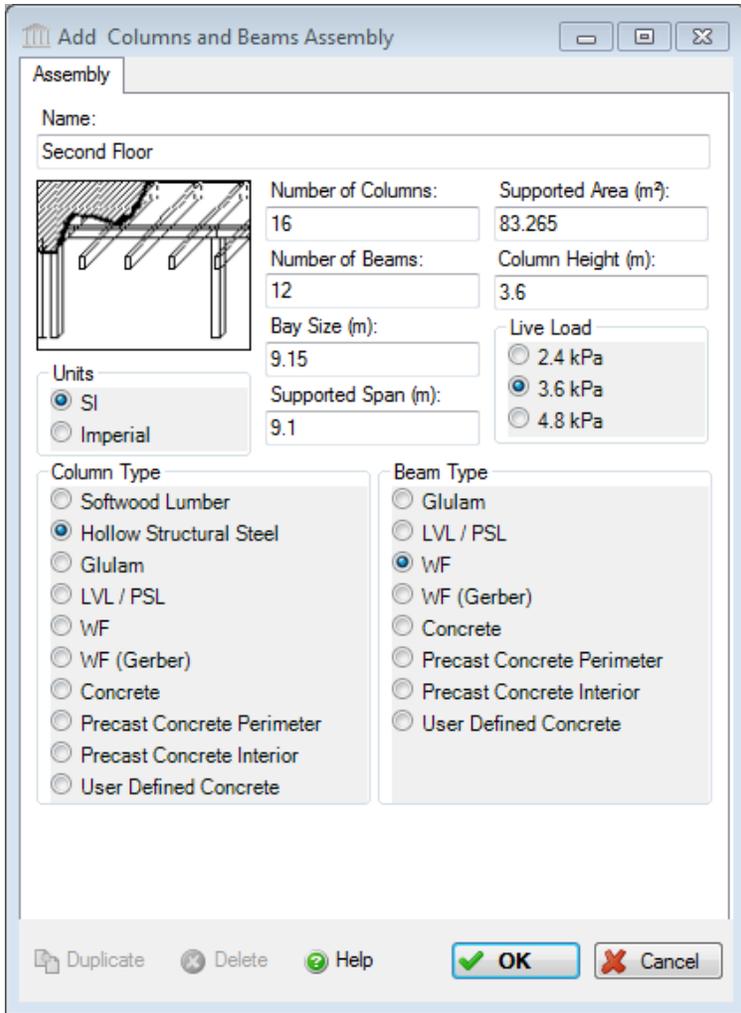
Figure 7

The graphic below *(Figure 8)* shows the basic material sizing calculation information used for a steel wide flange beam for a given bay size.

