Athena
Impact Estimator
for Buildings

User Manual and Transparency Document

Impact Estimator for Buildings v.5.5

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Athena Sustainable Materials Institute
www.athenasmi.org

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Acknowledgements

Disclaimer

The Athena Institute provides no warranty for the software and does not assume any liability for the accuracy, completeness, or usefulness of the software.

About the Athena Institute

The Athena Sustainable Materials Institute is a non-profit research group that advocates for environmental performance measurement and accountability in the built environment. We are the North American leader in LCA for construction and its materials and have been providing ground-breaking research and free resources since 1997.

Table of Contents

List of Tables

List of Figures

What's new in this version

Version 5.5 has the following changes from the latest previous version.

Biogenic carbon is now reported in the correct place

Biogenic carbon is moved out of Module D and reported in the modules where it occurs, per ISO 21930:2017.

More GWP indicators

GWP for biogenic carbon and for calcination are reported separately from total GWP, per ISO 21930:2017.

A new export feature to link Impact Estimator with the Athena web tool

A new "Bill of Materials by Assembly" report can be created in the tool and exported for use elsewhere. This report contains material quantities as installed in the building, organized by OmniClass® Table 21 elements. A primary purpose for this new feature is to enable use in early design of the advanced web tool Athena Building LCA. The web tool requires a bill of materials, which users generally do not have in early design. The Impact Estimator can be used to generate a bill of materials suitable for import into the web tool.

Many material updates

The following material data has been updated to the most recently available:
- Electricity grids
- North American steel products
- North American wood products
- Concrete masonry units
- Mortar and grout
- Precast concrete
- Portland cement
- Portland lime cement
- Slag cement
- Concrete ready mix A3 profiles
- Glass mat gypsum panel 1/2" and 5/8"
- Lightweight gypsum board 1/2"
- Fire-rated Type X gypsum board 5/8"
- PVC membrane 48 mil
- Metal building systems: frames, cladding, and roofing
- Extruded polystyrene (XPS)
- Polyisocyanurate foam board
- Mineral wool batt
- Fiberglass batt

- Fiberglass loose fill
- Cellulose
- Spray polyurethane foam-added
- EPDM membrane
- TPO membrane-added

LCI results no longer provided

The Impact Estimator no longer reports life cycle inventory (LCI) results. This is because we increasingly have less access to LCI data on products (except when we have done the LCA ourselves), due to industry trends to not provide that data publicly.

System requirements and revision history

The IE4B is a stand-alone PC desktop application that runs easily on most machines. For Macintosh users, it can be run on a Mac with suitable Windows capability, or it can be accessed remotely from the Athena server. To download the software, review specific requirements, review revision history in detail, and learn about remote Mac access, go to www.calculatelca.com.

Projects that were created in previous versions (v4.0 and later) remain compatible in new versions and will be updated (with a backup of the original file saved) when opened in a new version. Changes typically include new or updated environmental data databases, new or updated assembly options, updated LCA methodology, and new features for better usability. Changes made to the physical models of projects from previous versions are typically minor. As an example, the softwood lumber data was revised in v5.0, and green lumber, which was previously available as a material choice, but is no longer in v5.0 (it is no longer a commonly used material), has to be replaced by kiln-dried lumber. So, a project in a previous version that used green lumber for a wood stud wall, when opened in v5.0, will have that wall assembly automatically changed to kiln-dried lumber, since that is now the only choice available. While this a minor change to the model (it's the same amount of lumber), the LCA results may be significant, since kiln-dried lumber is more energy intensive than green lumber. In summary, although project files are compatible from version to version, their results will not be if the model includes any materials in which the data has changed in a new version. If you wish to reproduce results from previous versions, you will need to use that previous version to do so.

The IE4B began life in 2000 as a spreadsheet model. It was converted to a software application in 2002 under the name *Environmental Impact Estimator*. In 2005 it was migrated to a C++ object-oriented platform, and then in 2007 completely re-written in C#. Along the way, it went through several major updates and was renamed the *Athena Impact Estimator for Buildings*.

Please refer to the web site www.calculatelca.com for the latest updates on the software, system requirements, and "what's new" in the current release.

Limitations

LCA by definition is uncertain; it is an estimating science. There is a margin of error in all results. **The numbers may be presented as precise, but they are not.** Bear this imprecision in mind when making big decisions based on the results.

There are many factors that can contribute to uncertainty in results. These factors apply to all whole-building LCA tools, including the IE4B. The following are some key sources of error and uncertainty:

- An incomplete building model.

- An incomplete or inaccurate bill of materials.

- Exclusion of some life cycle stages.

- Gaps in material and scenario data.

- Low quality or non-harmonized material data.

Users are responsible for errors in results due to errors in their inputs. Be advised that you use this software at your own risk, recognizing that there may be bugs in the software and gaps or errors in the background data. The Athena Institute is not responsible for any outcomes as a result of using the software.

If using the IE4B to generate a bill of materials, be advised that this is an estimate and likely not an exact match for the real building.

Overview

This document explains the inner workings of the Impact Estimator for Buildings (IE4B) including the underlying databases and methodology, and it provides detailed instruction on how to use the software. **View this document on-line for maximum access to the user help features. Find it at http://www.calculatelca.com/ (Software>Impact Estimator for Buildings>User Guides).**

What the software is all about

The IE4B is a software tool that delivers environmental life cycle-based performance information about buildings. It provides decision support for building design teams who wish to include environmental impact among the factors assessed during design; it can be used to meet the requirements of policy; and it can produce environmental indicator results for publicly declaring an estimate of a building's impact.

The IE4B is a simplified LCA tool

Life cycle assessment (LCA) is the science behind the IE4B and is typically practiced by experts. The IE4B software package is an LCA-based tool that has been developed specifically for architects, engineers, and sustainable design consultants. The tool provides access to

sophisticated environmental data and life cycle assessment methods without requiring advanced LCA skills.

The IE4B reports results for the following environmental impact measures consistent with the US EPA TRACI methodology[1]: global warming potential, acidification potential, human health particulate, ozone depletion potential, smog potential, and eutrophication potential.

The IE4B helps designers reduce embodied impacts of buildings

Buildings already have a large environmental footprint even before the lights are turned on for the first time. The "embodied" environmental effects include the resource consumption and air/land/water emissions to make, transport, install, maintain, replace and remove all of the products used in a building. This part of a building's footprint is often ignored in favour of a focus on operating energy or is inadequately addressed by design measures or product choices that sound good but have no applicable performance data that can be related to the actual building life cycle footprint.

The IE4B substitutes meaningful environmental impact metrics for much of the current guesswork about sustainable design decisions. The software is also the way to properly consider embodied versus operating impacts. When more materials are added to a building in order to reduce operating energy, the environmental impact of those additional materials needs to be factored into the total environmental impact math.

While operating energy use is critically important and generally outweighs embodied impacts in the long term, the short-term embodied impacts should not be ignored. The timeframe for mitigating climate change is the present, not 60 years down the road. Reducing the embodied impacts of the construction sector is an important tactic. In addition, many of the other environmental degradations such as acidification and eutrophication that are due to construction and its upstream activities are only addressed by LCA and are heavily weighted to the manufacturing phase – these effects are missed if only looking at operating energy.

The IE4B provides holistic whole-building results

Designers need to look at total building results to best understand trade-offs and to know where to focus attention when looking for improvements. The IE4B provides whole-building results while also allowing users to assess components, assemblies, and products as needed.

Products or assemblies with a heavy environmental burden can be balanced out by other building elements. In addition, the environmental performance of individual products is properly considered within the context of the whole building – this is an issue of scale. Traditional sustainability metrics don't provide any indication of the relative scale of impact. For example, Product One might have much lower environmental burdens than Product Two, yet choosing Product One could have a negligible impact on total building performance. If Product Two has other product advantages, it would likely be the better choice, and a designer would look elsewhere for meaningful environmental improvements in the building.

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[1] *Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts* (TRACI) is a life cycle impact assessment methodology developed by the US EPA and the most commonly used method in North America.

The software can be used at any point during design but is particularly useful early in the process. Focusing attention on environmental footprint during conceptual design will yield the biggest impact, because it is during this early stage when key decisions are made that affect a large proportion of the building's ultimate mass.

The IE4B is not a scoring or rating program – it just delivers the performance numbers. Use it to inform design as it progresses from concept to development to construction documents – the early results can be a benchmark to gauge against through subsequent design refinements.

The IE4B covers a wide range of building types and construction systems

The IE4B can model constructed works at any scale: whole-building, building element, construction assembly, and building product. It can be used for all types of buildings (residential, commercial, and industrial) and construction projects (new construction, renovation, and refurbishment).

The geographic coverage of the tool is the United States and Canada.

Environmental profiles of building products and operating energy fuels typically reflect industry-average practice, although brand-name products from specific manufacturing facilities are added to the databases at the discretion of individual manufacturers. Where possible, data is specific to the region where the building is located; this is an important aspect to the LCA calculations and is a distinguishing quality feature of the Athena databases.

The IE4B modeling capacity currently encompasses a building's structure, enclosure, and interior partitions and doors. Furnishing, most finishes, conveyance systems, and mechanical and electrical equipment are not currently included. Building products can be combined in various ways to model the vast majority of construction assemblies commonly in use in North America (an estimated 1,500+ combinations using the IE4B built-in elements). The LCA modeling can also optionally include the operating energy use of the building – energy use is calculated using other means, and fuel consumption results are entered in the IE4B which will then include the associated LCA impacts of fuel and electricity use in the results.

The IE4B delivers actionable results

Users can view data in a number of different ways. The reporting functions make it easy to find environmental hot spots and to compare up to five design options simultaneously. When using the software, users 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.

All this for free?

The Athena Institute has a mandate to bring LCA to the construction sector for a verifiably reduced footprint of the built environment. We believe the best way to do this is by making the IE4B as accessible as possible. To us, this means keeping it free.

How do we do it? Through the generous support of our funding network: our partners, supporters, and members.

It's expensive for us to perform on-going development and maintenance of the IE4B and its underlying databases. We never have quite enough funds to move as quickly as we'd like to tackle the wish list – please consider joining our family of supporters at http://www.athenasmi.org/membership/overview/.

How the software works

The IE4B is a desktop software application that runs on most PC platforms. It can also be accessed by Macintosh users via our server (or can be run on a Macintosh with Windows capability). Download the software or learn about Mac access by heading to our software web site www.calculatelca.com.

The IE4B has the complex life cycle databases and methodology in the background, meaning the user need only address inputs about the physical nature of the building. The software is easy to learn and easy to use. A building is described through various dialogue boxes, with context-specific pop-up help available for each one. In addition, we offer short video demonstrations and we have an extensive FAQ section, all accessible at www.calculatelca.com.

See Figure 1 for a diagram of software inputs, outputs, and processes.

First, general information is collected: building location, building type, area, height, and service life. These factors will trigger specific internal calculations. For example, geographic region is important — appropriate electricity grids, transportation modes and distances, and product manufacturing technologies are applied depending on the building location.

Next, the building model is developed by creating a series of assemblies: walls, roofs, and so forth. Users quickly describe building assemblies through dialogue boxes that request information like bay sizes, structural systems, and loads. The software then applies structural algorithms to calculate a bill of materials. Users have flexibility to add or subtract materials.

Alternatively, users can import their own bill of materials from any source.

When the model is complete, users can generate results in a variety of categories and formats. A number of background calculations and database access activities are put in action depending on what results are requested by the user. Scenario[2] databases are accessed to quantify all life cycle material and energy use. The Athena background environmental database and the TRACI methodology are applied to perform life cycle impact assessment. The software reports results for the following environmental impact measures consistent with the latest US EPA TRACI methodology: global warming potential, acidification potential, human health particulate, ozone depletion potential, smog potential, and eutrophication potential. The Impact Estimator additionally reports fossil fuel consumption. The IE4B takes into account the environmental impacts of the following life cycle stages: material manufacturing, including resource extraction and recycled content; related transportation; on-site construction; maintenance and replacement effects; demolition and disposal; and benefits and loads beyond building life.

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[2] In LCA lingo, "scenario" means an assumption about a future situation – for example, what might happen to building materials at the end of the building's service life.

Operating energy can be included in the building LCA if the user inputs an estimate for annual operating fuel consumption. The software will calculate total 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 various design options, allowing the user to better understand the inherent trade-offs between (for example) adding more insulation in exchange for a reduction in operating energy use.

Accommodating multiple comparisons at once, the IE4B allows users to change the design, substitute materials, and make side-by-side comparisons for any one or all of the environmental impact indicators. It also lets users compare similar projects with different floor areas on a unit floor area basis.

Figure 1   How the Impact Estimator for Buildings works

LCA 101

Life cycle assessment is typically a cradle-to-grave quantification of potential environmental impacts of products or services; it is based on natural sciences and considers the entire value chain. LCA has long been used in the industrial sector to understand environmental "hotspots" in products so that improvements can most effectively be made. Similarly, LCA can help building designers focus their efforts when a reduced footprint is desired. This application is called "whole-building LCA" when the entire building project is considered holistically in an LCA exercise – as opposed to LCA applied to parts of a building (for example, LCA for only the floor assembly, or LCA used when selecting individual products). Whole-building LCA allows maximum flexibility in trade-offs. For example, the addition of more insulation will result in increased material impacts of a building, but it will often result in a net life cycle benefit due to reduced operating energy consumption.

In a whole-building LCA, all of the flows between the building and nature are inventoried – that is, the resources consumed and the substances or wastes emitted to air, water and land are calculated for every stage of the building life cycle. Next, those environmental flows are assessed for their likely consequential impact on the environment. For example, once we know the lifetime consumption of coal-fired electricity for constructing, operating, and disposing of a building, we can then estimate the greenhouse gas emissions attributable to this consumption and the subsequent increase in global warming potential.

Figure 2   **The life cycle stages of LCA for buildings and building products.**

It's important to look at LCA results in the right context and with the right expectations. LCA is a comprehensive assessment process, but it can't do everything on the sustainability agenda, and it is not intended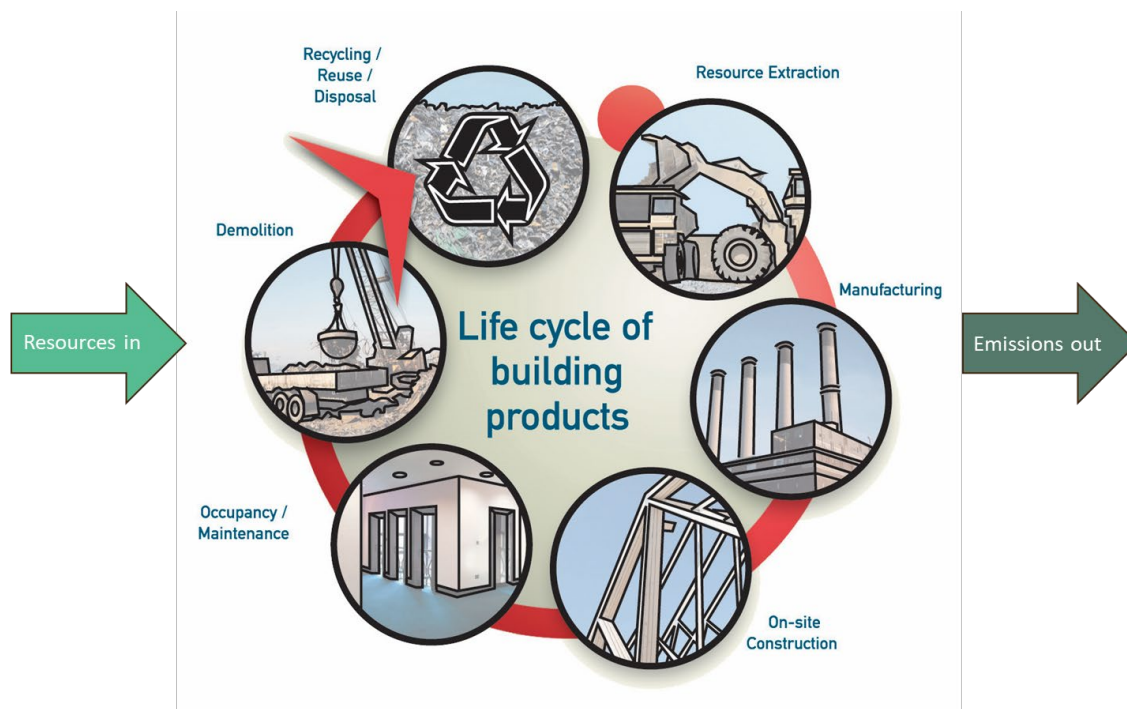 to do so. Multiple tools are required for that. In addition, there are uncertainties inherent in LCA, as with any complex modeling. This is why LCA is a science of best estimates and not a science of absolute measurement. Use LCA to help gauge relative performance across options, which then helps to refine the direction of further decisions.

