UNIVERSITY OF DENVER

PATHWAY TO DETERMINE THE EMBODIED MATERIAL CARBON FOOTPRINT OF A SINGLE-FAMILY STICK BUILT HOME:

THRIVE HOME BUILDERS

CASE STUDY

thrive HOME BUILDERS

Homes that do more.

Pathway to Determine the Embodied Material Carbon Footprint of a Single-Family Stick Built Home: Thrive Home Builders Case Study

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Executive Summary

Thrive Home Builders engaged the University of Denver (DU) faculty and student team to help determine the embodied carbon footprint of one of their Single-Family Homes. The product assessed was a 2,883 square foot (sf) ranch home with a partially finished basement, four bedrooms, four bathrooms, and a two-car garage. Utilizing the plans and a bill of materials (BOM) from a virtual design and construction (VDC) model, the research team ran the BOM through five (5) different carbon calculators; EC3, BEAM Estimator, Once Click LCA, Athena, and EHDD's EPIC (Early Phase Integrated Carbon). The calculators produced a scope 1 (A1 to A5 Material and Construction only) report, **ranging from 47.5 to 103 Metric Tons of embodied carbon** for the home. The team concluded that One Click LCA is the most straightforward and complete carbon calculator for the SFH project. It had the lowest learning curve time, the best user interface, and the simplest BOM imported without much inputting of conversions from the original output of the VDC model. It can also perform Scope 2 and 3 calculations for Operational Carbon and Whole Building Lifecycle Analysis. Thrive has elected to focus on the Product and Construction stages of the Whole Building Lifecycle Analysis due to the nature of their business.

Background

Thrive Home Builders is committed to healthy homes in Denver, Colorado, and surrounding areas. They believe a new home should be built to the highest health and sustainability standards, creating a space where a family can grow and Thrive. They are an Award-winning builder utilizing green building program designed to meet the highest standards of LEED®, Indoor airPLUS, Zero Energy Ready Homes, and Energy Star®. Recognized as 2020's EPA Indoor airPLUS Leader Award Winner, homeowners can breathe easy knowing their Thrive home was built to the highest health standards with superior air quality.

Thrive has been focused on the three legs of its brand: Efficient, Healthy & Local. Gene Meyers, founder of Thrive and Chief Sustainable Officer, tells the story of his experience during the Covid lockdown. During the COVID lockdown, at least here in Colorado, we could always go into the great outdoors. Then, the smoke from wildfires in the west made that impossible. It occurred to him that perhaps we should be focused on two things: the health of our customers & the health of our planet. Thrive energy efficiency goals will, in effect, be a means to an end: the decarbonization of their company and their products.

View from Gene's home office:

Denver tops the list of most-polluted cities in the world. On August 7, 2021, IQAir said particulate matter levels were 11 times the World Health Organization's exposure recommendation.

Author: Nate Lynn - Published: 6:02 PM MDT August 7, 2021

For Thrive, it has been a natural evolution from Energy Efficiency to Zero Carbon. They have been a member of the Energy & Environmental Building Alliance (EEBA) since it initially focused on energy efficiency via Energy Star. The next evolutionary step -- EPA Indoor airPLUS and EPA WaterSense under the DOE Zero Energy Ready Home program. Now, the next giant step and greatest opportunity is to incorporate decarbonization into program requirements.

Definition of Terms - The vocabulary used for carbon related issues in practice

a) Life Cycle Assessment (LCA) – Analysis used to quantify greenhouse gas emissions and their potential effects on climate change (Simonen, 2022)
   i) Global Warming Potential (GWP) – A metric used to quantify potential effects on the environment. Portrayed as kilograms of Carbon Dioxide equivalent (kg CO2e). (Simonen, 2022)
   ii) Environmental Product Declarations (EDPs) – Report environmental impacts from cradle to gate for many construction products. (Current EDPS, 2022)
b) Carbon Emissions/ Greenhouse Gas Emissions (GHG)
   i) Embodied Carbon – Refers to the greenhouse gas emissions arising from the manufacturing, transportation, installation, maintenance and disposal of building materials (Simonen, 2022)
   ii) Operation Carbon – The greenhouse gas emissions due to building energy consumption (Simonen, 2022)
c) Carbon Footprint Scope

i) Scope 1 – Direct GHG – These occur from sources that are owned or controlled by the company (Carbon Footprint, 2016)
ii) Scope 2 – Electricity and heat indirect GHG emissions – This accounts for GHG emissions from the generation of purchased electricity and heat consumed by the company. Scope 2 emissions physically occur at the facility where the electricity is generated (Carbon Footprint, 2016)
iii) Scope 3 – Other indirect GHG emissions – This is a reporting category that allows for the treatment of all other indirect emissions. Scope 3 emissions are a consequence of the activities of the company, but occur from sources not owned or controlled by the company. (Carbon Footprint, 2016)