Span
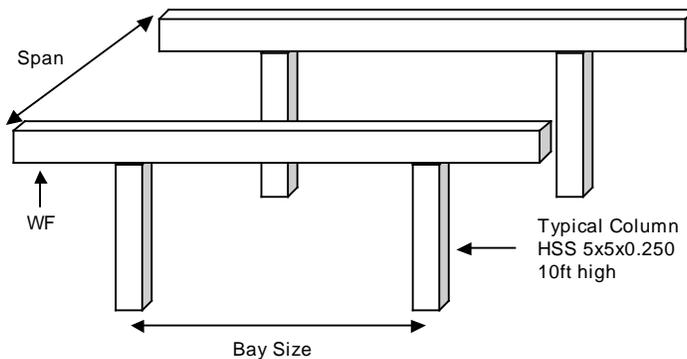
WF

Typical Column
HSS 5x5x0.250
10ft high

Bay Size

Figure 8

Figure 9 below shows the quantity take-off curves used to determine the weight of steel beam required based on the bay size and span for a 50 psf live load. For the purpose of developing algorithms in the IE, curves of this type have been segmented into linear sections. To be conservative, the software then uses the beam sizing for the high end of the linear segment corresponding to the specified bay size and span. Similar curves are used for the different user-selectable live loads.
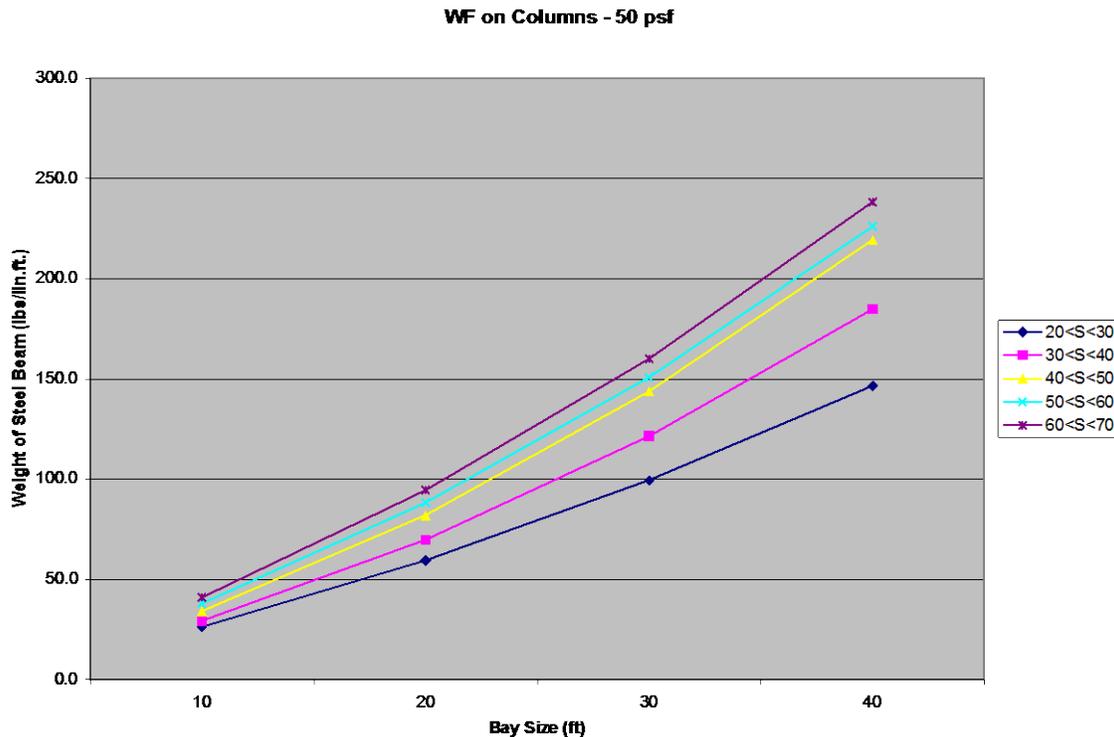
Figure 9

The software is not a design tool; it is intended to quickly express a design in sufficient detail for the purpose of estimating the environmental effects of a building at the schematic or conceptual design stage – say during an integrated design session. As indicated previously, that estimate starts with the bill of materials. These material quantity take-offs have been compared against detailed manual take-offs and have been found to be generally within +/- 10% of typical "engineered" quantities (exclusive of unique site considerations (e.g., soil conditions). Taking other factors into account (e.g., assumptions and uncertainties in the basic LCI data, many of which are compensating in terms of ultimate impacts), the Institute considers a comparative impact measure differences of 15% or less between two design scenarios as being equal or insignificant.

There is also an assembly type called Extra Basic Materials, and the user can input any amount of any material (positive or negative), in order to fine tune the bill of materials to known quantities from an existing or already designed building. There is also a Bill of Materials Import utility, which allows the user to export a bill of materials from a CAD or BIM program, map the material names and units of measurement to those supported in the Impact Estimator, and then import that bill of materials into the tool. This will automatically populate the Extra Basic Materials assembly with the user's known material quantities. Instructions of how to use the Bill of Materials Import utility are available in the help files under "Add or Modify Assemblies". Additional "how-to" videos are also available on our [website](#) and on our [YouTube channel](#) to walk you through the process of importing a bill of materials directly.

The software assumes a building will be built on the site and does not take account of site development issues such as land disturbance, eco-system alteration and destruction of vegetation. Such effects are very site specific and the intent of the software is to focus on the building design issues as opposed to these site-specific issues.

3.4 Regional Considerations

In the software, North American cities are used to designate regions because material or product flows, energy use and other considerations are not readily defined by strict political boundaries. The user selects the city that best represents the location of the building site.

The software was initially developed for Canada and includes regions designated by the cities of Halifax, Quebec City, Montreal, Ottawa, Toronto, Winnipeg, Calgary and Vancouver. Since its original commercial release in 2002, a US average was added to the software and more specific US regions were added over time. Currently, New York City, Pittsburgh, Minneapolis, Atlanta and Orlando are included. US regional coverage has since been expanded to include Seattle and Los Angeles (two seismic zones). Other cities with additional supporting regions are to follow in due course (e.g., Washington, D.C., Phoenix, etc.).

For each region, a regional product market share analysis is completed to determine where products are typically coming from. This information is used to develop weighted average life cycle inventory profiles for the products, as well as weighted average transportation profiles based on distance and modal split. Some products, such as cement and aggregate, are more regional while others, such as aluminum, travel greater distances, and some products are often sourced offshore (e.g., steel). For modeling purposes, to the extent possible and where relevant, all offshore products are treated as though they were manufactured in North America, an assumption that may change in the future as

more reliable and consistent international datasets become available.