Learn more about LCA at www.athenasmi.org.

Getting started as a new user

Wondering if the IE4B is the right tool for your work? Consider starting with some education on LCA in general – you'll find several introductory webinars and other resources at www.athenasmi.org. Next, perhaps watch our 11-minute overview video demo to see what you're getting in to with the IE4B software.

The IE4B is easy to learn and easy to use, but new users typically need a day or two to get comfortable with the software. Once up to speed, users can typically perform LCA on projects fairly quickly. Depending on the size of the building and at which point in the design process (a conceptual design will typically be less detailed than a final design), and with some experience, the amount of time it typically takes to run a project through the software can be as little as an hour – but plan on spending up to a day or more for the initial modeling of complex projects. If the material quantities and the project dimensions are well documented and available, the modelling process speeds up considerably. There is also an option to import the bill of materials from another source; importing and mapping takes perhaps an hour.

Remember that the IE4B is only recommended for building projects located in the US or Canada. As with any LCA software and data, geographic relevance is critical – the IE4B contains highly detailed data very specific to North American regions. Using this tool for a different world region increases uncertainty in the results.

Ready to go? Here are the steps to get started:
1. Go to www.calculatelca.com and create a user account.
2. Download the software – we have choices – most common is the 64-bit version.
3. When download is complete, open your downloads folder.
4. Open the readme file – important! – read this and follow the instructions to complete the installation.
5. Watch our short demo videos – the overview video may be enough for starters.
6. Take it for a test drive. The IE4B will be intuitive for anyone familiar with typical Windows-based applications – it has a standard menu bar and standard menu actions.
7. Need help? Watch the other videos, check out our FAQs, use this manual and don't forget that the IE4B has context-specific help embedded throughout the program – just click the question-mark icon.

What's under the hood

The Athena Institute is committed to transparency. Whenever possible, and where our limited resources allow, we provide as much information as we can about the mechanics, assumptions, and data underlying our tools.

LCA Methodology

The underlying LCA method used in the IE4B is in alignment with North American standard practice and is consistent with global best practices. We regularly update our methodology as required to maintain compliance with ISO, EN, and North American standards.

Scope and system boundary

The IE4B can model constructed works at any scale (whole building, building element, construction assembly, building product) and can be used for various types of buildings (residential, commercial, industrial) and construction projects (new construction, renovation, refurbishment).

The geographic coverage of the tool is the United States and Canada.

The IE4B conforms to the EN 15804/EN 15978/ISO 21930 system boundary and reporting format. Table 1 (next page) summarizes which information modules are currently covered by the program and the processes accounted for by each. While it is expected that some of the missing information modules[3] will be incorporated into the program as data and funding become available, its present capacity is sufficient for most current needs including compliance with the LCA requirements in all North American green building codes and rating systems.

The software 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.

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[3] While the IE4B does not fully support Maintenance (B2), Repair (B3), and Refurbishment (B5) modules, an advanced user can model these effects provided [1] material/fuel use quantities for these activities are known and [2] the materials/fuels are available in the program.

Table 1   IE4B system boundary capacity

Information Module	Supports?	Processes Included
A1 Raw material supply	Y	Primary resource harvesting and mining
A2 Transport	Y	Transportation of materials up to manufacturing plant gate
A3 Manufacturing	Y	Manufacture of raw materials into products
A4 Transport	Y	Transportation of materials from manufacturing plant to site
A5 Construction-installation process	Y	Construction equipment energy use, and life cycle affects effects of construction waste
B1 Installed product in use	N	Not currently well-supported with data
B2 Maintenance	Partial	Painted surfaces are maintained (i.e. repainted), but no annual maintenance aspects are included due to lack of data
B3 Repair	N	Not currently well-supported with data
B4 Replacement	Y	Life cycle effect of replacement materials
B5 Refurbishment	N	This module applies to known future refurbishment and needs to be addressed on a case-by-case basis if applicable
B6 Operational energy use	Y	Energy primary extraction, production, delivery, and use
B7 Operational water use	N	Not supported
C1 De-construction demolition	Y	Demolition equipment energy use
C2 Transport	Y	Transportation of materials from site to landfill
C3 Waste Processing	Y	Most material data does not include waste processing effects, except for metal scrap collection and pre-processing.
C4 Disposal	Y	Disposal facility equipment energy use and landfill site effects
D Benefits and loads beyond the system boundary	Partial	Metals recycling

Object of assessment

IE4B modeling capacity currently encompasses the structure, enclosure, partitions, and operating energy use of a constructed work, as summarized in Table 2. The available building products can be combined in various ways to model the vast majority of structure, enclosure, and partition construction assemblies commonly in use in North America (an estimated 1,500+).

Similarly, the available operating energy fuels noted in the table cover the vast majority of building service system fuel sources used. Environmental profiles of the building products and operating energy fuels typically reflect industry-average practice (i.e. not specific to any particular manufacturing plant or energy producer) and the region the building is located in.

Table 2 IE4B object of assessment scope capacity

Material Use	Operating Energy Use
There are currently 200+ pre-defined structure and enclosure building products that can be used to model the following OmniClass Table 21 level 2 elements: 01 10 Foundations 01 20 Subgrade Enclosures 01 40 Slabs-On-Grade 02 10 Superstructure 02 20 Exterior Vertical Enclosures 02 30 Exterior Horizontal Enclosures 03 10 Interior Construction	Can be used to model any energy end-use fuelled by: • Grid electricity • Natural gas • Liquefied petroleum gas • Diesel • Heavy fuel oil • Gasoline

Impact assessment

The IE4B creates 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 differentiated flows from and to nature in the form of energy and raw material flows as well as emissions to air, water, and land. The IE4B supports the following midpoint life cycle impact assessment measures based on the US EPA Tool for Reduction and Assessment of Chemical and Other Environmental Impacts[4] (TRACI) and in accordance with ISO 21930/31:

- Global Warming Potential - CO_2 equivalent mass

- Acidification (Air) Potential - SO_2 equivalent mass

- Human Health Particulate - 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 mass

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[4] TRACI v2.1; 2012.

Additional primary resource indicators reported:

- Total Primary Energy Consumption – MJ
- Non-Renewable Energy Consumption – MJ
- Fossil Fuel Consumption – MJ

Additional inventory parameters reported:

- Global Warming Potential – Biogenic – CO_2 equivalent mass
- Global Warming Potential – Calcination – CO_2 equivalent mass

Environmental data

Calculations in the IE4B draw on background environmental data on materials and energy. Athena environmental databases include detailed, high quality, harmonized, regionalized, life cycle inventory (LCI) data when available. Where LCI data is not available for a product, we create proxy LCI data for the single purpose of conducting our internal life cycle impact assessment (LCIA) calculations.

The Athena LCI database is comprised of ISO 14040/14044-compliant unit process LCI data (e.g., concrete manufacturing LCI results per m^3 concrete) related to basic materials, building products and components, fuel use, and transportation. The database is regionally sensitive, taking into consideration manufacturing technology, transportation, and electricity grid differences. Athena databases are typically built from the ground up using actual mill or engineered process models. New regions are added to the software as our resources allow.

See Table 3 for structural and envelope materials supported by the IE4B and the vintage of the LCI data for each one. Additional LCI data available in the IE4B – not listed in this table – includes a large number of raw materials such as aggregates, recycled concrete aggregate, and so forth.

Table 3 IE4B product LCI database

Product	Vintage	Comments
Cement and Concrete products		
Canadian and US Cements	CDN 2023 US 2021	- General use (GU) and portland limestone (GUL) cements supported for Canada and the US based on industry wide EPDs - US cement profiles available at https://pcr-epd.s3.us-east-2.amazonaws.com/634.EPD_for_Portland_Athena_Final_revised_04082021.pdf and https://pcr-epd.s3.us-east-2.amazonaws.com/635.EPD_for_PLC_Athena_Final_revised_04082021.pdf - Canadian Profile available at https://pcr-epd.s3.us-east-2.amazonaws.com/919.CAC_General_Use_(GU)_and_Portland-Limestone_(GUL)_Cements.pdf

Product	Vintage	Comments
Ready Mix Concrete – includes over 150 benchmark and alternative concrete strength class mix designs (see File>Bulk Product projects library folder included in the software)	CDN 2022 US 2021	• Profiles are linked to the above cement profiles depending on location. Note that the mix designs provided for use in Tools>User Defined Concrete Mix Design Library are the mixes only, i.e. the physical quantities of each material that were used in the EPD study. The background data used in the calculation of the LCA effects may (probably) have changed since the LCA was published. For example, both in the US and Canada, the Portland cement profiles have both been updated (see above) since the LCAs mentioned below were performed. • The A3 (Ready Mix Concrete Process) effects have been modeled for each region in the US and Canada as reported in both LCAs and are used in the tool's ready mix calculations. • US mix designs derived from NRMCA industry wide EPD and LCA benchmark report – see https://www.nrmca.org/wp-content/uploads/NRMCA_LCAReportV3.2_2023.pdf • The 2021 version of the US (NRMCA) reports Benchmark and EPD mix designs and those are reflected in the mixes accessible in the File>Bulk Products Projects feature. • Canadian mix designs derived from 2015 CRMCA industry wide EPD– see https://www.crmca.ca/ • The 2022 Canadian ready mix LCAs were performed differently from 2015. Each regional association has published its own LCA, and the mix designs are regionalized, and there are also no Industry Average Benchmark designs as in 2015. The mix designs themselves have also not been published. For those reasons, the Canadian mix designs in File>Bulk Products Projects and the benchmark designs used in assembly dialogs have not changed in v5.5, They still represent reasonable designs for those strength classifications, but they are not the same mixes that were used in the LCAs. Keep in mind that those mix designs can still be used as starting points in designing your own mixes by copying and tweaking the designs to your needs. • The regional Canadian ready mix EPDs can be found at https://www.astm.org/products-services/certification/environmental-product-declarations/epd-pcr.html
Concrete Masonry Units (CMU) normal and light weight	US 2016 CDN 2022	• Canadian profiles based on CCMPA EPD see https://pcr-epd.s3.us-east-2.amazonaws.com/311.EPD_for_CCMPA_Normal-Weight_And_Light-Weight_Concrete_Masonry_Units.pdf • There is no US industry wide profile; the v5.5 data remains unchanged from 2016, which were adjusted for electricity, cement profile and raw material transportation for US locations.
Precast products – structural, architectural panels and insulated panels	US 2019 CDN 2023	• CDN profiles based on 2023 regional EPDs-see https://pcr-epd.s3.us-east-2.amazonaws.com/914.CPCI_Structural_Precast_Concrete.pdf and https://pcr-epd.s3.us-east-

Product	Vintage	Comments
		2.amazonaws.com/912.CPCI_%20Architectural_Precast_Panel.pdf and https://pcr-epd.s3.us-east-2.amazonaws.com/915.CPCI_Insulated%20_Precast_Panel_Concrete.pdf • US Profiles based on N. American industry average EPDs - see https://pcr-epd.s3.us-east-2.amazonaws.com/464.EPD_for_Precast_Concrete_Architectural_and_Insulated_Wall_Panel.pdf • https://pcr-epd.s3.us-east-2.amazonaws.com/463.EPD_for_Structural_Precast_Concrete_Industry_Wide_EPD.pdf • Precast Panel based on a 6" wythe • Insulated Panel based on a 5" wythe and 2" XPS
Mortar and Grout - specified on a volume basis	2023	• Updated internally - adjusted with US 2021 and CDN 2023 cement profiles and raw material transportation (originally developed in 2005)
Aluminum Products – specified on a mass basis	2014	• Aluminum extrusion and cold rolled sheet profiles based on Aluminum Association EPDs see http://www.aluminum.org/sustainability/environmental-product-declarations • These profiles are methodologically comparable to those for steel see below and Metal Recycling section)
Steel Products – specified on a mass or area basis		
	N. America 2020, 2022	• All profiles updated for steel construction products based on Worldsteel "avoided burden" methodology approach. Data have been regionalized to reflect N. America steel production technologies (BOF/EAF) and market recovery rates (recycling rates). See Metal Recycling section for a brief description of the methodology.
	Source datasets:	
Nails	WR+FP	
Welded wire mesh	WR+FP	
Screws, nut, bolts	WR+FP	
Wide Flange sections	WF	• AISI Life Cycle Inventories of North American Steel Products, Nov 2020 for semi finished hot rolled coil (HRC), cold rolled coil (CRC), hot-dipped galvanized coil (HDG), steel plate (SP) and structural sections (WF).
Open-web joists	WF+FP	
Reinforcing bar	Rebar	
Hollow structural steel	SP+FP	
Steel tubing	HRC+FP	
Hot rolled sheet	HRC	• CRSI EPD Background Report: Fabricated Steel Reinforcement, Sep 2022 for semi finished Rebar. The rebar profile is used as a proxy for wire rod (WR).
Cold rolled sheet	CRC	
Galvanized sheet	HDG	
Residential cladding	HDG+FP (MBMA)	• Finished products include the semi finished profiles plus a fabrication process (FP). FPs are regionalised with Canadian and the US energy profiles.
Commercial cladding	HDG+FP (MBMA)	
Galvanized decking	HDG+FP	• Scrap profile based on Worldsteel's scrap profile.
Galvanized studs	HDG+FP	• Metal Building Systems updated as per MBMA 2021 LCA (this LCA based on AISI 2020 LCA).
MBS wall and roof cladding	HDG+FP (MBMA)	
MBS Primary and Secondary components	2021	
Wood Products – specified on a volume basis		
Softwood lumber (kiln dried)	US 2020 CDN 2018	• Canadian regional data updated in 2018. BC data 2023. CORRIM data for US reflects PNW, Inland West, NC and SE regions 2020. • Athena report available for Canadian cradle-to-gate profile. See Corrim.org for US reports.

Product	Vintage	Comments
Plywood	US 2020 CDN 2019	• Canadian regional (BC only) data originally developed in 1993 updated in 2006, 2012 and 2019. • BC Plywood profile updated 2023. • Athena report available for Canadian cradle-to-gate profile. See Corrim.org for US reports. • CORRIM data for US reflects PNW and SE 2020.
Oriented Strand board	US 2020 CDN 2019	• Canadian regional data originally developed in 1993 updated in 2006, 2012 and 2019. • Athena report available for Canadian cradle-to-gate profile. See Corrim.org for US reports. • CORRIM data for US reflects SE 2020.
Laminated Veneer Lumber	US 2020 CDN 2019	• Canadian regional data originally developed in 1993 updated in 2012 and 2019. • Athena report available for Canadian cradle-to-gate profile. See Corrim.org for US reports. • CORRIM data for US reflects PNW and SE production in 2020.
Glulam Sections	US 2020 CDN 2019	• Canadian regional data originally developed in 1993, updated in 2011 and 2019. • BC Glulam profile updated 2023. • Athena report available for Canadian cradle-to-gate profile. See Corrim.org for US reports. • CORRIM data for US reflects PNW and SE production in 2020.
Wood I-Joists	US 2020 CDN 2019	• Composite product of softwood lumber, LVL, OSB or plywood with fabrication process. Canadian fabricating data updated in 2019, US fabricating data updated in 2020.
Cross Laminated Timber	CDN 2020 BC 2022	• CLT data from the Canadian Mass Timber LCA (CLT and DLT) 2020. • British Columbia performed and LCA on BC CLT in 2023. • There is no industry wide CLT CLA in the United States; US regions are using the Canadian Mass Timber data.
Wood bevel siding Wood tongue and groove siding Wood shiplap siding	CDN 2018 US 2020	• Wood siding profiles derived from softwood lumber profiles and prorated by volume.
Envelope materials		
Metal cladding residential Metal cladding commercial MBS roof and wall cladding	2021	• Updated per MBMA 2021 LCA
Common clay brick (modular and standard)	2009	• Canadian clay brick data first developed in 1998 updated in 2009. Adjusted for US by substituting electricity grids and transportation distances. • Athena report available.
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. • Athena report available.