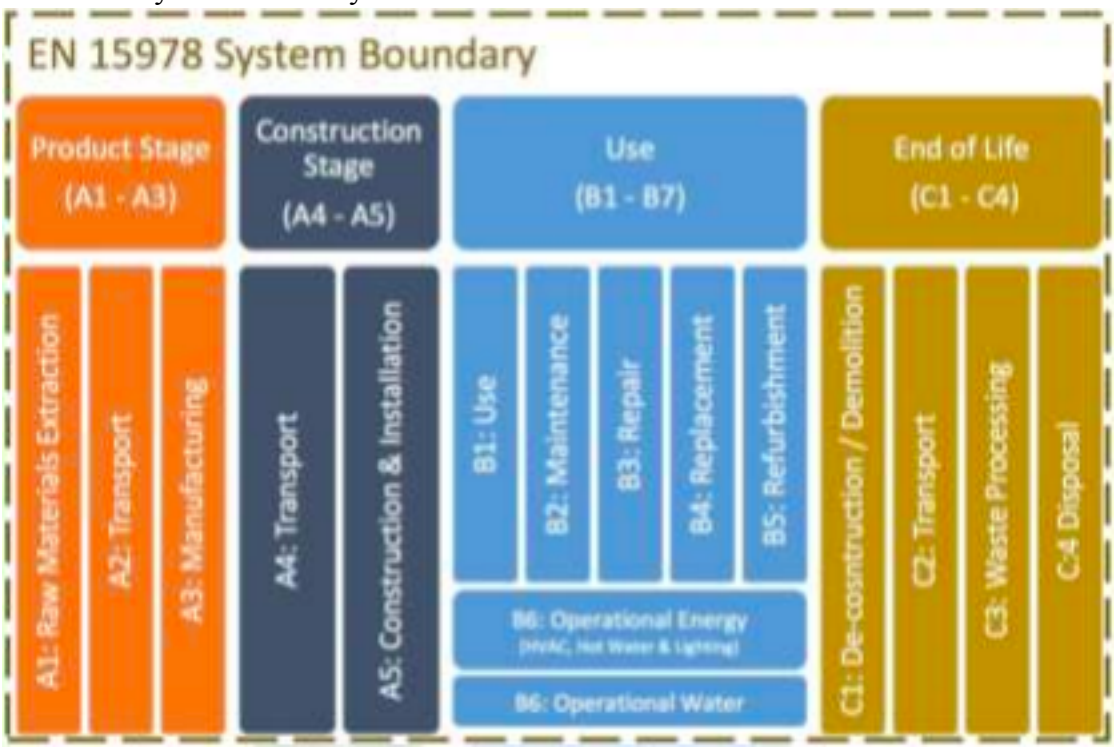
d) Whole Building Life Cycle Analysis (WbLCA) Stages
i) Production Stage – The energy and resources used to extract raw materials, to transport the materials to product manufacturing facilities, and to produce the final building product. (The Carbon Leadership Forum, 2019)
ii) Construction Stage – The transportation of materials to the construction site as well as the energy used to power the construction equipment, to supply supporting construction materials, and to dispose of any waste generated during the construction process. (The Carbon Leadership Forum, 2019)
iii) Use Stage – The impacts of occupying a building over its lifetime due to lighting, heating, water use, and any materials used for maintenance, repairs, and replacement. (The Carbon Leadership Forum, 2019)
iv) End-of-life Stages – The demolition and disposal of the building as well as waste processing. (The Carbon Leadership Forum, 2019)
v) Reuse, Recover and Recycle Stage (Not depicted in graphic below) – All the miscellaneous effects of reusing, recycling, and/ or recovering materials, energy, or water from the product. (The Carbon Leadership Forum, 2019)

One Click LCA Life Cycle Stages Table:

Product Stage			Construction Process Stage		Use Stage							End-of-Life Stage				Benefits and loads beyond the system boundary		
Raw material supply	Transport	Manufacturing	Transport to building site	Installation into building	Use/application	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction/demolition	Transport	Waste processing	Disposal	Reuse	Recovery	Recycling
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	D	D

(One Click LCA, 2022)

EN 15978 System Boundary Table:



(The Carbon Leadership Forum, 2019)

Research Questions

Thrive wanted to know the embodied carbon footprint of a stick-built Single-Family Home. For this study, the University of Denver (DU) research team of faculty and students worked with Thrive to calculate the carbon footprint of a stick-built single-family home. The initial focus is on the typical home builder material estimate that can be calculated from a BOM. Using the Whole Building Life Cycle Assessment (WBLCA) stages, they focused on the Product and Construction Stages, using Scope A1-A5, as a baseline starting point. This is a critical figure for Thrive due to the nature of their business operations. They exercise the most control over the product and construction stage of the WbLCA. Although, A1 – A5 are the most immediate to their operations, there needs to be an understanding for the remainder of the WbLCA in order to improve sustainability down the line in the future.

Methodology

The DU research team was given a set of plans and a Bill of Materials (BOM) for a project to be built in the Fort Collins, CO market. It is a single-family home, single-story, stick-built construction. The main floor is 1808 SF with two bedrooms and two bathrooms. A detached "Do More" suite also adds another 288 SF and another bedroom and bathroom to the main floor. The basement has another 787 finished SF with a rec room, bedroom, and bathroom. The total finished SF of the home is 2,883 SF with a 429 SF two-car garage. The foundation system is a poured concrete basement foundation on the main house and a slab foundation for the

garage and detached suite. It is a stick-built framing system with an engineered I-joist floor system, 2x6 exterior walls, 2x4 interior walls, and a 4/12 trusses roof with 24" overhang system.

The Virtual Design & Construction (VDC Model) created the BOM. The BOM listed all the material that could be counted from the VDC Model. It included all homebuilding systems from foundation, framing, MEP, and interior and exterior finishes. It included 443 SKUs, 670 rows of details, and 19,436 pieces. The BOM quantified the material only. It did not include packing or shipping materials, labor, equipment, or installation. It is limited to Scope A1 to A3 only.

The research team took the BOM and imported it onto different carbon calculators that focused on building materials. The team measured how long it took, what modifications were needed to import the BOM, how difficult they were to work with and learn, the completeness of the database, and what the final calculated amount of carbon was in the BOM.

Calculators tested:

1. EC3, by Building Transparency - https://www.buildingtransparency.org/
2. BEAM Estimator, by Builders for Climate Action - https://www.buildersforclimateaction.org/beam-estimator.html
3. One Click LCA - https://www.oneclicklca.com/
4. Athena, by the Sustainable Materials Institute - http://www.athenasmi.org/our-software-data/ecocalculator/
5. EHDD's EPIC (Early Phase Integrated Carbon) - https://www.ehdd.com/post/introducing-ehdds-early-phase-carbon-assessment-tool

EC3

EC3 is a product phase carbon footprint calculator that uses various EDP's with regional consideration options to derive the amount of kg CO2E developments emit. The calculator has a significant learning curve as it is not intuitive to navigate, and the site is a bit cumbersome when making changes, taking 30 seconds for the site to respond at times. Where the calculator adds value is in the ability to get an understanding of what can be achieved through varying materials or regions. In the outputs, there are "Conservative Estimate" figures as well as "Achievable Target" figures that show the good and the bad as far as product options are concerned. Another advantage is that the site is easy to sign up with and get started. It covers the A1 to A3 scope, but at the time of testing, it was not a Whole Building Life Cycle Analysis (WBLCA) tool. At the time of testing, the cost to utilize the site was free. The Site also has import functionality for BIM Collaborative Pro and Tally models, to ease use.