Electricity supply is also an important consideration and the software supports regional locations in various ways. First, it considers whether a region is a self-sufficient generator of electricity or whether it draws electricity from the larger interconnected grid. For instance, a location such as Montreal is in the Quebec electricity grid and Quebec is a net exporter of electricity to the Eastern North American grid. Since Quebec is a self-sufficient generator of electricity, the IE therefore uses the Quebec grid for electricity use in that region. For other regional locations some of the electricity may come from the larger interconnected grid, in which case the software uses data from both the region and from the interconnected grid. For example, the region represented by Atlanta is in the Eastern North America grid intertie. More traditionally, Atlanta belongs to the Southeast Electric Reliability Grid (SERC). Georgia is not a self-sufficient generator of electricity. Consequently, a composite of the Georgia grid and Eastern North America grid intertie are proportionally combined and used by the model to represent the electricity use in the region.

This approach to electrical grids is taken when calculating electricity-related environmental burdens associated with the manufacturing of basic materials, products and components used in a building, as well as electricity used in the construction and maintenance of a building, including annual operating energy. As an example, when construction grade plywood is specified for use in Ontario, the model locates the closest supplier (British Columbia) and applies the BC electricity grid in the manufacture of plywood, but uses the Ontario electricity grid to calculate any on-site electricity use during construction of the plywood based assembly. Due to new power wheeling agreements across North America, the Institute has integrated the three major interconnection grids - Eastern, Western and Texas - as the basis for electricity usage in Version 4 of the model. However, provinces and states that are deemed net exporters of electricity to the grid remain as standalone grids in the model. These data have been updated to reflect 2008 electricity generation information from various N.A. sources.

Much of the common fuels and energy carriers data called upon in the software are based on the US LCI database (www.nrel.gov/lci). Some of these data have been adjusted to account for missing processes and gaps in flows.

3.5 Database Details

The following table sets out both structural and envelope materials supported by the model and the vintage of these databases. A large number of raw materials are also available in the software (e.g., aggregates, recycled concrete aggregate, etc.) for users to choose from – not all of these are listed below.

Product	Vintage	Comments
Concrete products		

Product	Vintage	Comments
Ready Mix Concrete (3000, 4000, 9000 psi with various high volume fly ash levels (average, 25% & 35%) specified on a volume basis	CDN 2005 US 2004	• Canadian regional cement data updated from original 1993 data (concrete designs remain unchanged)
Concrete Masonry Units (CMU) specified on a number of units basis	CDN 2005 US 2004	• Added Portland limestone cement based on 2007 LCA study • US data reflects PCA design mixes and average cement for the US
Precast products	CDN 2011 US 2008	• Institute report available.
Mortar - specified on a volume basis	CDN 2005 US 2004	• US cement profile available at US LCI database (www.nrel.gov/lci)
Steel Products -specified on a mass or area basis	N.A. 2013	• All profiles updated for steel construction products based on worldsteel "avoided burden" methodology approach. Data have been regionalized to reflect N.A. steel production technologies (BOF/EAF) and market recovery rates (recycling rates). See section (4.5) for a brief description of the methodology.
Nails		
Welded wire mesh		
Screws, nut, bolts		
Wide Flange sections		
Open-web joists		
Reinforcing bar		
Hollow structural steel		
Steel tubing		
Hot rolled sheet		
Cold rolled sheet		
Galvanized sheet		
MBS wall and roof cladding		
Residential cladding		
Commercial cladding		
Galvanized decking		
Galvanized studs		
Wood Products – specified on a volume basis		
Softwood lumber (kiln dried)	2012	• Canadian regional data updated in 2012 Corrim data for US reflects PNW, Inland West, NC and SE production 2012. • Institute report available for Canadian cradle-to-gate profile. • See Corrim.org
Plywood	2012	• Canadian regional (BC only) data originally developed in 1993 updated in 2006 and 2012. • Resource harvesting profile updated in 2012 • Institute report available for Canadian cradle-to-gate profile. • Corrim data for US reflects PNW and SE production in 2012. • See Corrim.org
Oriented Strand board	2012	• Canadian regional data originally developed in 1993 updated in 2006 and 2012. • Resource harvesting profile updated in 2012 • Institute report available for Canadian cradle-to-gate profile. • Corrim data for US reflects PNW and SE production in 2012. • See Corrim.org
Laminated Veneer Lumber	2012	• Canadian regional data originally developed in 1993 updated in 2012. • Resource harvesting profile updated in