Product	Vintage	Comments
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. • Athena report available.
PVC vinyl siding	2010	• Originally developed in 1998 and updated in 2009. • PVC polymer portion reflects new 2010 ACC data. • See US LCI database (www.nrel.gov/lci) for data.
Fiber Cement Siding	2009	• Originally developed in 2009.
Natural Stone	2009	• Developed in 2009 from a secondary data source.
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 2007 based on ACC polypropylene profiles (updated in 2010).
Insulation products	Various for NA	• There have been several changes and updates to most insulation data; see Appendix A.
Expanded polystyrene	2007	• No change.
Spray Polyurethane Foam-closed and open cell	Various	• Added in 2023.
Mineral Wool	Various	• Updated in 2023.
Fiberglass	Various	
Polystyrene XPS and EPS	Various	
Polyisocyanurate	Various	
Cellulose	Various	
Paint Products	Various for N. America	
Basic latex, solvent based and varnish		• Originally developed in 1998 and updated in 1999. Athena report available – due to be updated.
Gypsum Board Products		• The North American 2020 gypsum board LCA was updated for ½" Lightweight (previously regular) and 5/8" Fire Rated only. Moisture resistant and gypsum fibre board have been discontinued and replaced by the above.
1/2" Lightweight 5/8" Fire rated	2020	• Originally developed in 1997. • 1/2" lightweight (replaces Regular) and 5/8" fire rated GWB updated in 2020.
Joint compound and paper tape	1997	• Originally developed in 1997.
Glass Mat Gypsum Panels	2021	• Industry wide EPD commissioned by the Gypsum Association see https://www.americangypsum.com/resource-center/sustainability/epd-environmental-product-declaration
Roofing Products	Various for N. America	
3 tab shingles - organic		• Originally developed in 2000 and 2001. • Athena report available

Product	Vintage	Comments
3 tab shingles - glass		• Originally developed 1998 to 2001.
#15 and #30 organic felt		• Athena report available.
Type III and IV glass felt		• Adjusted and updated for US by substituting US cement profile, electricity grids and transportation distances (2008).
Mineral roll roofing		
Clay tile		• Athena report available.
Concrete tile		• Originally developed in 1998. • Adjusted and updated for US by substituting US cement profile, electricity grids and transportation distances (2008). • Athena report available.
BUR glass felt based shingles	2001	• Originally developed in 2001.
BUR organic felt based shingles	2001	• Athena reports available.
Roofing asphalt	2001	• PVC 48mil updated with CFFA 2020 EPD https://www.astm.org/products-services/certification/environmental-product-declarations/epd-pcr.html.
GAF TPO membranes (white)	2013	
Duro-Last PVC membranes	2014/2016	
Sika Sarnafil PVC membranes	2018	
PVC Membrane-48mil	2020	
EPDM membrane (non-reinforced and reinforced)	2022	• EPDM white and black replaced by SPRI 2022 LCA for reinforced and non-reinforced, thicknesses from 45mil to 90mil https://www.spri.org/resources-education/
Modified Bitumen	2001	
TPO	2023	• TPO industry average EPD SPRI 2023 EPD, 45mil to 80mil https://www.spri.org/resources-education/ • GAF TPO (5 products) added in 2013. Based on EPDs. • Duro-Last PVC (12 products) added in 2014 and 2016 – based on EPDs. • Sika Sarnafil PVC (11 products) added in 2016 updated in 2018. Based on EPDs.
Windows	Various for N. America	
Unclad Wood Frame (Double and Triple pane)	2013	• Frame and insulated glazing unit data and quantity take offs updated in 2013. • PVC polymer portion to reflect new 2010 ACC data. • 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.
PVC Frame (Double and Triple pane)	2013	• Frame and insulated glazing unit data and quantity take offs updated in 2013.
Vinyl Clad Wood Frame (Double and Triple pane)	2013	• PVC polymer portion to reflect new 2010 ACC data.
Metal Clad Wood Frame (Double and Triple pane)	2013	• See US LCI database (www.nrel.gov/lci) for data.
Aluminum Frame (Double and Triple pane)	2002	• Added fiberglass frame in 2012.
Double and Triple pane glazing, Hard (Tin) and Soft (Silver or Tin) Coated, Air and Argon Filled	2013	• Updated quantity take-offs in 2010 for PVC and wood windows.

Regional specificity

User selection of a region activates appropriate electricity grids, transportation modes and distances, and product manufacturing technologies applicable to the product mix for the selected region.

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 is the closest representation of the actual building site location.

In regionalizing our data, we complete a regional product market share analysis to determine where products are typically coming from for each region. 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 aggregate, are more local 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. However, the transportation component for offshore products is included with regional specificity.

Having said that, there is a trend towards cradle to gate LCA and EPD reports focussing on producing average Canadian, American, or North American product profiles, using, for example, national average electricity profiles, which means the regional specificity of the manufacturing data is lost.

In other cases, the national or industry wide LCAs report regional subsets that do provide some regional specificity. An example of this would be the NRMCA ready mix concrete LCA, which used a national profile for US cement but specified ready mix processing (A3) energy for each of NRMCA's eight manufacturing regions.

As of v5.5, these "rolled up" datasets represent about two thirds of the material in the database, which means some of these have limited regionalization. The significant materials that are not rolled up and use more complete regional calculations are shingles and bitumen-based roofing products, brick and stucco, paints, window frames and glazing, and aggregates.

Electricity supply is also an important consideration, and the software supports regional locations in various ways. Starting with v5.4, the source data for electricity has been changed to Ecoinvent 3.8 profiles for Canadian provinces and US NERC regions, but the methodology described above remains the same. The Canadian provinces that are supported in the Impact Estimator are fully supported and compartmentalized in the EcoInvent electricity data. For the United States, EcoInvent electricity data is specified by NERC (North American Electric Reliability Corporation) Region. Some states consume electricity from multiple NERC regions. Each state has multiple electricity generation plants, each of which contribute to a specific NERC region. For each state, we use the percent breakdown of MWh electricity generated by plants in that state contributing to each NERC region to calculate the contribution by each NERC region to the electricity consumed in that state.

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.

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

Scenario data

To complete the life cycle past the factory gate (A3), scenario data is needed – these are the assumptions that determine gate-to-grave material and energy consumption. The following describes the scenario data in the IE4B.

Module A4: Transportation to construction site

Module A4 takes 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 and modes in our database were based on regional surveys and other information sources; some of this data is old and/or of unknown provenance. We have distance and mode data for every material and every region in our database, for a table with over 12,000 rows – too large to reproduce here.

Module A5: Construction

Module A5 takes account of processes during the construction stage, to the extent that we have data. This includes construction equipment energy consumption, construction waste, and management of the waste.

For the most part, A5 calculations are limited due to a severe lack of generic data on construction energy consumption. This means that A5 impacts are almost certainly underestimated. We do have some comprehensive A5 data available for a few assemblies in the software (e.g., the use of formwork for cast-in-place concrete), but not most. For applicable materials, whether part of an assembly, entered as Extra Materials, or from an imported BoM, the IE4B applies crane energy as described below.

The IE4B includes crane energy. For those assemblies and materials that are likely to be mechanically lifted (all envelope materials and Extra Materials), we calculate the energy required to lift those materials, by crane, an average distance of half of the height of the building.

Module A5 includes waste generated during construction. The IE4B applies a construction waste factor for each material to acknowledge the material consumption represented by cut-offs, and unused, lost, or damaged materials. Different materials have different waste factors, and some that arrive on site preassembled and ready to install (e.g. windows, precast panels) have a 0% waste factor. The waste factor for materials in the Athena database ranges from 0% to 15%. The source of this data was industry consultation. The life cycle impacts of waste material are included in the LCA.

On-site construction does not include site prep or utility hook-ups. Every site will be different with different soil conditions, and it is impossible to generalize the effects based solely on the building footprint. Also, since the IE4B is often used as a comparative tool for different building materials and systems, the site prep for any comparative designs will likely be similar for each design. Similarly, utility hook-ups, which will depend mainly on their proximity to existing services, will be the same for any comparative designs and therefore will not affect the relative differences between those designs.

Also not included in on-site construction effects are transportation of workers or equipment, capital equipment, or water use during construction.

Module B1: Installed product in use

This module is not applicable for most products. It typically is a factor for HVAC systems (refrigerant leaks), which are not addressed in the IE4B, and for some insulations (off-gassing from blowing agents); B1 for insulations is not addressed in the IE4B – see the appendix for more information on insulation methodology.

Module B2: Maintenance

The only B2 activity the IE4B includes is regular repainting of surfaces that were originally painted. The IE4B assumes a painting schedule of 10 years. The life cycle effects of the additional paint are included. Other maintenance activities are excluded due to a lack of data and due to a lack of required maintenance for most of the materials in the Athena database. Module B2 is more of an issue for materials that require cleaning, like floor finishes, which are not in the Athena database.

Module B3: Repair

The IE4B does not include repair activities due to a lack of data and the difficulty in predicting in advance what repairs will be required.

Module B4: Replacement

The IE4B assumes some materials have a shorter life span than the life of the building, and it includes life cycle effects for those additional materials. For example, if a roof is assumed to need replacement every 25 years, running a model for 60 years will include life cycle impacts for three roofs (the original, plus a replacement at year 25 and another replacement at year 50).

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.

Most materials in the IE4B are assumed to last as long as the building and therefore have no replacement effects. For other materials, typically those that are exposed to the elements or wear and tear, the IE4B assumes replacement schedules based on empirical data, industry data (product warranties), and other sources.

The IE4B assumes different replacement schedules for different building types. Specifically, it assumes 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.

The software assumes that replacement materials or components will be the same as those used in original construction. This may 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.

Replacement schedules for some IE4B materials are shown below. Ranges shown reflect variations across building types and specific products.

- Roofing membranes: 15-35 years
- Paints: 10 years
- Wood siding: 25 years
- Metal wall cladding: 30-35 years
- Vinyl cladding: 35 years
- Stucco: 50 years
- Brick: 75 years
- Spandrel panel: 33 years
- Window frames and glazing: 30 years
- Metal roof: 60 years
- Felts and shingles: 15-27 years
- Fiber cement; clay tile: 50 years
- Other roofing: 19-23 years
- Precast panels: 75 years

Module B5: Refurbishment

This module only applies if there is a known plan for refurbishment. The IE4B does not include B5 due to lack of data.

Module B6: Operational energy use

The IE4B can include operating energy (heating, cooling, ventilation, etc.) in the LCA results. Operating energy consumption by fuel type (electricity, natural gas, fuel oil, etc.) is calculated by other means, such as with energy simulation software, and then fuel figures are entered via an IE4B dialog box. The IE4B then calculates 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. If operating energy is provided by the user, comparisons between operating and embodied impacts can be made.

The IE4B does not include transportation by building occupants.

Module B7: Operational water use
The IE4B does not include B7.

End-of-life: Modules C1 to C4
Predicting what happens to the building materials at end of life is a significant forecast into the future and therefore brings uncertainty to the LCA results. Landfill dynamics are particularly important to the results for materials subject to decay, like wood. We use the best available industry literature and environmental data for the end-of-life calculations in the IE4B.

Module C1: De-construction/demolition
Module C1 includes the processes required to deconstruct or demolish the building. At the user-defined expected building end of life, the software estimates the energy required to deconstruct or demolish the major structural systems of the building. It is assumed that the envelope materials are demolished during the structural demolition but have little influence on the demolition energy use. The IE4B determines the final disposition of these materials based on demolition industry statistics: the proportions reused, recycled, incinerated, and landfilled. The IE4B assumes that materials commonly landfilled today will continue to be landfilled, and those currently recycled or re-used will continue to be recycled and reused.

Module C2: Transport
Module C2 is the transportation of materials from the building site to landfill, incineration, reuse, or recycling sites. The software takes account of the energy use and related emissions associated with transportation to these sites assuming typical modes and distances to landfill for the region.

Module C3: Waste processing
Module C3 is the collection and pre-processing of waste before it goes to landfill. Except for metals, products that are recycled, reused, or incinerated for energy recovery are deemed to have left the system boundary and any credits or burdens associated with these products are accounted for in the next use. For metals, the IE4B includes in Module C3 the collection and pre-processing of scrap. We acknowledge that this may be a misinterpretation of the standards.

Module C4: Disposal
The IE4B applies a landfill operations process to the mass of materials entering the landfill. This is the energy consumed to handle materials in the landfill (typically diesel-fueled heavy machinery)[5].

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[5] Sanitary landfill model as published in ecoinvent database: http://www.doka.ch/13_I_WasteTreatmentGeneral.pdf

Module C4 is primarily concerned with landfill dynamics. Most materials are inert in landfill. This is not the case with materials of biological origin, which can decay in landfill. In the IE4B, this is an issue for wood.

The IE4B assumes 72.6% of wood waste goes to landfill[6]. Of the wood that is landfilled, 90% is assumed sent to anaerobic landfills and 10% to aerobic landfills[7]. Anaerobic landfill is accounted as a first order decay with a 11% annual decay rate applied to the 12% 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[8]. The fate of this landfill gas is dependent on the presence of landfill gas capture equipment and its recovery efficiency. The software assumes 82% of the landfill gas generated in the anaerobic landfill occurs in those that have landfill gas capture wells in place[9]. The average efficiency of those landfills that have capture equipment is 90%[10].

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. Landfill gas generated in anaerobic landfills that is not captured is directly emitted as 55% carbon dioxide and 45% methane on a molar basis. Of the landfilled wood, the landfill gas generated in the anaerobic landfills that have no landfill gas capture wells in place is similarly emitted entirely to the atmosphere as 55% carbon dioxide and 45% methane.[11] Similar to the anaerobic landfill, in the aerobic landfill, the decomposition is accounted as a first order decay with an 11% annual decay rate applied to the 12% of wood that decomposes[12]. The carbon in the decayed wood is 100% converted to carbon dioxide.

Metal recycling

Metal recycling (as scrap) is modeled using a closed loop recycling or avoided burden methodology.

In 2011, the World Steel Association (worldsteel) completed its third iteration of its global LCI dataset covering 15 steel products[13]. In 2013, the latest North American regional steel LCI data

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[6] Advancing Sustainable Materials Management: 2018 Fact Sheet Assessing Trends in Materials Generation and Management in the United States. https://www.epa.gov/sites/default/files/2021-01/documents/2018_ff_fact_sheet_dec_2020_fnl_508.pdf

[7] Landfill model parameters from USEPA Documentation for Landfilling Used in the Waste Reduction Model (WARM).

[8] Ibid.

[9] Portion of anaerobic landfills w/ LFG technology from Dymond, Caren (2012): Forest Carbon in North America: annual storage and emissions from British Columbia's harvest, 1965-2065. Carbon Balance and Management: (7)8. Table 9.

[10] Landfill model parameters from USEPA Documentation for Landfilling Used in the Waste Reduction Model (WARM) Version 12. Documentation@ http://epa.gov/epawaste/conserve/tools/warm/pdfs/Landfilling.pdf

[11] Ibid.

[12] Dump decay rate from Skog, Kenneth E. (2008): Sequestration of carbon in harvested wood products for the United States. Forest products journal. (58)6: 56-72. Table 7. Derived from: IPCC (2006) Guidelines for National Greenhouse Gas Inventories. Vol 5. Table 3.4.

[13] Life cycle assessment methodology report © World Steel Association 2011 http://www.worldsteel.org/dms/internetDocumentList/bookshop/LCA-Methodology-Report/document/LCA%20Methodology%20Report.pdf

were made available to the Athena Institute by the Steel Recycling Institute (SRI) and worldsteel, in cooperation with the American Iron and Steel Institute (AISI). In 2015, North American aluminum LCI data were also made available by the Aluminum Association[14]. In 2020, AISI provided updates for structural steel. In 2022, the Concrete Reinforcing Steel Institute (CRSI) provided updates for rebar. The Athena Institute has integrated these LCI data into the IE4B, and the data is reflected in all steel and aluminum construction products in the software.

Four cradle-to-gate LCI profiles of North American semi-finished aluminum (castings, extrusions, and hot and cold rolled sheet) and seven semi-finished steel (plate, hot-rolled coil-HRC, cold-rolled coil- CRC, hot-dip galvanized steel-HDG) and finished (rebar, sections, wire rod) steel products, were provided to Athena. It should be noted that these data are constantly being reviewed by the industry and others and are deemed "*interim*".

These LCI datasets were used to model "cradle-to-grave" LCI profiles for all Athena finished aluminum and steel products such as aluminum window frames, aluminum curtain wall framing, 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.