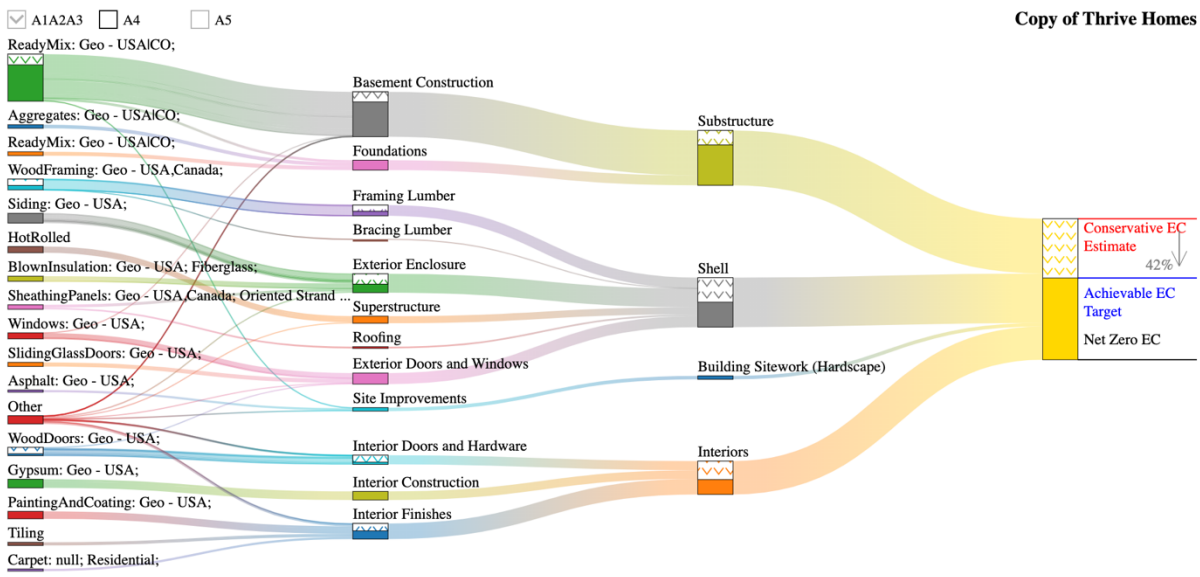
Analysis:

Advantages	Disadvantages
Updated interface (since first run-through), less glitchy and seems more user friendly	BOM quantity conversions can become complex, would be nice to have a built in calculator
Easy sign-up	Conversions were the most time-consuming process of utilizing this calculator
Import ability from REVIT - Pro for a builder who utilizes Autodesk/Revit	Missing a lot of material that were included in the BOM: o Concrete Mesh o rebar quantity o Egress window w/ window well o Anchor bolts o Drain tile o Waterproofing o Stone Sub Base o Adjustable steel column o Slab Vapor Barrier o Windows, doors, glass details o Stair Treads o Gutters o Roof Trusses o MEP Details o Engineer wood flooring dimensions o Baseboard dimensions/material o Joists o Fixtures, hinges, door hardware
EDP's can be customized based on regional preferences	Missing a lot of general info/dimensions--questioning the accuracy of the report based on limited material selection access and knowledge of the material location
	Free version access limits material options, less detailed
	Import ability from REVIT - Con for a builder who does not utilize Autodesk/Revit

General Notes:

- Search EPDs first, then enter quantities. EC3 will provide suggested unit/metric.

- It took the team 15 hours of inputs and calculations conversions to create a final report and the Sankey Diagram below.



According to EC3, the SFH has 103,000 kg CO2e, = 103 Metric Tons of Embodied Carbon Footprint.

BEAM

BEAM is an in-depth calculator that looks at the product phase carbon footprint. One of the main difficulties with operation of this calculator is it asks for a lot of data that may not be available such as material quantities in partition walls, garages, exterior walls, and the like. The calculator is designed in a manner where you pick from the listed options, with fill-in-the-blanks along the bottom of each section. This is not advantageous as it is possible to not be using the materials listed, at which point there are only 6 spots for additional materials that are not listed. But if you have all the additional information and a privy enough to find similar material offerings from the given options, this is a very good tool. The outputs are sectioned off in a more builder-friendly manner than simply the material and the kg CO2e for said material used based on quantities. Not a complete WBLCA tool. On the input side, it is essential to have a very detailed BOM or BIM to break down given section of the development. At time of testing, the cost to utilize is free.