Product	Vintage	Comments
		• 2012. • Institute report available for Canadian cradle-to-gate profile. • Corrim data for US reflects PNW and SE production in 2012. • See Corrim.org
Glulam Beams	2011	• Canadian regional data originally developed in 1993, updated in 2011. • Resource harvesting profile updated in 2009. • Latest Institute report available for Canadian cradle-to-gate profile. • Corrim data for US reflects PNW and SE production in 2012. • See Corrim.org or US LCI database (www.nrel.gov/lci) for US data
Wood I-Joists	2012	• Composite product of softwood lumber, LVL, OSB or plywood with fabrication process. Canadian and US regional data updated in 2012
Wood bevel siding – 3 species	CDN - 2009 US -2004	• Canadian regional data originally developed in 2000. Cedar siding data updated in 2009 • Institute report available for Canadian cradle-to-gate profile. • US profiles based on PNW/SE lumber with Canadian transformation processes (2004) – no report available
Wood tongue and groove siding - 3 species		
Wood shiplap siding - 3 species		
Claddings		
Metal cladding residential Metal cladding commercial MBS roof and wall cladding	2013	• Roll forming data from client report (2011) • Base steel sheet values updated in 2013.
Common clay brick (modular and standard)	2009	• Canadian clay brick data first developed in 1998. Adjusted for US by substituting electricity grids and transportation distances. • Institute report available. • data updated in 2009
Concrete brick and split faced block	2005	• Canadian concrete brick data first developed in 1998. • Split faced block updated in 2005. • Adjusted for US by substituting US cement profile, electricity grids and transportation distances. • Institute report available.
Stucco – over porous surface and metal mesh	2005	• Canadian data developed in 2001. • Cement portion updated in 2005. • Adjusted for US by incorporating US cement profile and substituting electricity grids, base fuel use and transportation distances. • Institute report available.
PVC vinyl siding	2010	• Originally developed in 1998 and updated in 2009. • PVC polymer portion to reflect new 2010 ACC data • See US LCI database (www.nrel.gov/lci) for data

Product	Vintage	Comments
Fiber Cement Siding	2009	• Originally developed in 2009.
Natural Stone	2009	• Developed in 2009 from a secondary data source.
Insulation and barrier products	Various for NA	
Polyethylene vapour barrier	2010	• Originally developed in 1998 and updated in 1999. • LDPE polymer portion reflect new 2010 Am. Chemistry Council data • See US LCI database (www.nrel.gov/lci) for data
Air barrier	2010	• Added in 20o7 based on ACC polypropylene profiles (updated in 2010)

Mineral Wool	2012	• Updated and expanded our fiberglass and mineral (rock) wool insulation materials. Working with NAIMA, these data have now been stratified by r-value to better reflect the density of these materials at various thicknesses:
		    Fibreglass Batt
		    Fibreglass Loose Fill
		    Mineral Wool Batt
		    FG Batt R20
		    FG Batt R30
		    FG Batt R40
		    FG Batt R50
		    FG LF Open Blow R13-20
		    FG LF Open Blow R21-30
		    FG LF Open Blow R31-40
		    FG LF Open Blow R41-50
		    FG LF Open Blow R51-60
		    FG LF Cavity Fill R15
		    FG LF Cavity Fill R22
		    FG LF Cavity Fill R30
		    FG LF Cavity Fill R38
		    MW Batt R20
		    MW Batt R30
		    MW Batt R40
		    MW Batt R50
		• Styrene polymer portion reflects new 2010 ACC data; Polyiso reflects 2011 PIMA data
		• See US LCI database (www.nrel.gov/lci)

Fiberglass	2012	
Polystyrene XPS and EPS	2007	
Polyisocyanurate (glass/foil faced)	2011	
Cellulose		
Paint Products	Various for N. America	
Basic latex, solvent based and varnish		• Originally developed in 1998 and updated in 1999. Institute report available – due to be updated
Gypsum Board Products	Various for N. America	
Regular		• Originally developed in 1997. • Regular and Fire rated updated in 2012. • Original Institute report available. GA report confidential
Fire rated		
Moisture resistant		
Gypsum fiber board		
Joint compound and paper tape		
Roofing Products	Various for N. America	
3 tab shingles - organic		• Originally developed in 2000 and 2001. • Institute report available
3 tab shingles - glass		
#15 and #30 organ felt		

Product	Vintage	Comments
Type III and IV glass felt		
Mineral roll roofing		
Clay tile		• Originally developed in 1998.
Concrete tile		• Adjusted and updated for US by substituting US cement profile, electricity grids and transportation distances (2008).
		• Institute report available
BUR organ felt based		• Originally developed in 2001.
BUR glass felt based		• Adjusted and updated for US electricity grids and transportation distances.
Roofing asphalt		• Institute reports available
GAF TPO Membrane (white)		• EPDM black updated in 2009 and EPDM white added.
PVC Membrane		
EPDM membrane (black & white)		• PVC updated in 2011
Modified Bitumen		• GAF TPO (5 products) added in 2013
Windows	Various for N. America	
Unclad Wood Frame (Double and Triple pane)	2013	• Frame and Glazing data and quantity take offs updated in 2013, with the exception of Aluminum Frame (awaiting new Aluminum data)
PVC Frame (Double and Triple pane)	2013	
Vinyl Clad Wood Frame (Double and Triple pane)	2013	• Originally developed in 1998 and updated in 1999.
Metal Clad Wood Frame (Double and Triple pane)	2013	• PVC polymer portion to reflect new 2010 ACC data
Aluminum Frame (Double pane only)	2002	
Double and Triple pane glazing, Hard (Tin) and Soft (Silver or Tin) Coated, Air and Argon Filled	2013	• See US LCI database (www.nrel.gov/lci) for data.
		• Added fiberglass frame in 2012
		• Updated quantity take-offs in 2010 for PVC and wood windows.