Aluminum and steel data use the same "avoided burden" methodology; we'll use steel as an example to describe it. 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:

$$\text{LCI for 1 kg of steel product including recycling} = X - (RR - S) \times Y \times (X_{pr} - X_{re})$$

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.

Y   is the process yield of the EAF (i.e. >1 kg scrap is required to produce 1 kg steel).

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[14] The Aluminum Association 2013. The environmental footprint of semi-finished aluminum products in North America.

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 the avoided burden 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)

The "**credit**" for steel recycling at the end of the final products life would result in subtracting the LCI value of steel scrap[15]. 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:
    $ScrapLCI = Y \times (X_{pr} - X_{re})$

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, and multiplied by the yield of this process to consider losses in the process[16]. 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 IE4B as per the avoided burden recycling methodology.

Furthermore, we applied the SRI 2013[17] recycling rates (RR) for both structural and reinforcement steel for the reference year 2011. A 95% end-of-life recycling rate is incorporated in the IE4B for aluminum products.

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

To the "cradle-to-gate" North American steel LCI dataset the Athena 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:

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[15] Life cycle assessment methodology report © World Steel Association 2011, 7.2 LCI value of steel scrap, pg 39.
[16] Life cycle assessment methodology report © World Steel Association 2011, 10.6.2 The LCI of steel scrap, pg 75.
[17] SRI 2013:
http://www.recycle- steel.org/en/Recycling%20Resources/~/media/Files/SRI/Media%20Center/RateSheet2011.pdf

- 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.

- 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.

- 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*[18] as per worldsteel.

For example, the cradle-to-grave environmental profile of galvanized studs consists of the "cradle-to gate" profile of North American 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 the avoided burden recycling methodology.

Aluminum/Steel Database User Guidance
As a user of the IE4B software, when interpreting the summary impact indicator results for aluminum and steel products/assemblies, you may want to refer to project table reports 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. The Life Cycle Stage reports are aligned with EN 15804 and EN 15978 in terms of capturing recycling benefits that are "beyond the building life cycle" (Module D, grave).

Biogenic carbon

Biogenic carbon is an expression for the carbon dioxide (CO_2) flows between the atmosphere and bio-based products. Living plants absorb CO_2 from the atmosphere, store it as carbon in their mass, and the carbon is eventually released upon combustion or decomposition of the material.

The following references guide our method of accounting for biogenic carbon in the Athena Impact Estimator for Buildings and the web app Athena Building LCA:

- National Guidelines for Whole-building LCA (NRC 2022) section 6.3.1

- ISO 21930:2017 section 7.2.7

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

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

- UL Envt PCR for building products Part A (general PCR for all products) v4 and Part B: wood v1.1

- ACLCA guidance to 21930:2017, sections 8.1 and 8.2 (2019)

According to the national guidelines (Guideline 14.1), biogenic carbon should be included in whole-building LCA results. According to ISO 21930:2017 section 7.2.12, biogenic carbon shall be separately reported if included in the GWP. According to ISO 21930:2017 section 7.2.7 and 9.5.2, biogenic carbon flows shall be accounted for in the information module in which they occur. This is also stated in the national guidelines (Guideline 14.2). The ACLCA guidance recommends specific modules, which we are following. The UL Environment PCR Part A, section 4.2 and Part B: wood, section 3.10 specify that the requirements of ISO 21930 section 7.2.7 be followed.

Our reporting approach:

- Provide GWP total.

- Provide GWP biogenic carbon portion of the total.

- If users wish to have GWP without biogenic carbon, they can subtract GWP biogenic from GWP total.

- Report results in modules as follows:
  - Removals from atmosphere and captured in the product: module A1.
  - Emissions from biomass combustion, packaging and from wastes in manufacturing: module A3.
  - Removals and emissions associated with construction waste and biobased packaging: module A5.
  - Removals and emissions associated with product replacement: module B4.
  - Emissions at end of life: modules C3 or C4.

According to ISO 21930:2017 section 7.2.7 and section 7.2.11, bio-based products can only be credited with a CO_2 removal in module A1 if derived from sustainably harvested forests. Per ISO 21930 Section 7.2.11, wood is deemed sustainably sourced if either:

- The forest is certified to recognized forest management standards such as CSA, SFI and FSC; or

- The source country can demonstrate non-decreasing forest stocks through the national reporting for the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC annual national reports generally show non-decreasing forest carbon stocks in the US and Canada, and thus our default assumption is that source forests meet the conditions for characterization of removals with a factor of -1 kg CO_2e/kg CO_2.

Emissions other than CO_2 associated with biomass combustion (e.g., methane or nitrogen oxides) are characterized by their specific radiative forcing factors in the calculation of the GWP based on modeling published by the US EPA WARM model[19].

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[19] https://www.epa.gov/warm

The following is an example calculation of the Biogenic GWP LCA measure[20] for 1m^3 Small Dimension Softwood Lumber, kiln-dried based on the WARM model and the North American EPD for softwood lumber[21].

Assumptions for the example:

- wood density = 460.18 kg/m³ (from the EPD)

- Construction waste factor = 8% (IE4B factor)

- % of material that goes to landfill = 72.6% (WARM model)

- Methane GWP characterization factor = 25 (TRACI factor)

- Carbon dioxide, biogenic, landfill factor= 94.75 kgCO_2/m³ (WARM model)

- Methane, biogenic, landfill factor= 1.62 kgCH_4/m³ (WARM model)

- Hog fuel- Biogenic Carbon Removal from Combustion of Waste from Renewable Sources Used in Production undergoes complete combustion (100% of carbon is converted to CO_2)

- Mass of molecular carbon C = 50% mass of softwood lumber

- kgCO_2eq = mass of carbon in kg x 44 (molecular weight of CO_2) / 12 (molecular weight of C)

See Table 4 for the results, also explained below.

The A1-A3 total includes (shown in red in the table):

- Biogenic Carbon Removal from Product (BCRP) of the material = - 460.18 kg/m³ x 0.5 kg C/kg of material x 44/12 = - 843.66 kg CO_2eq (removal from atmosphere by the living tree)

- Hog fuel BCRP = - 100.8 kg x 0.5 kg C/kg of material x 44/12 = - 184.40 kg CO_2eq (removal)

- Biogenic Carbon Emission from Combustion of Waste from Ren. Sources Used in Production (BCEW) of the Hog fuel = 100.8 kg/m³ x 0.5 kg C/kg of material x 44/12 = - 184.40 kg CO_2eq (complete combustion, emitted to atmosphere)

- Biogenic Carbon Removal from Packaging (wood portion of packaging) (BCRK) = -0.736 kg/m³ x 0.5 kg C/kg of material x 44/12 = - 1.35 kg CO_2eq

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[20] It should be noted that wood manufacturing data is somewhat regionalized and the results in the database reflect this. Different manufacturing regions generally have different densities and hog fuel use (important factors in the biogenic removal and emission calculations). However, the GWP Biogenic calculations are using the weighted average values from the North American EPDs (Canadian mass timber report for CLT) in every location/region.

[21] https://awc.org/sustainability/epd-tb/

The A5 total includes (shown in blue in the table):

- Biogenic Carbon Emission from Packaging (BCEK) – this calculation is based on 1 m³ of lumber in A1-A3, but it is accounted for in A5. In the table below it is included in the A5 total, but is in red because it is dependant on the A1-A3 material quantity.

- The remaining A1, A3 and A5 calculations are the same as above, but for the waste portion of wood, 0.08 m³, they are listed under the module to which they pertain, but all are included in the A5 total.

- The waste 0.08 m³ goes to landfill and is treated the same as below (same calculations as C3/C4), but is included in the A5 total.

The C3/C4 total includes (shown in green in the table):

- This accounts for the end of life accounting of the original A1-A3 1 m³ of wood that is demolished and leaves the building system boundary.

- BCEP 72.6% goes to landfill, therefore 27.4% is otherwise used or recycled, module C3. The IE4B does not calculate end of life processing other than landfilling, so 0.274 x 1 m³ x 460.18 kg/m³ x 0.5 kg C/kg of material x 44/12 = 231.16 kg CO_2eq (positive because it is leaving our system boundary-treated as an emission)

- BCEP for the 72.6% that goes to landfill, and decomposes, emitting CO_2 and methane in proportions provided by the WARM model, module C4. 0.726 x 1 m³ x 94.75 kgCO_2/m³ = 68.79 kg CO_2eq (positive-emission to atmosphere)

- BCEP Methane, module C_4, 0.726 x 1 m³ x 1.62 kgCH_4/m³ = 1.17 kgCH_4 x 25 char. Factor = 29.40 kg CO_2eq (positive-emission to atmosphere)

B4 Replacement note: Wood sidings and window frames with wood are replaced in B4 and the same calculations as described in A5 (except for the first one which comes from the 1 m3 of A1) will apply, but the material quantity will include the replacement amount plus the construction waste factor.

Table 4 Example Biogenic GWP Results, 1 m³ Softwood Lumber, kg CO₂eq

	Additional Inventory Parameters	A1	A3	A5	C3	C4
BCRP-A1	A1 Biogenic Carbon Removal from Product (1m³)	-843.66				
BCRP-A1	A1 Biogenic Carbon Removal from Combustion of Waste from Ren. Sources Used in Production (hog fuel) (1m³)	-184.80				
BCRK-A3	A3 Biogenic Carbon Removal from Packaging (1m³)		-1.35			
BCEW-A3	A3 Biogenic Carbon Emission from Combustion of Waste from Ren. Sources Used in Production (hog fuel) (1m³)		184.80			
	A1-A3 Total	-845.01				
BCEK-A5	A5 Biogenic Carbon Emission from Packaging (A1 1m³)			0.75		
BCRP-A5	A1 Biogenic Carbon Removal from Product (A5 construction waste 0.08m³)			-67.49		
BCRP-A5	A1 Biogenic Carbon Removal from Combustion of Waste from Ren. Sources Used in Production (hog fuel) (A5 construction waste 0.08m³)			-14.78		
BCRK-A5	A3 Biogenic Carbon Removal from Packaging (A5 construction waste 0.08m³)			-0.11		
BCEW-A5	A3 Biogenic Carbon Emission from Combustion of Waste from Ren. Sources Used in Production (A5 construction waste 0.08m³)			14.78		
BCEK-A5	A5 Biogenic Carbon Emission from Packaging (A1 construction waste) (A5 construction waste 0.08m³)			0.06		
BCEP-A5	C3/C4 Biogenic Carbon Emission from Product (portion not landfilled) (A5 construction waste 0.08m³)			18.49		
BCEP-A5	C3/C4 Biogenic Carbon Emission from Product (decomposition of landfilled portion) (A5 construction waste 0.08m³)			5.50		
BCEP-A5	C3/C4 Biogenic Methane Emission from Product (decomposition of landfilled portion) (A5 construction waste 0.08m³)			2.35		
	A5 Total			-40.44		
BCEP-C3	C3 Biogenic Carbon Emission from Product (portion not landfilled) (A1-A3 1m³)				231.16	
BCEP-C4	C4 Biogenic Carbon Emission from Product (decomposition of landfilled portion) (A1-A3 1m³)					68.79
BCEP-C4	C4 Biogenic Methane Emission from Product (decomposition of landfilled portion) (A1-A3 1m³)					29.40
	C3/C4 Total					329.36
	Net biogenic carbon emission	-556.10				

Calcination and carbonation

Calcination is a chemical process in cement production that causes carbon dioxide emissions. Calcium carbonate (limestone) is heated to create lime, with carbon dioxide as a by-product. The carbon dioxide emissions for concrete due to calcination are included in the GWP results and additionally called out separately, per ISO 21930:2017.

Carbonation is a process that can happen with concrete exposed to air, whereby carbon dioxide is removed from the air. Calcium hydroxide in cement reacts with atmospheric carbon dioxide (in the presence of water) to create calcium carbonate. The IE4B does not account for carbon dioxide uptake by concrete due to lack of data and method applicable for this tool.

Organization of inputs by building assembly

The IE4B thinks of a building as a collection of assemblies. Users create each assembly by selecting a basic structural system and then adding cladding, insulation, and so forth. This allows for a tremendous amount of flexibility and means the IE4B can address the vast majority of construction systems.

Table 5 IE4B assembly categories and structural systems

Foundations
Concrete footings – perimeter and/or column
Concrete slab on grade
Foundation Extra Materials
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
Cross Laminated Timber
Curtain wall
Concrete tilt-up
Insulated concrete form
Metal Building System Walls
Structural Insulated Panels
Wall Extra Materials
Columns and Beams
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
Column and Beam Extra Materials
Floors
Composite Metal
Concrete suspended slab
Concrete parking garage – drop panel system
Concrete hollow core
Concrete pre-cast double ”T”
Cross Laminated Timber
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)
Floor Extra Materials
Roofs
Composite Metal
Concrete suspended slab
Concrete parking garage – drop panel system
Concrete hollow core
Concrete pre-cast double ”T”
Cross Laminated Timber
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)
Roof Extra Materials

Material quantity calculations

The IE4B operates on a bill of materials: the software needs to know what types and quantities of materials are in the building. Users can directly specify these quantities either through the “extra basic materials” dialog or by importing a bill of materials from a CAD or BIM program – both of these approaches are explained in another section.

However, IE4B users in early design typically don't yet have bill of material information, and they will allow the software to calculate material quantities for them.

The IE4B allows users without a bill of materials to create one, using "assembly dialog" inputs. The software determines the associated bill of materials using a series of background calculations. As more assemblies are selected, the software aggregates the bill of materials to the whole building level. The bill of materials is dynamically updated as you modify and add more assemblies and materials to your project. This section explains how the IE4B calculates material quantities.

Structural materials

The IE4B calculates the amount of structural material required in walls, floors, roofs, and column and beam systems by applying sizing algorithms to user-specified loading and geometry conditions. 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. These background structural sizing algorithms have been developed by the Athena Institute in partnership with structural engineers.

The IE4B material quantity calculations have been compared against detailed manual take-offs from actual design documents and have been found to be generally within 10% of typical "engineered" quantities (exclusive of unique site considerations). This is within the LCA margin of error. However, users are advised to proceed with caution, in recognition that the bill of materials is an estimate and may not fully reflect the actual design intended by the user.

The IE4B has built-in structural data in the form of sizing curves. See Figure 3 below for an example of the sizing curves used by the IE4B. This is the curve used to determine the weight of steel beam required as a function of 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 different user-selectable live loads.
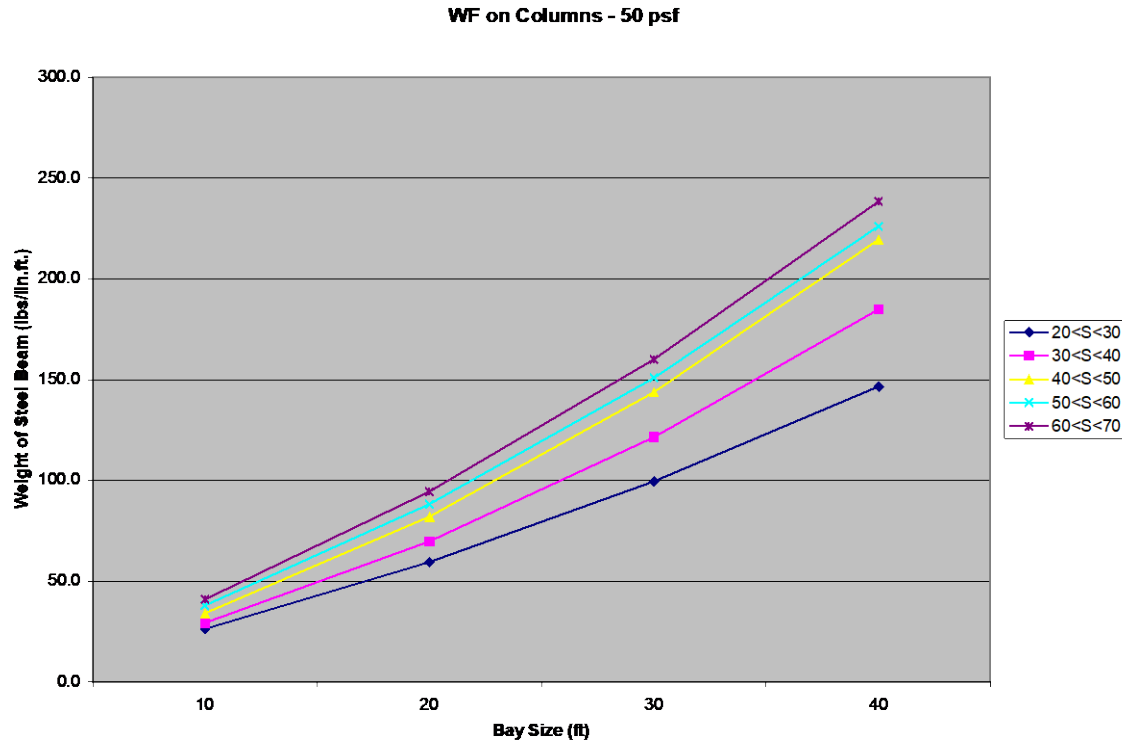
WF on Columns - 50 psf

Figure 3   Example of a structural sizing curve

Note that the IE4B 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. As the design progresses through construction drawings, users may augment these initial take-off quantities with their own bill of materials to better reflect their design and site conditions.