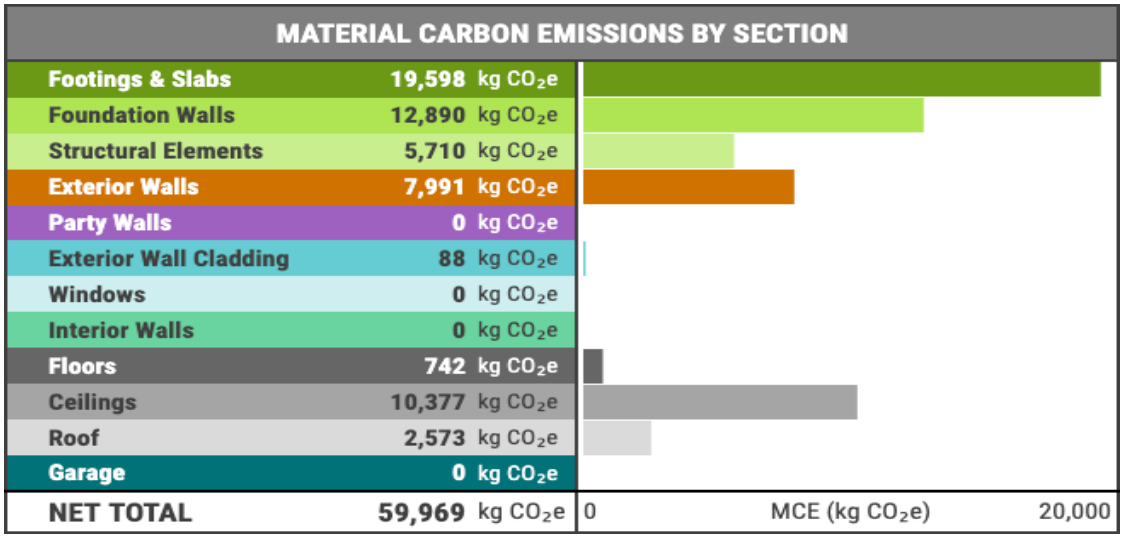
Analysis:

Advantages	Disadvantages
User guide--lengthy but very digestible and helpful	This calculator is for very detailed BOM's coupled with blueprints.
Can toggle units between imperial and metric	With the given information is it challenging/ impossible to break down the information into

	smaller pieces without knowing proportions of items used. I.E. How many 2x4's were using in the garage/ for interior walls/ exterior walls/ flooring and roofing/ partition walls
Excel/google sheets format-- has the potential to be a collaborative document	Using the calculator without a Gmail account makes it non-transferable/ sharable (App says that it can be done, but the team kept getting error codes when trying to utilize the additional features like saving)
Can add up to 5 custom materials by length (included at the bottom of each sheet)	Separates garage from main structure
Extensive material option (broken down by location)	Better then EC3 in that it is more in depth, accounting for particular portions of the house, but the team believes for the exercise at hand it is super overwhelming albeit the majority of the options are not applicable
	Many inputs will be left blank as they do not correlate with BOM
	Extensive material option (broken down by location) but hard to match exact materials based on existing BOM

General Notes:

- The team thought it best used by inputting the information at the bottom of the screens as opposed to sifting through the offerings to find your product or material.
- EC3 is a more compatible app with the info given and is easier to use for the average Joe
- Very detailed calculator, but it seems like your BOM would need to correlate perfectly with the format of BEAM in order to get the most accurate results
- Prefer EC3 and One Click



- According to BEAM, the SFH has 59,969 kg CO2e, = 59.9 Metric Tons Embodied Carbon Footprint.

One Click LCA

One Click LCA is a very user-friendly carbon footprint calculator. The interface is quite easy to use and assimilate yourself with. There is a lofty amount of material offerings, with some regional differentiators, although the regional selections are not always exhaustive. It is seen as more beneficial to find as close of a material match as you can as opposed to focusing on regional consideration for this tool. The free version breaks down the outputs based on material, ranking the materials based on the kg CO2e, highest to lowest intensity. A1 - A3 (free) WBLCA (Commercial/ Paid Version). The free version lacks a WBLCA component. Just like all other calculators to date, the small and miscellaneous portions of the developments are not present or somewhat skewed.

Analysis:

Advantages	Disadvantages
The team's favorite Calculator yet	Lacks in the ability to generate an "achievable" GWP through altering materials like EC3 offers.
Calculator has an additional output that considers the transportation of the materials chosen	Paid version offers a WBLCA, but free version only offers A1-A5 scope
The options on materials are robust and there are options for both general and specific materials	
Easy access and breakdown of results	

Most user friendly interface thus far	
It took the team 12 hours to learn and produce the report below	

General Notes:

- This is the team's preferred calculator, please reference the conclusion of this report.