3.6 On-site Construction Effects

The onsite construction effects take account of the energy used to transport materials or components from the manufacturer to a notional distribution centre and from the distribution centre to the building site. The transportation distances are based on regional surveys. The IE also takes account of the energy used to construct the structural elements of the building and the emissions to air, water and land associated with the on-site construction activity. Below, we use the example of pouring a cast-in-place concrete wall assembly to illustrate the calculation of on-site construction effects.

Pouring a cast-in-place wall typically consists of assembling the formwork and placing reinforcing rebar in the forms and around openings, then pouring concrete into the forms.

The forms may be moved about the site by forklift or crane and may be assembled by hand or crane for large-scale formwork. Rebar is moved around the site using forklifts and/or cranes and would

typically be assembled by hand. The concrete will arrive on site in a concrete mixing truck and will be poured using a concrete pump or a crane and bucket. Both concrete and rebar are assumed to make a 40 km round trip from mixing plant or distributor to the building site.

On site waste for concrete is estimated at 5%, and consists of any spillage from the forms and the dumping of excess concrete not required on site.

Formwork is re-used until its degradation adversely affects the surface finish of the concrete work. On average, a 10% loss of material is assumed after each use.

A wall might also need temporary heating for concrete curing. It is difficult to estimate whether or not a wall may be poured in sub zero weather, as such, a proportion of the energy needed has been factored into the construction equal to the proportion of the year that the temperature falls below 0°C.

Prior to version 4.2 (Sept. 2012), construction effects were calculated solely on structural elements as described above, but starting with v4.2, the on-site construction effects of installing envelope and extra basic materials are also accounted for based on the energy required to lift those materials by crane, an average distance of half of the height of the building.

3.7 Maintenance, Repair and Replacement Effects

Maintenance and repair effects of building materials exposed to the elements or to wear (e.g., asphalt shingles, wood windows, gypsum board, etc.) include the following:

- o Material usage including quantity take-offs on a square meter basis for maintenance, repair and replacement of products and components;

- o Typical frequency of maintenance and repairs for each of the urban centers supported in the software;

- o Energy use for maintenance and repair activities;

- o Typical transportation mode and distance by region from the distributor to the site for the relative components; and

- o On-site waste generated by maintenance and replaced components and their final disposition.

Replacement effects of building materials include the following:

- o Typical life expectancy (service life) of each material/product by region, based on empirical evidence and or product warranty periods; and

o   Mass of waste material and its final disposition.

Maintenance, repair and replacement schedules have been separately assessed for each of the building types specified in the Impact Estimator. Essentially, the maintenance and repair algorithms in the software assume two levels of maintenance; a more aggressive maintenance and replacement schedule for owner-occupied buildings and a less aggressive schedule for rental and leased properties, with single family residential, institutional, commercial and industrial building archetypes assumed to be owner-occupied. Maintenance repair and replacement schedules for envelope elements have also been developed for each region supported by the software.

The software assumes that replacement materials or components will be the same as those used in original construction. This is almost certain not to be the case, but the alternative is technological forecasting, which would introduce a higher level of uncertainty.

In situations where the service life of a replacement material or component exceeds the remaining user specified service life of the building, the difference is credited. For example, a 20-year service life window installed 10 years prior to the end of the building service life will be credited with half of the environmental burden of the window.

Using stucco as an example we can further illustrate some of the environmental impacts arising from its repair or replacement. The table below demonstrates a typical stucco repair and its environmental impact for two different regions.

Stucco is rarely replaced in its entirety, although it is commonly over-clad with a different material (such as PVC or wood). For the purpose of the software, we have developed an average frequency of exterior wall cladding replacement for each urban centre supported by the software, under the assumption that the stucco is removed and replaced. See Figure 10 below.

STUCCO			Residential				ICI			
Description:				Multi-unit			Office			
Removal or overcladding of 100% of the stucco siding.		Single Family	Low-Rise (rental)	High-Rise (rental)	High-Rise (owner occupied)	Rental	Owner-Occupied	Institutional	Commercial	Industrial
Replacement Cycle										
Minnesota	years	75	65	35	35	35	35	35	35	na
Atlanta	years	25	20	20	20	20	20	20	20	na

MASS OF MATERIALS			DISPOSITION		
Material			Landfill	Recycle	Other
Base coat	kg/m²	30.0	100%		
Finish coat	kg/m²	6.0	100%		
Expanded metal mesh	kg/m²	1.0	100%		
Fasteners	kg/m²	0.028	100%		
Building paper (15# asphalt impregnated felt)	kg/m²	2.295	100%		

Figure 10

3.8 Operating Energy Use

The software does not simulate operating energy use; however, if a user has annual operating energy data by fuel type (electricity, natural gas, fuel oil, etc.) they may be entered into the software. Thereafter, the software can contrast embodied energy with operating energy of the project.