Non-structural materials

Non-structural and envelope material quantities are calculated based on the surface area of the specific assembly to which they are applied. Users identify material layers applicable to each assembly. For example, when insulation and gypsum board materials are added to a wall assembly, the user specifies type and thickness of those elements, and the software determines the amount based on the area of the assembly.

Windows and doors

Window material quantities are calculated based on the total area of openings as well as the number of openings, both of which are indicated by the user for various assemblies. For windows, the software determines the total frame perimeter for each window (either as a fixed or operating frame, assuming an average size based on the total window area and number of windows), and the hardware and net glazing (double or triple lite) required for the type of window selected. As openings are specified, the structural framing requirements of the wall automatically change (addition of studs and headers) to accommodate the opening.

User manual

The IE4B has extensive context-specific help files embedded in the software, which are also accessible here if you are reading this document on-line[22]. In this section, we summarize how to use the software and provide some tips. See the on-line help for detailed explanations.

Starting a new project

When you open the IE4B to start a new project, you will see a blank "workspace" and a blank "tree" to the left of the screen. The workspace is where dialog boxes and result will show. The tree is an organizational display technique used by the IE4B to help you keep track of assemblies, add and modify assemblies, and keep your eye on running totals of LCA results.

Your first step is to "add project." Click File/New, or right-click on "Impact Estimator" in the tree and select "new project." A dialog box appears – you will enter general data about the project: its name, location, building life span, total building height (from basement to roof), total building area, and building type. Enter energy consumption data, if you have it. Also, choose the units – SI (metric) or Imperial – that you wish to operate in. Units can be changed later, or in individual dialog boxes if necessary. Add any notes and click "OK." Now the tree shows a project-level entry with a "P" icon and the name of your project. Save the project.

Now you're ready to build the project. If you already have a model of this building in a CAD or BIM program, you may want to skip down to "using the bill of materials import feature." Otherwise, see below for the steps involved in adding assemblies to your building file.

- Watch a six-minute video demonstration on starting a new project 01-Getting Started.

- Read the help file for adding and modifying projects – Click >Creating a New Project >Add or Modify a Project

- Read the help file about how the tree works – Click >Tree

- Read the help file about how the menus work – Click >Menus

Adding foundations

With a project started and saved in the tree, right-click on the P icon and hover your mouse over Add Assembly, then Foundations, and choose your assembly type, in this case either Concrete Footing or Concrete Slab on Grade. A dialog box will open where you can describe the geometry of your assembly. Enter an assembly name and enter the required values and/or choose options from the radio button lists, and change the units if necessary. For example, in Concrete Footing, you will need to enter a name, length, width, and thickness, and choose a rebar amount and concrete type. Concrete types can be user defined (explained later in this document) or one of the benchmark designs for each strength. Canadian locations will use benchmark mix designs from the CRMCA Ready Mix EPD and US locations will use mix designs from the NRMCA Ready Mix EPD.

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[22] Find it at http://calculatelca.com/software/impact-estimator/help-files/

There is an Envelope tab at the top of the form, from which you can add envelope materials to your assembly. Click on Envelope, then Insert, and a dialog box will appear, where you can choose the Envelope Category and Envelope Material from the drop-down lists. In the case of insulations, you need to enter an insulation thickness. Click OK, and the envelope material that you've just selected will appear in the Envelope Components list. To add another envelope material, click Insert again and repeat the last step.

If you want to use this particular configuration of envelope materials again, click Save as Predefined and give it a name. This will be added to your predefined envelope library and can be quickly added to subsequent assemblies by choosing it from the Predefined Envelope Systems drop down box, then clicking Add.

When you've finished adding envelope materials, click OK, and the new assembly will appear in the tree under the project level, P, as a Foundations assembly group, G, and an assembly, A. Any subsequent Foundation assemblies will appear as a new A under the same G level.

If you wish to modify the assembly, right click and choose modify, or double click on the assembly name at the A level in the tree, and the dialog will open and you can make changes to the assembly.

As with all assembly dialogs, there is a help file specific to that assembly; click the Help button at the bottom of each dialog box.

Starting with v5.2 there is an Extra Materials assembly type added to the Foundations assembly group that allows you to add extra materials specific to this group, and the bill of materials and results tables will account for these materials in this group instead of as Project Extra Materials.

- Watch a six-minute video demonstration on adding a foundation assembly - 02-Adding Assemblies-Foundations.

- Read the help file about how to add a foundation – Click >Add or Modify Assemblies >Foundations

Adding walls

Right click on the Project level, P, in the tree, hover over Add Assembly and Walls and click Custom Walls. Enter an assembly name and the length and height of the wall. Then double click on one of the Available Assembly Components (wall types):

- Concrete Block Wall
- Concrete Cast In Place Wall
- Concrete Tilt–Up Wall
- Cross Laminated Timber Wall
- Curtain Wall
- Insulated Concrete Form Wall
- Steel Stud Wall

- Wood Stud Wall
- Structural Insulated Panels
- Metal Building System – Wall

A dialog will open, and you will have several choices to make, depending on the wall type. For example, in a wood stud wall, you will choose the wall type, sheathing type, stud spacing and stud thickness. Don't forget the Help button at the bottom of each dialog box for explanations on the specifics of each assembly type.

Click on the Opening tab if you want to model windows or doors in the wall. For windows, you need to enter the number of windows and the total area of all the windows in this assembly. The area of each window is assumed to be an average of the total area divided by the number of windows, and the shape of each window is assumed to be a rectangular shape that is longer on the sides and narrower at the top and bottom. Choose Fixed or Operable windows, and the frame and glazing types from the drop-down boxes. For doors, you need to enter the height and width and number of doors and choose the door type from the drop-down box.

Windows will show up in the bill of materials (BOM) as window frames and glazing panel, depending on which ones you choose. We do not have LCA data on "doors" as a whole; the program calculates the amount of individual materials that would typically make up the doors and frames and adds them to the BOM. So a wood door would show as lumber and nails (not "wood door"), or an aluminum door will show up as aluminum extrusion, glazing and nails.

As with foundations, you can click on the envelope tab, and add envelope materials to your wall assembly. The envelope quantities will be calculated based on the area of your wall assembly (height x width – total window area – total door area), and for insulations, on the thickness that you enter.

When you're done, click OK, and a new Walls assembly group, G, and your new wall assembly, A, will appear in the tree under your project level P. If you wish to add a new wall, simply click on the walls group level, G, and choose Add Assembly>Custom walls, and repeat the steps above.

Starting with v5.2 there is an Extra Materials assembly type added to the Walls assembly group that allows you to add extra materials specific to this group, and the bill of materials and results tables will account for these materials in this group instead of as Project Extra Materials.

- Watch a nine-minute video demonstration on adding a wall assembly - 03-Adding Assemblies-Walls.
- Read the help file about how to add a wall – Click >Add or Modify Assemblies >Walls

Adding columns and beams

Right click on the Project level, P, in the tree, hover over Add Assembly and Columns and Beams and click Columns and Beams or Metal Building Systems-Columns and Beams. As usual, enter an assembly name and fill out the required information in the form`s fields.

Complete the required fields, number of columns and beams, bay size, supported span, supported roof or floor area, column height, live load, and the column and beam types. Metal building systems has its own dialog box and the fields include length, width, height, column spacing and live load. The following shows the column and beam material choices that are available:

- 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

The column and beam choices are independent of each other, so you have the flexibility to mix material types (e.g. steel column and glulam beam).

There is no envelope tab in Columns and Beams. If you wish to add envelope materials to an assembly, you will need to calculate the material quantities separately and add them in Extra Basic Materials.

When you're done, click OK, and a new Columns and Beams assembly group, G, and your new assembly, A, will appear in the tree under your project level P.

A short note about terminology. There is sometimes confusion about our choice of labels for different structural elements. The IE4B refers to the Bay Size as the length of a beam supported by two columns, and Span as the distance between adjacent, parallel beams (see figure 4 below).

Some assemblies ask for the number of bays and rows. Bay Size and Span will determine the area of one bay, and a row is a row of bays. The drawing below shows two rows of bays, and each row is three bays long. The total floor area in the example below is (Bay Size x Span) x Number of Bays per Row x Number of Rows (Bay Size x Span x 6).
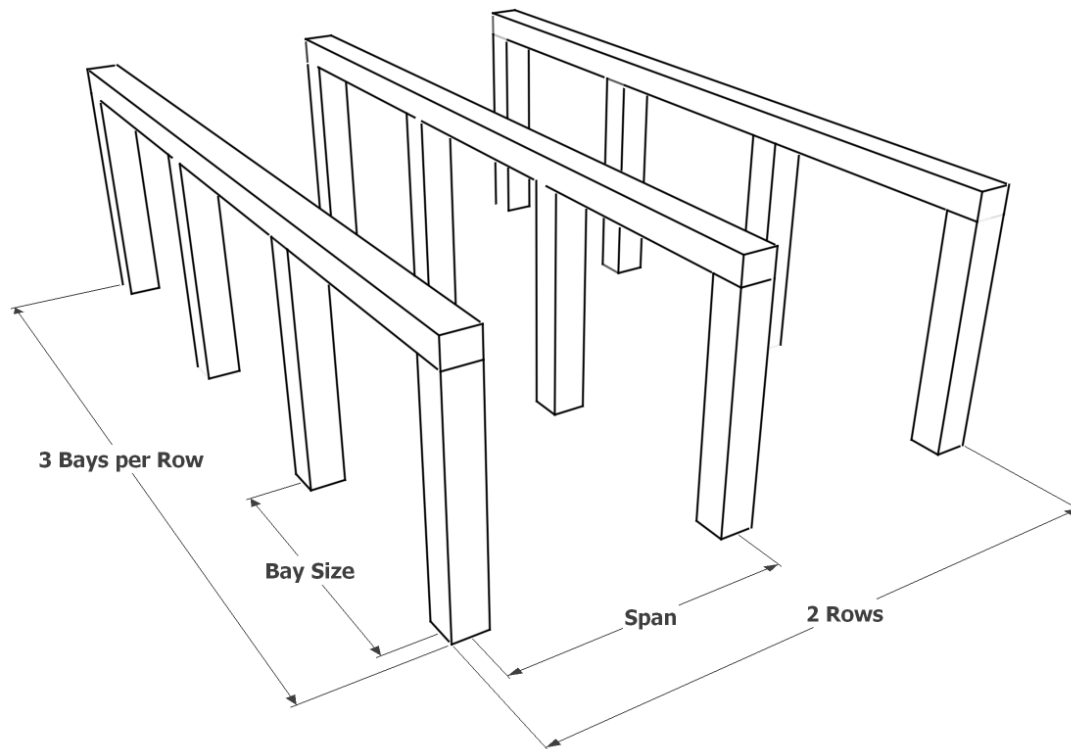
Figure 4   **Bay and Span terminology**

Starting with v5.2 there is an Extra Materials assembly type added to the Columns and Beams assembly group that allows you to add extra materials specific to this group, and the bill of materials and results tables will account for these materials in this group instead of as Project Extra Materials.

- Watch a seven-minute video demonstration on adding a column and beam assembly - <u>04-Adding Assemblies-Columns and Beams.</u>

- <u>Read the help file about how to add columns and beams</u> – Click >Add or Modify Assemblies >Columns and Beams

Adding floors and roofs

Roof and floor assemblies are almost identical (metal building systems is a roof only, and light frame wood truss floors do not have a pitched option) in the IE4B, so they're described here together.

Right click on the Project level, P, in the tree, hover over Floors or Roofs and click on the assembly type that you want, from the list below. As usual, enter an assembly name and fill out the required information in the form's fields.

- Composite Metal System
- Concrete Hollow Core
- Concrete Suspended Slab

44

- Concrete Parking Garage Floor System
- Concrete Precast Double T System
- Cross Laminated Timber
- Light Frame Wood Truss System
- Metal Building System (Roof only)
- OWSJ & Steel Decking with Concrete Topping
- Steel Joists and Plywood or OSB Flooring System
- Wood Glulam Joist and Plank Decking System
- Wood I-Joist & Plywood or OSB Decking System
- Wood Joists & Plywood or OSB Decking System
- Wood Chord & Steel Web Truss System

The information required will differ depending on which assembly type you choose, but generally you need a bay size and span or a width and span, and the live load to add an assembly to your project. The help button at the bottom of each form will explain the details of the required fields.

The envelope tab is available with floors and roofs if you wish to add envelope (claddings, roofing materials, insulation, vapour barrier etc.) materials to your assembly.

When you're done, click OK, and a new Floors or Roofs assembly group, G, and your new assembly, A, will appear in the tree under your project level P.

Starting with v5.2 there is an Extra Materials assembly type added to the Floors and Roofs assembly groups that allow you to add extra materials specific to each group, and the bill of materials and results tables will account for these materials in each group instead of as Project Extra Materials.

- Watch a six-minute video demonstration on adding a floor or roof assembly – 05-Floors/Roofs.
- Read the help file about how to add a floor or roof – Click >Add or Modify Assemblies >Floors or Roofs

Adding extra materials

Extra Materials is a different kind of assembly type. Instead of entering dimensions to describe an assembly and have the IE4B calculate material quantities, the user can input any value he/she wants, for any material, and it will be added to the bill of materials (BOM). The construction waste factor for each material will also be added to the BOM, e.g. if you enter 1 m^3 of concrete (5% waste factor) in EBM, there will be 1.05 m^3 added to the BOM.

Starting with v5.2 there is an Extra Basic Materials assembly type added to each assembly group that allows you to add extra materials specific to a group, and the bill of materials and results

tables will account for these materials in this group instead of as Project Extra Materials. But you can still add extra materials to the project as a whole by entering them in Project Extra Materials.

This allows the user to customize assemblies that have been developed using the IE4B automated features. If for instance, you think that the IE4B has overdesigned your concrete beam, you could adjust for that in EBM by adding a negative amount of concrete so that the BOM reflects the actual amount of concrete in that assembly, and you can enter that concrete in either the Columns and Beams Extra Materials assembly or the Project Extra Materials assembly group, depending on which assembly group that you want to reflect those materials effects.

To enter a material, select it from the Materials drop down box. You can use the Search String or Material Type boxes in order to filter the list in Materials. Choose a Material, and click Add, and the material will appear in the table, then enter an Amount. The Net Amount will show the total that will be added to the BOM, including the construction waste factor. Units can be toggled between Si and Imperial.

When you've added all your materials, click OK and a new Extra Materials assembly group, G, and an Extra Basic Materials assembly, A, will appear in the tree under your project level P (or in the Columns and Beams assembly group).

Note there can only be one entry per material in any one Extra Materials dialog box; you cannot add a material twice. For example, if you want to add 0.5 tonnes of WF steel sections to a beam assembly and 0.1 tonnes of WF steel sections for a column, you can't enter these separately, you need to calculate the total and enter 0.6 tonnes of WF Sections once. If you are entering a lot of EBMs, it's recommended that you keep a running tally of each material on the side, as you enter your assemblies, and at the end, go to EBM and enter the totals all at once.

Users can model a building entirely this way without using the assembly dialogs – the BOM Import feature (see below) is using this route.

Adding custom concrete mixes

In v5.0 we added the ability for users to define their own custom concrete mixes, and to use them instead of the database mixes in assemblies. Under the Tools menu, open the User Defined Concrete Mix Design Library dialog, where you can create new mix designs (or edit existing ones).