Entity users	Project name				
Isabella Vasquez	Lot 279				
Section	Result category	Global warming t CO_2e	Global warming kg CO_2e	Mass of raw materials t	Mass of raw materials kg/m
1	Ready mix concrete (A1-A3)	28.37	147.03	185.73	962.52
2	Precast concrete (A1-A3)				
3	Cement (A1-A3)				
4	Steel (A1-A3)	32.53	168.56	22.89	118.65
5	Aluminium (A1-A3)				
6	Bricks (A1-A3)	2.05	10.6	1.48	7.69
7	Glass (A1-A3)				
8	Insulation (A1-A3)	1.94	10.07	0.67	3.49
9	Wood (A1-A3)	14.41	74.7	73.57	381.25
10	Gypsum (A1-A3)	2.88	14.94	8.79	45.53
11	Other materials (A1-A3)	10.51	54.45	75.44	390.95
A1-A3	Construction Materials	92.69	480.36	368.57	1910.07

According to Once Click LCA, the SFH has 92,690 kg CO2e, = 92.69 Metric Tons Embodied Carbon Footprint.

Athena Impact Estimator for Buildings

Athena Impact Estimator for Buildings is a WBLCA. It incorporates all scopes from A - D. The calculator allows for generic excel BOM's to be inputted. In following this method, it makes the calculator easy and fast. By far the fastest input to output with the smallest learning curve. It also saves a library on their estimator that makes sequential projects very easy, if the same materials are used, it could result in minimal to zero alterations, just click and play. Athena also uses their own database with supplemented EDP's when their database does not have the listed material. The kg CO2e or GWP (global warming potential) generated by this calculator have been slightly lower than the competitor calculators with the same data.

Analysis:

Advantages	Disadvantages
This calculator gives a great overarching view of the embodied carbon that goes into a project	In order to import materials, a simplified BOM is needed. This analysis focused on three large inputs: concrete, lumber, and steel
There does need to be some amendments made to the BOM to utilize it in entirety, but once those amendments are made, mapping out the BOM is fairly simple and generating an output is also simple.	Importability is tricky, a simplified BOM must be calculated in a specific format in order to import into the software

There is also a function where you can save mapping data, to make subsequent analysis' much easier than the first	Results are more holistic, given the simplified inputs. Simple inputs= simple output
This estimator also provides conversion tables that remove the use of internal calculations	

General Notes:

- The results from this calculator are interesting in that they have outputs for both the materials itself and the transportation factor that goes into play.
- The results are also more broken out to account for different life cycles of the project from the product manufacturing to the end-of-life disposal.