3.9 End of Life Effects

The software uses a simple algorithm to discern the final disposition of building materials at the building's expected "end of life" because it is difficult to forecast the state-of-the-art for material final disposition 60, 80 or 100 years in the future. Building materials are proportionately categorized as being recycled, reused or landfilled. Except for metals, products that are recycled, reused or incinerated for energy recovery are deemed to have left the system boundary and any credits associated with these products are accounted for in the next use. Metals recycling (as scrap) are modeled using a closed loop recycling or avoided burden methodology and these effects are captured in the software as opposed to "potentials" outside the system boundary.

At the user defined expected building end of life, the software first estimates the energy required to deconstruct/demolish the major structural systems of the building (wood, steel and/or concrete). It is assumed that the envelope materials are demolished during the structural demolition, but have little influence on the demolition energy use. The software then calculates the bill of materials at the building's end-of-life and determines the final disposition of these materials. The software assumes that those materials currently landfilled will continue to be landfilled, and those currently recycled or re-used will continue to be recycled and reused. All environmental burdens associated with materials leaving the system boundary are a charge to the next use. For the materials assumed to be land filled, the software takes account of the energy use and related emissions associated with transportation to the landfill assuming typical distances to landfill for the region. The model then applies a landfill operations process to the mass of materials entering the landfill.

3.9.1 Metal Recycling[2]

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[2] This method is awaiting application to Aluminum products supported in the IE database. Currently, the steel and aluminum databases are not comparable and hence any product comparisons should be avoided.

In 2011 the World Steel Association (worldsteel) completed its third iteration of its global LCI dataset covering 15 steel products[3]. In 2013, working with the American Iron and Steel Institute (AISI), the latest North American (N.A.) regional steel LCI data were made available from the Steel Recycling Institute (SRI) and (worldsteel) to the Institute. The Athena Institute has integrated these LCI data into our Impact Estimator for Buildings software database for steel construction products.

Seven (7) new cradle-to-gate LCI profiles of N.A semi-finished steel (plate, hot-rolled coil-HRC, cold-rolled coil- CRC, hot-dip galvanized steel-HDG) and finished (rebar, sections, wire rod[4]) steel products, were provided to Athena. It should be noted that these data are constantly being reviewed and are deemed "*interim*". Updates to these data will be communicated as they become available.

These LCI dataset were used to model the "cradle-to-grave" LCI profiles for all Athena finished steel products such as hollow structural steel (HSS), steel tubing, hot rolled sheet, cold rolled sheet, galvanized sheet, galvanized decking, galvanized stud, rebar, wide flange sections (WFS), open web joists (OWJ), nails, welded wire mesh / ladder wire, screws, nuts & bolts (SNB), MBS primary frames, secondary frames, wall panels, and roof panels.

In general, worldsteel provides the semi-finished steel data in two formats – cradle-to-gate (production) and cradle-to-gate with end-of-life (EoL) recycling. The latter approach is characterized as a "closed material loop recycling methodology", which follows ISO 14044:2006 section 4.3.4.3.3 (a), which describes the allocation procedures for closed loop material recycling. This system expansion methodology is also known as and is often referred to as the "avoided burden" method.

The general life cycle equation for this "closed material loop recycling methodology" is applied as shown by the equation below [1]:

LCI for 1 kg of steel product including recycling = $X - (RR - S) \times Y \times (Xpr - Xre)$ [1]

Where:

X is the cradle-to-gate LCI of the steel product

$(RR - S)$ is the *"net amount of scrap"* produced from the system:

RR is the end-of-life recycling rate of the steel product

S is the scrap input to the steelmaking process – this is the net scrap consumed in the steelmaking process and does not include internal scrap. Home scrap is considered when the scrap comes from a process which occurs on the steelmaking site, but does not contribute to any of the production stages of the product.

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[3] Life cycle assessment methodology report © World Steel Association 2011
http://www.worldsteel.org/dms/internetDocumentList/bookshop/LCA-Methodology-Report/document/LCA%20Methodology%20Report.pdf
[4] Rebar, sections and wire rod are labelled by the data provider as "interim" for now;

Y	is the process yield of the EAF (i.e. >1kg scrap is required to produce 1kg steel)
Xpr	is the LCI for 100% primary metal production. This is a theoretical value of steel slab made in the BOF route, assuming 0% scrap input.
Xre	is the LCI for 100% secondary metal production from scrap in the EAF, assuming 100% scrap input.

As per worldsteel recycling methodology, a credit or burden is given for the net scrap that is produced or consumed/lost at the end of a final products life.