To define a new mix, simply add the constituent materials and define their percentages by weight or volume, or add the actual mass of each material (Unit Contribution). Once a mix is defined, it will be available as a concrete choice in any assembly dialog that uses concrete. Detailed instructions on how to define a new mix are available in the help file at the bottom of the dialog box or at Tools>User Defined Concrete Mix Design Library in the online help files. There is a new folder under the File menu called Bulk Product Projects, and this contains project files that contain around 150 US regional benchmark and EPD mixes based on the National Ready Mix Concrete Association's 2016 LCA/EPD and Benchmark reports and 125 Canadian EPD mixes based on the Canadian Ready Mix Association's 2017 EPD report. These are provided in several different project files so users can import the mix designs that apply to their situations

into their local libraries without having to load all of them. There is an instruction sheet describing how to use these mix designs projects, available in a PDF document or in the help files, and it will appear each time you choose Bulk Product Projects under the File menu.

Using the bill of materials import feature

The Bill of Materials Import feature allows users to import a BOM from an existing design in a CAD program directly into Extra Basic Materials in an IE4B project, thereby accounting for all the materials in the building without entering individual assemblies or entering all the materials by hand in EBM. From your CAD program, export a bill of materials to an Excel file (recommended) or a delimited text file.

The process involves four main steps. To start, create a new project in the tree, then right click on the P icon in the tree and choose BOM File Import. Step 1 is to load the export file by browsing to it in windows and selecting it. The IE4B will try to identify which is the header row and in which row the data begins. If it gets it wrong, you can identify them yourself.

Step 2 is to map the columns. The IE4B is only looking for three or four columns of information to import: material names, units of measure (UOM), quantities and unit contribution type (assembly group). The IE4B will look at the header row defined in step 1 and try to identify which column is which. If it gets it wrong, you can manually identify the material, UOM and quantity columns. Any other columns in the export file will be ignored.

Step 3 is to map the rows. You need to map each material and UOM in the export file to the equivalent material name and UOM in the IE4B. For instance, if you have a material named W30x10 Steel Girder in pounds in the export file, you will need to tell the IE4B that this corresponds to WF Sections, and assign a conversion factor from pounds to tonnes (the material name and UOM in the IE4B database). This will need to be done for each unique material name of UOM in the export file. The most common units of measure are included in a UOM mapping library, but users can add to this library any custom units or conversion factors. If you have material names and UOMs that repeat in rows throughout the export file, you need only map the first row; click the Green icons to save those mappings to the material and UOM libraries, then click Rescan Mapping Libraries, and all identical materials names will be mapped automatically.

Step 4 is optional, and it allows you separate your entire Bill of Materials into the assembly groups if you wish. This will require a fourth column to be mapped to Unit Contribution Type, and each row must have an assembly group (wall, floor, foundation, column and beam, roof) assigned to it. Then when the BOM is imported, those materials will be added to the assembly group extra material assemblies instead of to the Project Extra Materials assembly group.

Once all the rows are mapped, you can import the list into the project and you have the option to include or not include the construction waste factors for each material.

 A summary of the mappings is available as a tab delimited text file for your records. All material or UOM mappings can be saved in the library, so the next time you try to import a BOM file, any materials and UOMs of the same name will be mapped automatically. If you use the same nomenclature in your CAD program from project to project, the mapping step will be greatly

reduced, as you will only need to map any new material names or UOMs. After some experience with the IE4B, you will become familiar with what is expected and with UOMs in particular, you can do some of the conversions in Excel if you wish, before importing the file. The mapping libraries can also be copied so that another user in the same organization can use them to avoid having to remap material names and UOMs.

Some users may want to map their material names in Excel; to this end there is a project file in the Sample Projects folder called "Material List-One of Everything-SI.AT4". This is a file with every material in the database entered in Extra Materials: one unit of whatever the SI base unit is for each material. You can open this file, produce a bill of materials report, and export it to Excel. This will give you a complete material list, one plus the construction waste factor of each, in Excel. This can also be used as a list of waste factors. If you have, for example, 1.05 ^{m3} of concrete in this list, you know that the waste factor for that concrete is 5% (1.05-1). [23]

Detailed step by step instructions are available by clicking the Help button at the bottom of the dialog box or you can watch a two part video demonstration at 10 & 11 -Bill of Materials Import-Parts 1 & 2

Inputting operating energy data

The IE4B is not an energy simulation tool, but you can enter the results of an energy simulation, and the IE4B will calculate the environmental effects of that energy use. If you double click on the project level P in the tree, and click on Operating Energy Consumption at the bottom of the Modify Project dialog, the Building Operating Energy Consumption dialog will appear. Here, you can enter the annual operating energy amounts (as calculated in an energy simulation) for electricity, natural gas, LPG (propane), Heavy Fuel, Diesel and Gasoline. If your energy totals are in MJ or Btu, there is a tool available to convert these into physical quantities of each fuel. The effects of electricity will change depending on the project location, while the other fuels are based on continental data, and the effects will not change from location to location.

- Watch a five-minute video demonstration on entering operating energy – 07-Operating Energy.

- Read the help file about how to enter operating energy – Click >Creating a new Project>Set Operating Energy Consumption

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[23] This works best if you export the BOM in SI units. Otherwise, you can still calculate the waste factor, it just won't be 1.05-1, it will be (1.3733-1.30795)/1.30795 yd^3 (the math is easier in SI). Note also that this is a large project file with all of the materials, and thus it will take a few minutes to open and load into your project tree.

Work-arounds

The Impact Estimator is flexible enough that users can manipulate their inputs to accommodate circumstances not easily approached using the built-in features.

Bill of materials adjustments

The IE4B produces a bill of materials as a result of user inputs in the assembly dialog boxes. Material quantities can be modified, if needed, to better match the project. Follow these steps:

- Change the project's *Building Life Expectancy* to 1 year.

- Produce the Bill of Materials report; it includes the materials the building is comprised of and the construction waste quantities associated with its initial construction.

- For the material you wish to modify, divide the quantity as shown in the bill of materials by the material's construction waste factor[24]*; the result is now just the quantity of material found in the building.

- Determine and input the adjustment to be made:

    o A material can be completely removed from the model by inputting into the Extra Basic Materials dialog the quantity determined in step c as a <u>negative</u> number.

    o A material quantity found in the building can adjusted by inputting into the Extra Basic Materials dialog the difference between the desired quantity and that determined in step c. To increase or decrease the quantity, input the difference as a positive or negative number, respectively.

Project location proxies

Not all locations in the US and Canada are currently available in the IE4B. Here is some guidance for selecting a location when the project city is unavailable.

For the US:

- Select the nearest available city located in the same state;

- If no city is available in the same state, select "USA average".

For Canada:

- Select the nearest available city located in the same province;

- If no city is available in the same province, select the nearest available city (there is no "Canada average" location currently available).

Operating energy fossil fuel proxies

The IE4B's fossil fuel operating energy use options don't necessarily directly relate to the fuel types or names used by building service systems. Here is some guidance for selecting fossil fuels proxies when a fuel appears unavailable in the program.

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[24] Construction Waste Factors can be found in the Extra Basic Materials input dialog.

The following fuel proxies shall be used for operating energy:

- "LPG" for fuels containing proportions of propane, ethane, propylene, and butane;

- "Diesel" for heating oil (no. 2 fuel oil);

- "Heavy fuel oil" for furnace fuel oils (residual fuel oils, or no. 5 and no. 6 fuel oils);

- A 50/50 mix of "Diesel" and "Heavy fuel oil" for no. 4 fuel oils.

Material proxies

It is often the case that materials unavailable in the IE4B can be modeled using proxy materials. While the results will only approximate the effects of the desired material, it is our opinion that this practice is acceptable (if modeled according to the rules provided) since the majority of effects will generally be captured.

Example:

A user wishes to model 1 m^2 of aluminum composite panel composed of two layers of 0.5 mm thick aluminum sheets sandwiching a 2 mm polyethylene core. The service life of the cladding is 35 years and the service life of the building is 60 years.

For this example, IE4B materials "Aluminum Cold Rolled Sheet (tonnes)" and "6 mil poly (m^2)" will be used as proxy materials for the aluminum composite panel.

1. Calculate the amounts of aluminum and 6 mil poly in the aluminum composite panel
   Aluminum: 1m2 * 2 * 0.0005m * 2.7 tonne/m3= 0.0027 tonnes Aluminum
   6 mil poly = 1m2 * (2mm/0.0254mm/mil) / 6mil = 13.1 m^2 6 mil poly

2. Calculate the number of aluminum composite panel replacements that occur over the building service life and the resulting material use:
   NR = (60 yrs – 35 yrs) / 35 yrs = 0.71
   tonnes of Aluminum = 0.0027 * 0.71 = 0.0019
   m^2 of 6 mil poly = 13.1 * 0.71 = 9.30

3. Model the aluminum composite panel in the IE4B with the material quantities calculated in steps 1 and 2, entered as extra basic materials, according to the rules provided below.

   Aluminum = 0.0027 tonnes + 0.0019 tonnes = 0.0046 tonnes

   6 mil poly = 13.1m2 + 9.3m2 = 22.4m2

Rules for using material proxies:

1. A material may be modeled using an available IE4B material as a proxy provided the materials have the same basic chemical/alloy composition.

2. The proxy material quantity input into the IE4B shall reflect the amount (on a mass basis) of material used in the project.

3. Two or more proxy materials may be used to model a composite building product, provided each constituent material of the composite is in accordance with rule 1.

4. The following procedure shall be used when modeling with proxy materials:

   a. Produce *Project* results: model the complete building except the proxy material(s) and export the desired results, by "Life Cycle Stage" (i.e., by information module), to Excel.

   b. Produce *Material* results: in a separate file with the same building information (e.g. location, height, etc.) input the quantity of proxy material(s) into the Extra Basic Materials input dialog. Export the desired results, by "Life Cycle Stage", to Excel.

   c. Add *Material* A1/A3, A2, A3, A4, A5, C1, C2, C4 information module results to the corresponding *Project* information module results.

5. If the material undergoes replacement during the building service life, replacement effects shall be calculated according to the following procedure:

   a. Calculate the number of replacements the proxy material(s) undergoes:

   Number of replacements = (Building service life – Product service life) / Product service life

   b. Sum *Material* A1/A3, A5, C1, and C4 information module results, multiply the total by the number of replacements from step (a) and add to the *Project* B4a information module results.

   c. Sum *Material* A2, A4, and C2 information module results, multiply the total by the number of replacements from step (a) and add to the *Project* B4b information module results

Reused materials

While the IE4B does not currently support modeling reused materials, here is a procedure for estimating these effects. Essentially, it entails removing the effects of the material's raw resource extraction and manufacturing from the total life cycle effects (A1, A2, A3), including when the material undergoes periodic replacement. Follow these steps:

1. Produce *Project* results: model the complete building except the reused material and export the desired results, by "Life Cycle Stage" (i.e. information module), to Excel.

2. Produce *Material* results: in a separate file with the same building information (e.g. location, height, etc.) input the quantity of reused material into the Extra Basic Materials input dialog. Export the desired results, by "Life Cycle Stage", to Excel.

3. Add *Material* A4, A5, C1, C2, C4 information module results to the corresponding *Project* information module results.

4. If the reused material undergoes replacement during the building service life, replacement effects shall be calculated according to the following procedure:

   a. Calculate the number of replacements the reused material undergoes:
   Number of replacements = (building service life – product service life) / product service life

b. Sum *Material* A5, C1, and C4 information module results, multiply the total by the number of replacements from step (a), and add to the *Project* B4a information module results.

c. Sum *Material* A4 and C2 information module results, multiply the total by the NR from step (a) and add to the *Project* B4b information module results.

District energy facilities

While the IE4B does not directly support modeling building operating energy sourced from district cogeneration, conventional boiler, and cooling facilities, users can model these effects according to this section provided that the requisite information about the plant is available and the fuels used by the facility are available in the IE4B.

1. The operating energy from a district system attributable to a building shall be calculated according to the following equation:

$$F_{Pn} = (E_P * (1 + L / 100)) / E_D * F_{Dn}$$

where,

F_{Pn} is the annual fuel use quantity[1] for fuel type n, attributable to the project and to be input into the IE4B (e.g. kWh electricity, m^3 natural gas)

F_{Dn} is the total annual fuel use of the district system facility for fuel type n, inclusive of facility operating energy (e.g. kWh electricity, m^3 natural gas, etc.)

E_P is the project's operating energy use demand, in MJ, Btu, etc.

E_D is the total annual net[2] energy production of the district facility[2], in MJ, Btu, etc.

L   is the estimated line losses of the district system, in %

[1] In accordance with the "polluter pays" principal, a user can neglect the environmental effects of that portion of district energy facility energy produced with secondary fuels (e.g. municipal waste, tires, solvents, etc.).

[2] "Net" energy production for steam, hot water, and chilled water = Supply Energy – Return Energy.

[3] For cogeneration plants, E_d is the total net energy production of the plant (net heat + electricity).

2. Each type of fuel the district energy facility uses for its operation shall be attributed to the project.

Combining IE4B and EPD results

If users wish to include a product not available in the Athena database, it is possible to manually add this product's LCA data from an EPD, with caution. Be aware of a number of factors that will increase uncertainty of results if adding EPD data to IE4B results. This includes likely non-harmonization of background data, missing life cycles in the EPD, missing scope in the EPD, and results given for an incompatible unit (declared unit not functional unit). Read the entire EPD first to check for scope and boundary; for example, if the EPD is missing important parts of the product system, product transportation to the construction site, or product maintenance and

replacements over the life of the building, users will need to calculate these additional effects and add them to the results. Uncertainty in results will increase if the EPD was calculated with background data different than that in the IE4B, if the impact categories reported in the EPD were not characterized according to TRACI 2.1 methodology, if the EPD is not applicable to the project location, or if the EPD is expired.

Viewing results and generating reports

Results are produced by clicking on the Reports menu, which opens a dialog box from which all available reports can be selected. For individual reports, the user can select either Table or Graph format for LCA Measures, and sorted by Life Cycle Stage, Assembly Groups or Operating vs Embodied. Tables will automatically include all LCA Measures, while graphs will produce one graph per LCA Measure chosen.

Note that as of v5.5 the five LCI Category tables (data for energy consumption, resource use and air, water and land emissions) are no longer available. One of the effects of the LCA data issues, as discussed in the Regional specificity section, is that the LCI information often does not correspond exactly to the LCA results presented and have therefore been discontinued.

All tables and graphs can be exported to Excel and PDF (graphs are exported to Excel as pictures, not as Excel charts).

Starting in v5.4, there is a new feature under the File menu to Export the core tabular results to Excel directly, without generating the reports on screen first, either for the selected project, or all the projects that are open in the project tree. By choosing this option, you can export the Bill of Materials (not the new Bill of Materials by Assembly) and the Detailed LCA Results Table by Life Cycle Stage (summary measures) into one document, instead of generating and exporting them individually. Once that document is created, you can use it to compare results from different projects, or to calculate the differences between two projects. Instructions on how to use those functions are included in the export documents. ote that those documents are macro enabled Excel documents; if macros cannot be enabled on your local Excel installation the functions will not work, but the report data will be available for you to use as you wish.

Excel export documents are saved in the same folder that the project files are saved in and are labeled with the project file name and a "-Results" suffix.

Please note that Microsoft Excel must be installed on your PC for this function to be available.

The heart of the results are included in the Detailed LCA Results Table by Life Cycle Stage, which presents the results of a project, by the life cycle stages conforming to the EN 15804/15978 system boundary and reporting format (modules A to D). A partial picture of the table (modules A & B only) is shown in Figure 5.