Detailed LCA Measure Table By Life Cycle Stages

Project: Lot 279

		PRODUCT (A1 to A3)			CONSTRUCTION PROCESS (A4 & A5)			USE (B2, B4 & B6)				END OF LIFE (C1 to C4)			BEYOND BUILDING LIFE (D)			TOTAL EFFECTS	
LCA Measures	Unit	Manufacturing	Transport	Total	Construction-Installation Process	Transport	Total	Replacement Manufacturing	Replacement Transport	Operational Energy Use Total	Total	De-construction, Demolition, Disposal & Waste Processing	Transport	Total	BBL Material	BBL Transport	Total	A to C	A to D
Global Warming Potential	kg CO2 eq	3.70E+04	1.23E+03	**3.82E+04**	3.44E+03	2.41E+03	**5.85E+03**	0.00E+00	0.00E+00	0.00E+00	**0.00E+00**	2.51E+03	9.48E+02	**3.45E+03**	-8.04E+03	0.00E+00	**-8.04E+03**	**4.75E+04**	**3.95E+04**
Acidification Potential	kg SO2 eq	1.09E+02	1.36E+01	**1.23E+02**	3.03E+01	2.39E+01	**5.42E+01**	0.00E+00	0.00E+00	0.00E+00	**0.00E+00**	3.53E+01	9.12E+00	**4.45E+01**	-1.72E+00	0.00E+00	**-1.72E+00**	**2.22E+02**	**2.20E+02**
HH Particulate	kg PM2.5 eq	4.94E+01	6.30E-01	**5.01E+01**	3.01E+00	1.30E+00	**4.30E+00**	0.00E+00	0.00E+00	0.00E+00	**0.00E+00**	1.22E+00	5.05E-01	**1.72E+00**	-7.55E-01	0.00E+00	**-7.55E-01**	**5.61E+01**	**5.53E+01**
Eutrophication Potential	kg N eq	3.85E+01	8.45E-01	**3.94E+01**	3.54E+00	1.48E+00	**5.02E+00**	0.00E+00	0.00E+00	0.00E+00	**0.00E+00**	2.21E+00	5.67E-01	**2.77E+00**	-8.85E-02	0.00E+00	**-8.85E-02**	**4.71E+01**	**4.71E+01**
Ozone Depletion Potential	kg CFC-11 eq	7.78E-04	4.45E-08	**7.78E-04**	3.90E-05	8.63E-08	**3.91E-05**	0.00E+00	0.00E+00	0.00E+00	**0.00E+00**	1.09E-07	3.31E-08	**1.43E-07**	0.00E+00	0.00E+00	**0.00E+00**	**8.17E-04**	**8.17E-04**
Smog Potential	kg O3 eq	1.94E+03	4.36E+02	**2.37E+03**	9.31E+02	7.55E+02	**1.69E+03**	0.00E+00	0.00E+00	0.00E+00	**0.00E+00**	1.17E+03	2.88E+02	**1.46E+03**	-1.74E+01	0.00E+00	**-1.74E+01**	**5.52E+03**	**5.50E+03**
Total Primary Energy	MJ	3.23E+05	1.77E+04	**3.41E+05**	4.07E+04	3.51E+04	**7.58E+04**	0.00E+00	0.00E+00	0.00E+00	**0.00E+00**	3.73E+04	1.38E+04	**5.11E+04**	-3.45E+03	0.00E+00	**-3.45E+03**	**4.68E+05**	**4.65E+05**
Non-Renewable Energy	MJ	2.74E+05	1.76E+04	**2.91E+05**	3.71E+04	3.51E+04	**7.22E+04**	0.00E+00	0.00E+00	0.00E+00	**0.00E+00**	3.73E+04	1.38E+04	**5.11E+04**	-3.45E+03	0.00E+00	**-3.45E+03**	**4.15E+05**	**4.11E+05**
Fossil Fuel Consumption	MJ	2.39E+05	1.76E+04	**2.56E+05**	3.61E+04	3.51E+04	**7.12E+04**	0.00E+00	0.00E+00	0.00E+00	**0.00E+00**	3.72E+04	1.38E+04	**5.10E+04**	-6.91E+03	0.00E+00	**-6.91E+03**	**3.79E+05**	**3.72E+05**

According to Athena, the SFH has 47,500 kg CO2e, = 47.5 Metric Tons Embodied Carbon Footprint.

EHDD's EPIC (Early Phase Integrated Carbon)

EHDD's mission is to give valuable information to developers, architects, and the like in the early stages of planning a building's development. The information is in relation to the GHG emissions from the particular product phase of the process. The tool aims to be complementary to the likes of EC3, Tally and other LCA tools. An interesting metric that EHDD tracks that no other calculator the team has seen uses is the amount of sequestered carbon inherent in the project. Sequestered carbon is present in most materials used for construction but are particularly prominent in wood products.

Analysis:

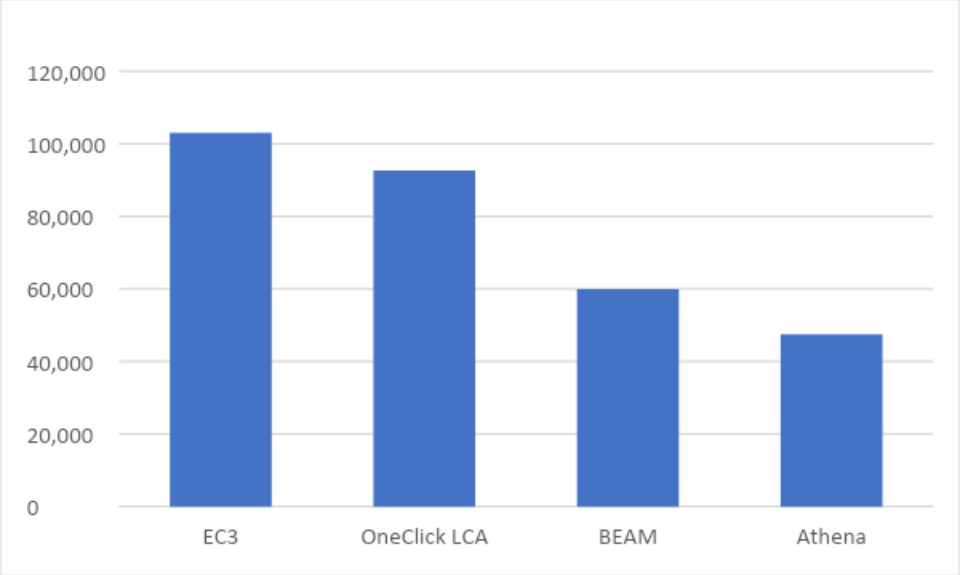
Advantages	Disadvantages
	This tool takes a very overarching approach.
	To utilize the tool, there are no inputs for quantities of products, but the software uses base scenarios based on the sqft above and below grade, the landscape and site development.

	The tool focuses on using overarching metrics (primary structure system - reinforced concrete/ mass timber and the like) to provide scenarios for reducing the embodied and operational carbon.

General Notes:

- To beat the dead horse.... the tool is more of a strategy tool opposed to an informative series of calculations that can be portrayed to show the environmental effect of the project. This software takes an overarching approach. There is no opportunity to enter quantities or the like, simply, the type of structure (Reinforced concrete, mass timber, steel frame and wood frame.) Then the calculator dives into the operational carbon aspects of the project.

Conclusion



The team concluded that One Click LCA is the easiest and most complete carbon calculator for the SFH project. It had the lowest learning curve time, the best user interface, and the simplest BOM imported without a lot of inputting conversions from the original output from the VDC model. It can also to Scope 2 and 3 calculations for Operational Carbon and Whole Building Lifecyle Analysis. We think it is worthwhile to run multiple calculators in creating a conservative figure for carbon foot printing. Although there are slightly different methodologies, it is pertinent to remain conservative in the estimations of tons of kg CO_2e, building creates as this process is relatively new. Completing a WbLCA is a frugal use of time in looking to drive forward thinking solutions that add value or reduce carbon further down the lifecycle chain. Lastly, which tool you use should be based on the overall objective of the analysis, coupled with the operations that your business undergoes.

Future Research

1. What materials can substitute in for concrete and wood sheathing that make economic sense and still meet structural and building code requirements
2. Based on the outputs generated from all of the calculators studied, the most impactful changes to materials that Thrive can act on is the use of lumber and concrete.
    a. Lumber as a material that can have a net positive carbon effect through the sequestered carbon inherent in the material and the emergence of "sustainably managed forests." Ensuring the lumber supplies originated from said sustainable managed forests nullifies the emissions from the production creation and implementation
    b. For concrete, there are companies such as Brimstone that are starting to tackle this issue of embodied carbon emitted from the creation of concrete. Not as economically beneficial as the concrete itself, but there seems to be growing interest in this space as concrete creates.
        i. "Cement is the source of about 8% of the world's carbon dioxide emissions" (Rodgers, 2018)
3. Expanding the boundary- Where do you draw the line?
    a. Lot, Subdivision, waste stream, labor, tools & equipment, fuel that can be booked directly to the site, how far does the carbon rabbit hole go?
    b. Transportation

Errors and Corrections

In diving into the numbers for the Sonders carbon footprint figures we discovered an error in the early calculations. When formulating the amount of cubic feet of each lumber line item, we originally, incorrectly took the height in inches, multiplied by the width in inches and multiplied these figures by the linear feet. This generated an over estimation of cubic feet for all lumber line items in the Bill of Materials provided. In recalculating these figures, converting all numbers into feet, we were able to get an accurate kilograms of carbon dioxide equivalent with all above the mentioned calculators. The difference in the outcomes were massive as anticipated. The updated outputs for EC3, OneClick, BEAM and Athena are as follows accordingly: 103k kgCO2e, 92.60k kgCO2e, 57.9k kgCO2e and 47.5k kgCO2e. This large reduction in embodied carbon is not representative of differing materials or methodologies of the tools utilized, but an incorrect input generated from an incorrect calculation of the lumber volumes.

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