This "*net scrap*" is determined as follows:

Net scrap = Amount of steel recycled at end-of-life (RR) – Scrap input (S)   [2]

The "**credit**" for steel recycling at the end of the final products life would result in subtracting the LCI value of steel scrap5. For example, for steel products with a low S-scrap input value e.g. 0.20 kg/kg product and a very high EOL recycling rate of 98% (0.98 kg/kg product), a credit based on the net amount of scrap of +0.78 kg (0.98- 0.20) is given to the product system.

The "**burden**" for scrap consumption would result in adding the LCI value of steel scrap. For example, for steel products with a high S-scrap input value e.g. 1 kg/kg product and a lower EOL recycling rate of 70% (0.70 kg/kg product), a burden based on the net amount of scrap of -0.30 kg (0.70- 1.00) is given to the product system.

The "*LCI value of steel scrap*" is determined as follows:

$$ScrapLCI = Y \times (X_{pr} - X_{re})$$ [3]

The "LCI value of steel scrap" is thus equal to the credit associated with the avoided primary production of steel (assuming 0% scrap input), minus the burden associated with the recycling of steel scrap to make new steel, multiplied by the yield of this process to consider losses in the process[6]. The "LCI value of steel scrap" dataset was provided to Athena to model the "cradle-to-grave" LCI profiles for all steel products supported in the IE as per worldsteel recycling methodology.

Furthermore, Athena applied the SRI 2013 recycling rates (RR) for both structural and reinforcement steel for the reference year 2011

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[5] Life cycle assessment methodology report © World Steel Association 2011, 7.2 LCI value of steel scrap, pg 39.
[6] Life cycle assessment methodology report © World Steel Association 2011, 10.6.2 The LCI of steel scrap, pg 75.
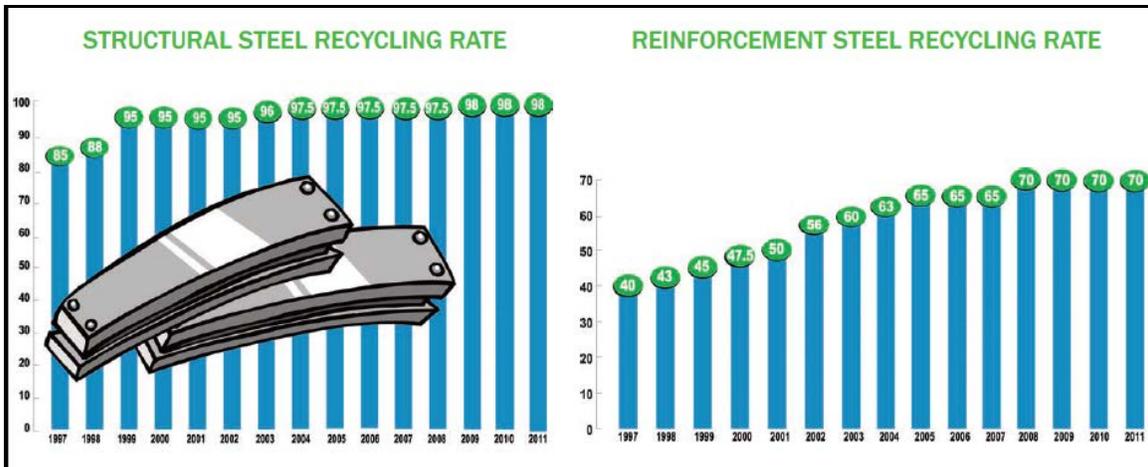
Figure 11: Recycling rates of N.A steel products [SRI 2013[7]]

The closed material loop recycling methodology is the "baseline" database methodology applied in the IE4B software.

To the "cradle-to-gate" N.A. steel LCI dataset the Institute has added the environmental burden of all downstream processes (specific to the building steel products) on a life cycle stage basis (in accordance with ISO 14044:2006 and ISO 21930:2007) as follows,

- **Manufacturing stage**
  (Includes the "cradle-to-gate" of semi-finished steel product; fabrication process; fabrication scrap collection, processing and transport to steel mills and "*the LCI value of fabrication scrap*" as per worldsteel methodology;

- **Construction stage**
  (Includes the final product transportation to the building site; construction/installation process; construction/installation scrap collection, processing and transport to steel mills, and "*the LCI value of construction scrap*" as per worldsteel methodology)

- **Use stage**
  (No burden or credit is given to the steel products during the use stage)

- **Deconstruction stage (included as part of EoL)**

(Includes deconstruction process; deconstruction scrap collection, processing and transport to steel mills, and "*the LCI value of the net scrap*[8]" as per worldsteel methodology.

For example, the cradle-to-grave environmental profile of galvanized studs consists of the "cradle-to gate" profile of N.A HDG steel; fabrication processes for turning HDG steel into galvanized studs (e.g., stamping, cutting and roll-forming of HDG sheet into steel studs), final transportation of galvanized studs to the building site, construction process (e.g. steel stud wall assembly), steel scrap collection with processing and delivery back to steel plants as and where it occurs (manufacturing, construction and EoL); and "the LCI value" of the fabrication, construction and deconstruction scrap as per woldsteel recycling methodology.