Detailed LCA Measure Table By Life Cycle Stages

Project: Case Study - R2000 House Design

LCA Measures	Unit	PRODUCT (A1 to A3) Manufacturing	Transport	Total	CONSTRUCTION PROCESS (A4 & A5) Construction-Installation Process	Transport	Total	USE (B2, B4 & B6) Replacement Manufacturing	Replacement Transport	Operational Energy Use Total	Total
Global Warming Potential	kg CO2 eq	8.92E+03	2.96E+02	9.22E+03	1.76E+03	2.34E+03	4.10E+03	0.00E+00	0.00E+00	5.76E+03	5.76E+03
GWP - Biogenic	kg CO2 eq	-2.18E+04	0.00E+00	-2.18E+04	-8.50E+02	0.00E+00	-8.50E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
GWP - Calcination	kg CO2 eq	8.59E+02	0.00E+00	8.59E+02	1.29E+02	0.00E+00	1.29E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Acidification Potential	kg SO2 eq	1.39E+02	2.96E+00	1.42E+02	2.02E+01	2.76E+01	4.78E+01	0.00E+00	0.00E+00	4.94E+01	4.94E+01
HH Particulate	kg PM2.5 eq	2.97E+01	1.58E-01	2.98E+01	1.87E+00	1.18E+00	3.05E+00	0.00E+00	0.00E+00	2.95E+00	2.95E+00
Eutrophication Potential	kg N eq	2.36E+01	1.84E-01	2.37E+01	2.57E+00	1.71E+00	4.28E+00	0.00E+00	0.00E+00	4.84E-01	4.84E-01
Ozone Depletion Potential	kg CFC-11 eq	1.05E-03	1.06E-08	1.05E-03	7.73E-05	8.64E-08	7.74E-05	0.00E+00	0.00E+00	1.90E-09	1.90E-09
Smog Potential	kg O3 eq	1.42E+03	9.39E+01	1.51E+03	4.90E+02	8.88E+02	1.38E+03	0.00E+00	0.00E+00	1.24E+02	1.24E+02
Total Primary Energy	MJ	4.52E+05	4.31E+03	4.57E+05	4.13E+04	3.32E+04	7.45E+04	0.00E+00	0.00E+00	1.01E+05	1.01E+05
Non-Renewable Energy	MJ	3.89E+05	4.31E+03	3.93E+05	3.68E+04	3.32E+04	6.99E+04	0.00E+00	0.00E+00	1.01E+05	1.01E+05
Fossil Fuel Consumption	MJ	3.20E+05	4.31E+03	3.24E+05	2.84E+04	3.31E+04	6.15E+04	0.00E+00	0.00E+00	1.00E+05	1.00E+05

Figure 5   Partial Results Table by Life Cycle Stage

The IE4B produces results for these mid-point impact measures:

1. global warming potential
2. global warming potential -biogenic
3. global warming potential -calcination
4. acidification potential
5. human health particulate
6. aquatic eutrophication potential
7. ozone depletion
8. smog
9. total primary energy consumption
10. non-renewable energy consumption
11. fossil fuel consumption

See the appendix for an explanation of these measures.

Summary measures are available in a condensed life cycle stage table (it shows only the Total columns of the detailed table), and an Assembly Group Embodied Effects table that presents the embodied effects (not including operating energy) by assembly groups (walls, floors, etc.).

Results are also available in graph format. Summary measures are available when sorted by assembly groups for individual projects, but graphs are mainly used when comparing one or more projects to each other. Comparison graphs can be produced for summary measures only, by life cycle stage or assembly groups, and can show results by their values, on a per metre squared basis, or on a percentage basis compared to a project baseline.

Operating vs embodied

If you input operating energy, you can now do some interesting operating versus embodied comparisons. Look at 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. This is available only for individual projects, as a graph, for global warming potential or energy consumption.

<u>Rating Systems Reports</u>

Graphs and tables are available that present LCA results in the formats that the LEED and Green Globes rating systems expect in their submissions. There is also a new LEED v4 Whole Building LCA Credit Report available. This is a Word document that pre-populates software and project information as well as comparison LCA results in a form that can be included in a LEED submission. The Word document contains blank fields that the user will still need to complete for LEED submittal, however all Impact Estimator and LCA information will already be there.

<u>Bill of Materials</u>

The Bill of Materials report is a running total of all the materials modeled in a project. As you add new assemblies or materials, the BOM report will be updated as you go along. It can be useful to monitor the BOM as you add assemblies or envelope systems so you can see what materials get added automatically (e.g. adding an asphalt roofing system in roof envelopes will add modified bitumen, insulation, gypsum board, nails etc.to the BOM). It is from the BOM that the individual material data are applied in order to calculate the absolute value (LCI) tables.

Starting in v5.5 a new BOM report is available BOM by Assembly. This BOM reports the materials separately for each assembly as opposed to one grand total for the project. The main purpose of this report is to assist users of the Athena Building LCA web app who don't yet have a bill of materials and wish to use the assembly dialogues in the IE4B to generate one. Additionally, the Element column indicates the OMNICLASS ® Table 21 element of each assembly. Materials entered as Extra Materials do not "belong" to any particular element (assembly) group and are indicated at a project level of [00 00 00] Structure.

<u>Project Report</u>

Since v5.4, users can export a full report that captures all relevant inputs and results for the project plus credential information about the Impact Estimator and its underlying data and methods. Under the File menu, select Export a Project Report. The Impact Estimator will create a report in Microsoft Word and PDF formats and will save both files in the same folder that the project files are saved in. The files will be labeled with the project file name and a "-ProjectReport" suffix.

Interpreting results

So, now you have modeled your building and produced the results – what do the results mean, and what should you do with them?

First, understand that the results say nothing about whether or not your building is a "good" environmental performer. There is no score or rating here. Your results are simply a statement of fact regarding the LCA performance of your building.

The interpretation step in LCA is when you look at your results critically, first to trouble shoot for any possible errors and then to dig deeper for information that may help inform design decisions. Two tactics to help with both these tasks is **contribution analysis** and **sensitivity analysis**.

In contribution analysis, results are grouped to identify "hot spots." In the IE4B, you can group by life cycle stage and by building element. Hot spots can then be targeted for improved environmental performance by modifying the design or the materials. This is the best approach to get measurable improvements. Tackling parts of the building that have relatively little impact won't get you much effect in the overall footprint.

See Figure 6 for an illustration of contribution analysis. Here, LCA results are shown with proportional contribution to each one by various building assemblies. If interested in reducing embodied energy of this example building, notice that the walls are the biggest contributor to fossil fuel consumption. You might consider reducing the total area of walls, or drill deeper into the wall results to explore different wall design and material options. Note that the IE4B currently does not generate graphs exactly like this – create this by exporting your results to Excel.
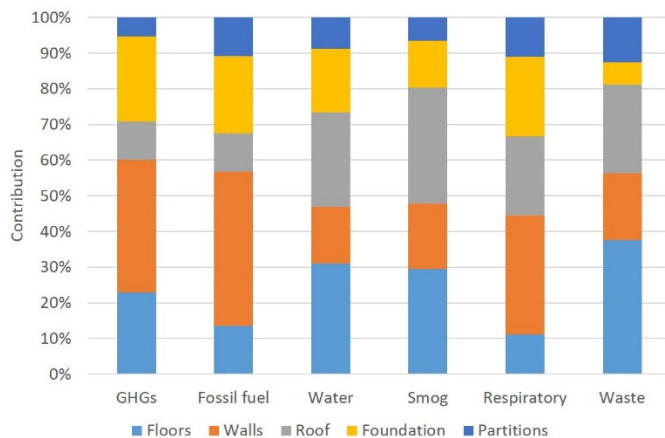

Figure 6   Example of contribution analysis.

If you are uncertain about any factors in your model (for example, a material quantity, or your choice of a proxy material), you can test for this with a sensitivity analysis. Do this by duplicating your model and making changes; for example, increase the quantity of a major material by 10% or so to see how much it matters if you underestimated that quantity.

Is one material, element, or life cycle stage showing counterintuitive impacts? This could be a sign of an incomplete model (check your model scope and material quantities) or an inconsistency or error with the background data in the software (let us know). Step back and do a common-sense check.

Before you take action in response to your model results, remember the uncertainty and limitations – refer back to our statements on limitations. Also, **be aware that the precision suggested by the software results, with numbers reported to several places past the decimal, is not real.** The software reports this way due to some numbers in the background data that are very small; there is no way to practically truncate these numbers. Users are advised to consider rounding their results to no more than two decimal places.

<u>Comparisons</u>

The IE4B makes it easy to compare two projects, but you need to ensure that your models are comparable. The building models you are comparing must be functional equivalents (don't compare a house to a hospital, for example), must have the same scope (don't compare a model with only structure to a model that also includes envelope), and the same life cycle stages.

Bearing in mind the inherent uncertainty in results, note that small differences in a comparison may fall within the margin of error.

Use extreme caution if comparing results from different versions of the IE4B or comparing IE4B results with those from another software tool. Even if scope, boundary, and functional equivalents are the same between the two sets of results, there are still likely significant differences in the background data on materials and scenarios that negate the ability for a fair comparison.

If intending to publicly disclose a comparison, ISO 14040/44 requires a peer review.

Use with green building programs

Green Globes®, LEED®, and other green building programs and policy have incentives or requirements to use LCA during design. The IE4B is well-suited for these programs. In addition to enabling easy comparisons between a reference building and a proposed design, the software also has several reporting options to assist:

- Automated reporting options for Green Globes and LEED that will give your results in the right format and the right units for those programs.

- An automated LEED v4 Whole Building LCA Credit Report that will cover off your demonstration that you used the right tool, data and method.

Read more about LCA in green building programs on our website: http://www.athenasmi.org/resources/lca-credits/

Where to find more help

Embedded help in the IE4B is available for all input dialogue boxes. The same help can also be accessed from our stand-along on-line resource: Help menu>Help Topics.

Up-to-date help files can be found online at http://calculatelca.com/software/impact-estimator/help-files/

Free download of the Impact Estimator for Buildings software plus user manuals, video tutorials and
FAQs: *http://calculatelca.com*

More information on LCA and additional resources:
http://www.athenasmi.org

Statement of compliance with guidelines and standards

The following documents are relevant to the IE4B:

- EN 15978:2011 Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method.

- ISO 21930:2017 Sustainability in buildings and civil engineering works – Core rules for environmental product declarations of construction products and services.

- National Guidelines for Whole-building LCA (National Research Council Canada 2022)

The National Guidelines interpret and address EN 15978 and ISO 21930. This statement of compliance is therefore keyed primarily to the National Guidelines, for efficiency. For each section of the Guidelines, our alignment is described below.

1. Purpose of the assessment

- The IE4B is a suitable tool for all three broad uses of wbLCA as defined in the Guidelines (informing design, meeting requirements, performance declaration).

2. Specification of the object of assessment

- Functional equivalent: This descriptive reporting task falls to the user and is not directly supported by the IE4B.

- Reference unit: The IE4B delivers results per unit of gross floor area (ft^2 or m^2) only within the "project report" export and the green building rating program reports. To normalize results to a reference unit, users can export results to Excel and do the calculations there.

- System boundary: See table 6 for inclusion of activities listed in Guidelines Appendix C:

- Reference study period: The IE4B allows users to set any length study period and module B results are adjusted accordingly. The software does not factor the building's required service life into these calculations (see Guidelines Figure 5).

- Building model scope: The Guidelines recommend using level 3 labels from OmniClass Table 21 (i.e., UniFormat classification) to indicate inclusions and exclusions of elements in the model. In the IE4B, users can export a bill of materials with labels to level 4, however some of these automated assignments may need to be corrected outside of the software.

Table 6 IE4B system boundary per national guidelines

Activity	Notes
A1-A3.1.1: production, building materials	
A4.1.1: transport to site, building materials	
A5.1.1: construction energy, installation	Limited scenario data and may be underreported
A5.10.1: production, construction losses	
A5.10.2: transport to site, construction losses	
A5.10.3: transport to waste processing/disposal, construction losses	
A5.10.4: waste processing, construction losses	
A5.10.5: disposal, construction losses	
B2.1.1: production, maintenance materials	
B2.1.2: transport to site, maintenance materials	
B2.4.1: transport to waste processing/disposal, materials & ancillary materials & losses	Only paint maintenance accounted for
B2.4.2: waste processing, materials & ancillary materials & losses	
B4.1.1: production, replacement materials & losses	
B4.1.2: transport to site, replacement materials & losses	
B4.4.1 : transport to waste processing/disposal, replacement materials & ancillary materials & losses	
B4.4.2: waste processing, replacement materials & ancillary materials & losses	
B4.4.3: disposal, replacement materials & ancillary materials & losses	
B6.1.1: operational energy, core building-integrated end-uses	User must input operational energy scenarios. IE4B does not differentiate between B6.1.1, B6.2.1, and B6.3.1,
B6.2.1: operational energy, other building-integrated end-uses	
B6.3.1: operational energy, non-building-integrated end-uses	
C1.1.1: construction energy, de-construction & demolition	Limited scenario data and may be underreported
C2.1.1: transport to waste processing/disposal, building materials	
C3.1.1: waste processing, building materials	
C4.1.1: disposal, building materials	
D1.1.1: recycling, metals	Steel and aluminum only

3. Scenarios for defining the building life cycle

- Default scenarios: Where data is available, the IE4B applies scenarios with information sourced from industry (e.g., replacement rates), market data (e.g., transportation distances), and expert opinion. We do not warranty the quality of this data, some of which is old and of unknown origin.

- Overrides: With some effort, users can manipulate results to accommodate different scenarios than the defaults. Users should note this in their reporting, with rationale.

- B6: Can be included if users supply estimated or actual fuel and electricity consumption.

4. Quantification of the building and its life cycle

- Quantification of the bill of materials:
  - The IE4B can export a bill of materials per Guideline 8.1.
  - The materials have Athena names and units of measure, per Guideline 8.2. If a proxy material is used, the IE4B does not facilitate meeting the requirement in 8.2 to preserve the real product name; users should make a note of the substitution in their project reporting.
  - The exported bill of materials will have a level x OmniClass Table 21 label (Guideline 8.3 asks for level 3) and does not assign a label from OmniClass Table 22 (requested in 8.3).

- Quantification of the bill of flows
  - The IE4B does not provide a report with a bill of flows per Guideline 9.1.
  - Per Guideline 9.4, the IE4B uses Guidelines equation 2 to calculate product replacements and other repeating activities.
  - With some effort, users can manipulate results to accommodate modeling of ancillary materials and temporary works in accordance with Guideline 9.5.

- Data quality of the life cycle flows: Guidelines 10 are primarily instructions for users with respect to assessing the quality of a bill of materials and thus not directly supported by the IE4B. If using the IE4B to calculate a bill of materials, per Guideline 10.8 the accuracy would be similar to a project at the schematic design stage (BIM LOD 200; quantity survey Class C).

5. Selection of environmental data

- Sources of environmental data
  - The IE4B has comprehensive built-in environmental data on materials and energy sources which includes both types called out in the Guidelines; this built-in data allows users to comply with Guideline 11.1.
  - Guideline 11.2 requires use of Canadian Construction LCI Project. The IE4B complies with this.

- Quality of environmental data
  - The IE4B built-in data meets the requirements of ISO 14044 and generally meets the requirements of ISO 21930 (Guideline 11.3)[25]. Geographic representation has been considered for each of the software's locations. While there are some older datasets still in use, the majority are considered current with respect to availability (Guideline 11.4).
  - Guideline 11.5: n/a, as the IE4B does not currently use EPDs directly.
  - Guideline 11.6 discourages the use of environmental data that draws on different background LCI data. To the extent possible, the IE4B follows this guideline and strives for data harmonization. However, for some products, the only environmental data available to us is "rolled up" LCA results; steel is a prime example. In the case of steel, we know the background LCI data is not harmonized with our other data and will create uncertainty in results. Users of any wbLCA tool should be aware that tool providers do not have control over some or all of the environmental data accessible in their tool and thus their background data will have some degree of non-harmonization; it is incumbent on the user to be aware of this uncertainty factor in their wbLCA results.
  - The IE4B built-in data complies with Guideline 11.7 (it does not reflect carbon offset purchases, etc.).
  - The IE4B does not currently draw on any cradle-to-grave EPDs and therefore Guidelines 11.8 and 11.9 do not apply.

6. Calculation of environmental indicators
- Indicators
  - The IE4B complies with Guideline 12.1; it uses TRACI 2.1 and reports the required indicators.
  - Guideline 12.2 requires conformance with ISO 21930:2017 Clause 7.2 regarding inventory-based indicators. The IE4B report three: primary energy consumption, non-renewable energy consumption, and fossil fuel consumption. The software may be out of alignment in few places with respect to HHV and LHV.
  - Guideline 12.3 requires that reported primary energy consumption be indicated as either gross or net calorific value. The IE4B reports the energy values from material LCAs, therefore it depends whether the LCAs are performed with HHV or LHV energy profiles. In general, recent LCAs are performed with LHV values as per standards, so any recently updated dataset will be LHV. But our older datasets that have not been recently updated will have been performed using HHV values.
- Module D
  - Guideline 13.1 requires compliance with ISO 21930:2017, clauses 7.1.7.6 and 9.4.7.
  - Per 7.1.7.6, the IE4B reports Module D results separately from A to C.

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[25] There are some exceptions, for example, LHV vs. HHV.

- The IE4B only addresses metals in Module D. The software follows the four steps in clause 7.1.7.6 to calculate environmental loads and benefits of net output flow of metals. There is ambiguity in the standard regarding the scrap processing that the software currently allots to C3, which some might interpret ought to be allotted to D.
- Clause 9.4.7 requires disclosure on the assumptions used in Module D calculations. This requirement is addressed elsewhere in this transparency document.

- Biogenic carbon
  - Per Guideline 14.1, the IE4B includes biogenic carbon.
  - Per Guideline 14.2, the IE4B accounts for and reports biogenic carbon flows in the appropriate modules.
  - Per Guideline 14.3, the IE4B follows the biogenic carbon accounting and reporting rules in ISO 21930:2017 Clause 7.1.5, 7.2.2, and 7.2.12.
  - Per Guideline 14.4, the IE4B scenarios for biogenic carbon removals and emissions are representative of contemporary technology and practice (see detailed documentation of our C4 method and data elsewhere in this document).

- Concrete carbonation
  - Guideline 15.1 states that carbonation should (not shall) be included in wbLCAs, presumably in recognition that a method for doing so within a wbLCA tool has not yet been established. The IE4B therefore does not include carbonation. The remainder of Guidelines 15 are thus not applicable.

- Interpretation
  - The IE4B supports sensitivity analyses, per Guideline Guideline 16.1.
  - The IE4B supports reporting biogenic carbon contribution, per Guideline 16.2.
  - The IE4B facilitates comparisons between sets of wbLCA results. Many of the comparability requirements set forth in Guidelines 17 are built into the software (17.6 to 17.13) and are not a concern to the user. Guideline 17.1, 17.2, 17.4, and 17.5 are the user's responsibility and not directly supported by the IE4B (the software will not check for comparability of two models per these four guidelines). Guideline 17.3 states that the same information modules must be included in both sets of results; the IE4B always reports all modules, however, we have no control over user manipulation of results outside of the software (e.g., in Excel) to potentially exclude some modules.

7. Reporting

- The IE4B supports comprehensive reporting per Guidelines 18. Much of the information required in Guidelines 18 is included in the "project report" export and would be supplemented by users with additional narratives.

Appendix A: Insulation Data Updates

Evaluating Athena's building insulation profiles relative to newer publicly available EPDs

In 2021, with the help of the City of Vancouver and Morrison Hershfield, a review of the representativeness of our aging insulation data was completed, with the goal of bringing it up to date and in line with recently released Environmental Product Declarations (EPDs). The review concluded that our Expanded Polystyrene (EPS) data still agreed with recent data, but Extruded Polystyrene (XPS), Mineral Wool and Fiberglass batt, Cellulose and Polyisocyanurate foam board data needed to be updated to better align with current EPDs.

In several cases we did not have access to the underlying manufacturer's life cycle inventory (LCI) data for each product, just the publicly published EPD results. In these situations, we elected to adjust our existing LCI product flow data to emulate the reported EPD life cycle indicator and resource use results more closely.

We also have consolidated some insulation types, like Fiberglass batt which had five versions for different typical thicknesses, to create one material profile, and that new profile has also been scaled up to create a new material of higher density.

Lastly, we added some insulations that would be more suited to roofs or wall (and labeled them as such for users), as well as open and closed cell spray foams to the database.

All the EPDs report on a functional unit of 1 m^2 of installed insulation material with a thickness that gives an average thermal resistance RSI = 1 m2·K/W (5.678 ft2·°F·h/Btu). The IE4B units are per 1m^2, 25.4mm (1") thick. The EPDs usually report the thickness required to meet the functional unit (RSI=1), and the values in the EPDs are adjusted using this thickness to scale to 25.4mm in the IE4B database. Using the mineral wool EPD[31] as an example, the A1-A3 GWP is reported as 1.31 kgCO$_2$eq. to achieve RSI=1, and that corresponds to a thickness of 37mm. The value in the IE4B database for A1-A3 is 25.4mm/37mm x 1.31 = 0.9 kgCO$_2$eq.

Please use caution if interpreting the IE4B data compared to the EPD data. Most of the source EPDs are based on cradle-to-grave LCAs, but the updates we have made to the IE4B database are only the cradle-to-gate (A1-A3) results. This is because the IE4B model is programmed to calculate scenarios in modules A4, A5, B and C modules using A1-A3 data and cannot report values in modules A4-D from individual EPDs (our Athena Building LCA web app has the ability to use all modules as reported in an EPD). Many times, the differences between the IE4B scenarios and the published modules do not affect the final results in a significant manner, but XPS using HFC as a blowing agent is one example of where the differences are substantial. Using the Dupont EPD[26] as an example, the A1-A3 GWP is reported as 29.4 kgCO$_2$eq., A4-A5 is 0.8 kgCO$_2$eq., but the use phase B1 includes blowing agent off-gassing throughout the life of the product is 31.4 kgCO$_2$eq. In other words, B1 is greater than A1-A5 combined, but the IE4B programming does not calculate any effects in the use phase. The EPD also reports disposal phases of C2 transportation of 0.008 kgCO$_2$eq. and C4 disposal of 38.5 kgCO$_2$eq. The C4 result includes additional blowing agent emissions, but the IE4B does not calculate these emissions. Again, the disposal phase is greater than the A1-A3 effects.

This only applies to the EPDs for XPS that we used as data sources, and to give a little context, the B1 effects of HFC blowing agents are more than 100% of A1-A5, while only approximately 40% for HFO blowing agents.

Extruded Polystyrene (XPS)

The use of blowing agents used in XPS production is evolving, with HFC being widely used, and HFO (with lower environmental effects) making headway into the marketplace. Building codes that may some day mandate the use of HFO XPS are evolving as well, but currently both types of XPS are used; as such we have included both in the database (HFC EPDs from 2018, HFO EPDs from 2021). There are also different densities of XPS; the lower densities are typically used in walls and higher densities in roofs. With that in mind we have included four XPS datasets to be available to users:

- **Extruded Polystyrene-Wall (HFC 2018):** Average of 3 EPDs, Dupont[26], Owens Corning (150/250)[27], excludes high density XPS typically specified for roof applications.

- **Extruded Polystyrene-Wall (HFO 2021):** Average of lower density Owens Corning NGX™ products (150/250)[28].

- **Extruded Polystyrene-Roof (HFC 2018):** Average of Dupont[26] and Owens Corning (400)[27].

- **Extruded Polystyrene-Roof (HFO 2021):** Based on Owens Corning EPD for NXG™ 400[28].

Polyisocyanurate Foam Board

We have updated:

- **Polyiso Foam Board-Wall (GRFF faced):** PIMA EPD Polyiso board with glass reinforced aluminum foil facer for walls[29]

- **Polyiso Foam Board-Roof (GRF faced):** PIMA EPD Polyiso board with glass fiber reinforced cellulosic facer for roofs[30]

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[26] Dupont EPD, "Styrofoam™ Brand XPS Products"-1 m2 of insulation with a thickness that gives an average thermal resistance RSI = 1 m2K/W for a period of 75 years, January 1, 2021

[27] Owens Corning EPD, "FOAMULAR® XPS INSULATION", 1 m2 insulation at RSI-1, January 1, 2019

[28] Owens Corning EPD, "FOAMULAR® NGX™ XPS INSULATION", 1 m2 insulation at RSI-1, January 1, 2021

[29] PIMA EPD, "Polyisocyanurate Insulation Manufacturers Association Polyiso Wall Insulation Boards", 1 m2 of installed insulation material with a thickness that gives an average thermal resistance RSI = 1 m2·K/W (5.678 ft2·°F·h/Btu) and with a building service life of 75 years (packaging included), November 4, 2020

[30] PIMA EPD, "Polyisocyanurate Insulation Manufacturers Association Polyiso Roof Insulation Boards", 1 m2 of installed insulation material with a thickness that gives an average thermal resistance RSI = 1 m2·K/W (5.678 ft2·°F·h/Btu) and with a building service life of 75 years (packaging included), November 4, 2020

Mineral Wool Batt

We have updated:

- **Mineral Wool Batt (low density):** ROCKWOOL™ STONE WOOL SAFE'n'SOUND EPD batt insulation [31]. There were previous "versions" of batt insulations for different wall sizes (e.g. R20), these have all been replaced by these profile (R values are achieved by applying different thicknesses in the model).

- **Mineral Wool Batt (medium density):** multiplied low density values by 1.3 in accordance with factor given in EPD for CURTAINROCK insulation compared to batt.

- **Mineral Wool Batt (high density):** multiplied low density values by 4.3 in accordance with factor given in EPD for TOPROCK insulation compared to batt.

Fiberglass Batt

We have updated:

- **Fiberglass Batt (low density):** Average of 2 EPDs, Owens Corning[32] and Knauf[33]. There were previous "versions" of batt insulations for different wall sizes (e.g. R20), these have all been replaced by these profile (R values are achieved by applying different thicknesses in the model).

- **Fiberglass Batt (medium density):** Multiplied low density values by 2 to arrive at medium density profile.

Fiberglass Loose Fill

We have updated:

- **Fiberglass Loose Fill**: Owens Corning EPD for unbonded loose fill insulation[34]. There were previous "versions" of loose fill insulations for different wall sizes (e.g. cavity fill R30, open blow R30), these have all been replaced by this profile (R values are achieved by applying different thicknesses in the model).

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[31] Rockwool™ EPD, "ROCKWOOL™ STONE WOOL Insulation", 1 m2 of stone wool thermal insulation product with an RD=1 m2K/W, July 17, 2019

[32] Owens corning EPD, "EcoTouch® PINK® FIBERGLAS™ Batt & Roll Insulation – Unfaced and Faced", EcoTouch® Unfaced and Faced Insulation for use in wall, floor, roofing and ceiling applications for residential and commercial installations, 1 m2 insulation at RSI=1, September 19, 2018.

[33] Knauf Insulation EPD, "EcoBatt® batts and rolls- Unfaced, Kraft, FSK, Foil", One square meter of installed insulation material, packaging included, with a thickness that gives an average thermal resistance of R =1m ·K/W over a period of 75 years, March 12, 2018.

[34] Owens Corning EPD, "Owens Corning Unbonded Loosefill", Unbonded loosefill insulation for attics and wall, floor and cathedral ceiling cavities, 1 m2 insulation at RSI=1, September 19, 2018

Cellulose

We have updated:

- **Loose Fill Cellulose-Roof:** CIMA-CIMAC Industry-wide EPD conventional loose-fill cellulose insulation[35].

- **Blown Cellulose-Wall:** multiplied the industry average loose fill roof (attic insulation) values by two to convert into a denser packed wall insulation.

Spray Polyurethane Foam

We have updated:

- **Spray PUR Foam-HFO-Closed Cell**: SPFA industry average EPD for closed cell spray polyurethane foam[36].

- **Spray PUR Foam-HFO-Open Cell**: SPFA industry average EPD for closed cell spray polyurethane foam[36].

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[35] CIMA-CIMAC EPD, "Industry-wide Type III EPD Conventional Loose-Fill Cellulose Insulation", 1 m² of installed insulation w/packaging; thickness that gives an avg thermal resistance of RSI = 1 m²·K/W over 75 years, December 23, 2019.

[36] SPFA EPD, "Spray Polyurethane Foam Insulation (HFO)", Spray Polyurethane Foam Association, 1 m² of installed insulation material with a thickness that gives an average thermal resistance RSI=1 m2·K/W, October 29, 2018.

Appendix B: Explanation of impact measures

Global Warming Potential (GWP)

Global warming potential is a reference measure. The methodology and science behind the GWP calculation can be considered one of the most accepted LCIA categories. GWP will be expressed on an equivalency basis relative to CO_2 – in kg or tonnes CO_2 equivalent.

Carbon dioxide is the common reference standard for global warming or greenhouse gas effects. All other greenhouse gases are referred to as having a "CO_2 equivalence effect" which is simply a multiple of the greenhouse potential (heat trapping capability) of carbon dioxide. This effect has a time horizon due to the atmospheric reactivity or stability of the various contributing gases over time.

As yet, no consensus has been reached among policy makers about the most appropriate time horizon for greenhouse gas calculations. The International Panel on Climate Change 100-year time horizon figures have been used here as a basis for the equivalence index:
CO_2 Equivalent kg = CO_2 kg + (CH_4 kg x 25) + (N_2O kg x 298).

While greenhouse gas emissions are largely a function of energy combustion, some products also emit greenhouse gases during the processing of raw materials. Process emissions often go unaccounted for due to the complexity associated with modelling manufacturing process stages. One example where process CO_2 emissions are significant is in the production of cement (calcination of limestone). Because the Impact Estimator uses data developed by a detailed life cycle modelling approach, all relevant process emissions of greenhouse gases are included in the resultant global warming potential index.

Please note that the GWP total includes biogenic carbon per the national guidelines[37]. If users wish to have GWP without biogenic carbon, they can subtract GWP biogenic from GWP total.

Global Warming Potential Biogenic (GWP-Biogenic)

Biogenic GWP is accounted for as described in the Biogenic carbon section. The biogenic carbon dioxide emissions are included in the GWP total results and additionally called out separately in this measure, per ISO 21930:2017.

Global Warming Potential Calcination (GWP-Calcination)

Calcination GWP is accounted as described in the Calcination and carbonation section. The carbon dioxide emissions for concrete due to calcination are included in the GWP total results and additionally called out separately in this measure, per ISO 21930:2017.

Acidification Potential

Acidification is a more regional rather than global impact effecting human health when high concentrations of NO_x and SO_2 are attained. The acidification potential of an air or water emission is calculated on the basis of its SO_2 equivalence effect on a mass basis.

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[37] National Guidelines for Whole-building LCA (National Research Council Canada 2022). The guidelines specify that biogenic carbon should be included in whole-building LCAs.

Human Health (HH) Particulate
Particulate matter of various sizes (PM_{10} and $PM_{2.5}$) have a considerable impact on human health. The EPA has identified "particulates" (from diesel fuel combustion) as the number one cause of human health deterioration due to its impact on the human respiratory system – asthma, bronchitis, acute pulmonary disease, etc. It should be mentioned that particulates are an important environmental output of plywood product production and need to be traced and addressed. The Institute used TRACI's "Human Health Particulates from Mobile Sources" characterization factor, on an equivalent $PM_{2.5}$ basis, in our final set of impact indicators.

Aquatic Eutrophication Potential
Eutrophication is the fertilization of surface waters by nutrients that were previously scarce. When a previously scarce or limiting nutrient is added to a water body it leads to the proliferation of aquatic photosynthetic plant life. This may lead to a chain of further consequences ranging from foul odours to the death of fish. The calculated result is expressed on an equivalent mass of nitrogen (N) basis.

Ozone Depletion Potential (ODP)
Stratospheric ozone depletion potential accounts for impacts related to the reduction of the protective ozone layer within the stratosphere caused by emissions of ozone depleting substances (CFCs, HFCs, and halons). The ozone depletion potential of each of the contributing substances is characterized relative to CFC-11, with the final impact indicator indicating mass (e.g., kg) of equivalent CFC-11.

Photochemical Ozone Formation Potential (Smog)
Under certain climatic conditions, air emissions from industry and transportation can be trapped at ground level where, in the presence of sunlight, they produce photochemical smog, a symptom of photochemical ozone creation potential (POCP). While ozone is not emitted directly, it is a product of interactions of volatile organic compounds (VOCs) and nitrogen oxides (NOx). The "smog" indicator is expressed on a mass of equivalent O_3 basis.

Total Primary Energy Consumption
Total Primary Energy Consumption is reported in mega-joules (MJ) .Embodied primary energy includes all energy, direct and indirect, used to transform or transport raw materials into products and buildings, including inherent energy contained in raw or feedstock materials that are also used as common energy sources. (For example, natural gas used as a raw material in the production of various plastic (polymer) resins.) In addition, the Impact Estimator captures the indirect energy use associated with processing, transporting, converting and delivering fuel and energy and energy plus the operating energy.

Non-renewable Energy Consumption
Non-renewable Energy Consumption is reported in mega-joules (MJ) and is a subset of Total Primary Energy Consumption, and includes all the fossil fuels and nuclear.

Fossil Fuel Consumption
Fossil Fuel Consumption is reported in mega-joules (MJ) and is a subset of Total Primary Energy Consumption, namely all the fossil fuels. In other words all the energy sources in the Energy Consumption Absolute Value table, except for hydro, non-hydro renewable, nuclear and wood.