Steel Database User Guidance

As a user of the Impact Estimator for Buildings software, when interpreting the summary impact indicator results for steel products refer to project tables showing results **"by life cycle stage".** This is the best view of how and where the use of the avoided burden method affects the LCA results.

If you would like to know more about the worldsteel "closed material loop recycling methodology", refer to "Life cycle assessment methodology report © World Steel Association 2011", Section 4.6.3 The end-of-life phase, Section 7.2 LCI value of steel scrap and Appendix 10: Recycling methodology.

3.9.2 Biogenic Carbon Sequestration Accounting

The latest version of the IE (v4.5) software applies a biogenic carbon sequestration accounting methodology that conforms to the PAS 2050 carbon footprint standard[9]. In this methodology, the amount of carbon in the product serves as the initial credit from which the end-of-life emissions are accounted against. North American average

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[8] "Net scrap" at the deconstruction stage is calculated as follows:

Net scrap$_{deconstruction}$ = RR − S$_{production}$ - S$_{fabrication}$ − S$_{construction}$

[9] PAS 2050. (2011): Specification for the assessment of the life cycle greenhouse gas emissions of goods and services. British Standards Institute. Available online @ http://shop.bsigroup.com/en/forms/PASs/PAS-2050

statistics were then aggregated from numerous sources to model the fate of biogenic carbon at the end of the product service life. This modeling was completed for the 100 years after the service life and is illustrated in Figure 12 below.
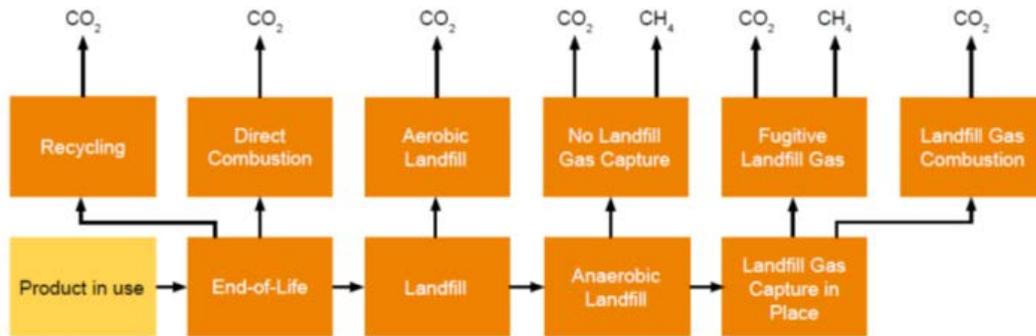

Figure 12: End of Life Model for Wood Products

The various processes in the end-of-life model shown in Figure 12 were modeled as follows:

End-of-Life/Landfill: Business-to-Business (B2B): The B2B tool applies a typical/average array of end-of-life treatment processes, which include combustion, recycling, and landfilling.

Landfilling: 80%
Recycling: 10%
Combustion: 10%

The non-GHG emissions of the landfill process were modeled based on ecoinvent data for sanitary landfills.

Anaerobic Landfill: The anaerobic landfill is accounted as a first order decay with a 4% annual decay rate (k/yr.) applied to the 23% of wood that decomposes. The carbon in the decayed wood is converted to both methane and carbon dioxide in equal portions (50% to each). A portion of the methane that is generated (10%) is oxidized to carbon dioxide before it reaches the landfill surface.

Landfill Gas Capture in Place: In the average landfill that was modeled, 82% of the

landfill gas generated in the anaerobic landfill occurs in those that have landfill gas capture wells in place.

Landfill Gas Combustion: The landfill gas that is captured is either burned for energy or flared without energy recovery. In both cases, 100% of the landfill gas carbon is emitted as carbon dioxide. The modeling did not account for any energy substitution effects.

Fugitive Landfill Gas: In the landfill modeling, the landfill gas generated in anaerobic landfills is directly emitted as 55% carbon dioxide and 45% methane on a molar basis.

No Landfill Gas Capture: Of the landfilled wood, the landfill gas generated in the anaerobic landfill that have no landfill gas capture wells in place is emitted entirely to the atmosphere as 55% carbon dioxide and 45% methane (molar basis).

Aerobic Landfill: In the anaerobic landfill, the decomposition is accounted as a first order decay with a 4% (k/yr) annual decay rate applied to the 23% of wood that decomposes. The carbon in the decayed wood is 100% converted to carbon dioxide.

Direct Combustion: The combusted material is accounted as a 100% conversion to carbon dioxide. The Impact Estimator also accounts for the non-GHG emissions of biomass combustion.

Recycling: The recycled material is assumed to leave the system boundary and is conservatively accounted as a 100% conversion to carbon dioxide.

The net result of these above processes (inclusive of transportation to waste treatment and landfill operations) is reported under the "End-of-life" category in the Impact Estimator for Buildings software "by life cycle stage" results.