Impact of Cellulose Insulation on the Carbon Footprint of Building Assemblies

Report produced for Apple - Greenfiber Insulation

By Builders for Climate Action

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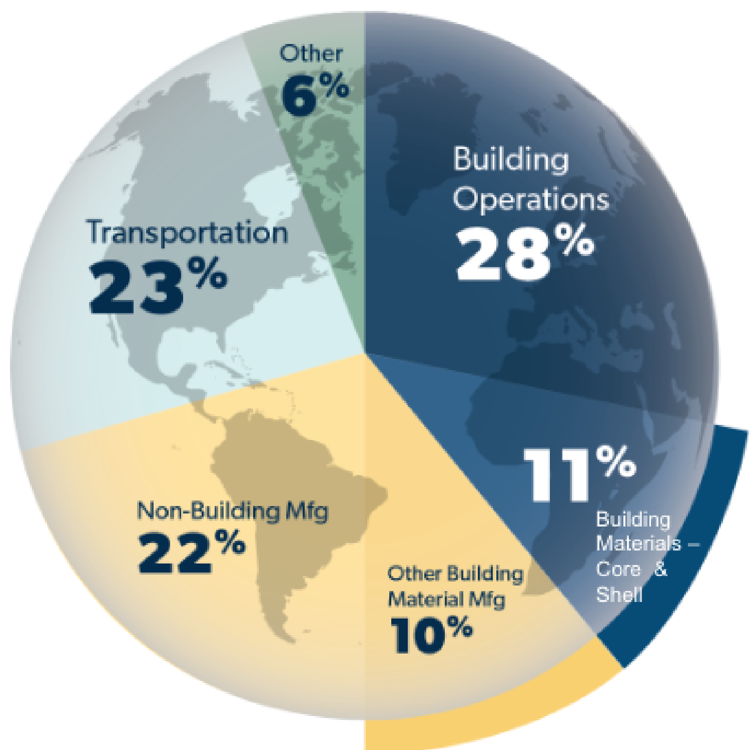
About Builders for Climate Action

Builders for Climate Action is working with builders, designers, developers, policy-makers, researchers and manufacturers to tackle the serious impact of buildings on our climate and work toward real zero carbon buildings.
We want to offer future generations our best efforts to reign in the worst effects of climate change through smart, coordinated and effective action to address emissions in the sector while building a world that is just and equitable.

The importance of embodied carbon in buildings

The US government has committed to reducing total emissions by 50-52% (from 2005 levels) by 2030, and to produce net zero emissions by 2050.[1] The building sector has been recognized as being responsible for a high proportion of emissions as a result of building operations, but only recently has the emissions arising from the life cycle of building materials – often called "embodied carbon" – been recognized as a leading source of greenhouse gasses. Globally, the manufacturing of building materials is estimated to be around 20 percent of total fossil fuel emissions.



 Data Sources: UN Environment Global Status Report 2017; EIA International Energy Outlook 2017

It is likely that new home construction in the US is responsible for at least 50-60 million tonnes of greenhouse gas emissions annually.[2,3] At this level of emissions, the home building sector has a carbon footprint for materials equivalent to the entire production-based emissions of countries such as Hungary, Sweden and Norway.[4]

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[1] https://www.whitehouse.gov/climate/ Accessed September 5, 2022
[2] Carbon Leadership Forum, Embodied Carbon Benchmark Study: LCA for Low Carbon Construction, 2017. https://carbonleadershipforum.org/lca-benchmark-database/ Accessed October 20, 2022.
[3] Builders for Climate Action, Achieving Real Net Zero Homes, 2021. DOI: 10.13140/RG.2.2.27404.23680
[4] Climate Analysis Indicators Tool (CAIT), Climate Watch. 2018. Washington, DC: World Resources Institute (2019).

The scale of embodied carbon in construction has begun to draw attention from regulators at the federal, state and city levels across the US and Canada. The recent Inflation Reduction Act in the US allocates $4 billion for the development of low-embodied carbon standards and procurement policies for the US government. This is an impactful tactic, as selecting low-carbon building material options can dramatically reduce emissions while maintaining the same level of building performance. Building insulation products in particular have a very wide range of material-related emissions (see Table 1) meaning that selection of low-carbon insulation options can have an outsized impact on the overall emissions of an entire building or renovation project.

Importance of insulation embodied carbon of houses

A study of 503 as-built new homes in the Toronto, Ontario region found insulation to be the second largest source of material-related emissions (after concrete), with 26 percent of total emissions from the sample homes arising from the manufacturing of insulation. An average of 10.4 tonnes of emissions per house are attributable to insulation products in that study.[5]

The important drive to reduce operating emissions from buildings will result in more insulation being required by building codes and voluntary standards. This will lower operating emissions from new homes built with more insulation, but we risk raising the embodied carbon for that additional material and offsetting some or all of the operational reductions due to the pulse of emissions generated by the production of the additional insulation material.

A study for Natural Resources Canada[6] demonstrated that increasing energy efficiency from current code minimum requirements to “net zero ready” standards could increase the embodied carbon of a two-story house by an average of 30 tonnes if high embodied carbon insulation products are used. In a region with carbon-intensive energy sources, this would offset nearly four years of operational emission reductions. However, in a region with a clean electrical grid, that increase in embodied carbon will take over 480 years to be matched by operational reductions. Clearly, an understanding of the impact of additional insulation materials and their material carbon footprint should be an important part of energy efficiency programs and codes.

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[5] Magwood, C., Bowden, E., Trottier, M. Emissions of Materials Benchmark Assessment for Residential Construction Report (2022). Passive Buildings Canada and Builders for Climate Action. DOI: 10.13140/RG.2.2.34242.66243

[6] Magwood, C., Ahmed, J., Bowden, E., Racusin, J. (2021). ACHIEVING REAL NET-ZERO EMISSION HOMES: Embodied carbon scenario analysis of the upper tiers of performance in the 2020 Canadian National Building Code . DOI: 10.13140/RG.2.2.27404.23680

Carbon accounting for insulation products: EPDs

In order to accurately compare the carbon footprint of competing insulation products, it is becoming common practice to use the Global Warming Potential (GWP) factors from Environmental Product Declarations (EPDs), which are an ISO-standardized way of reporting the results of life cycle assessments (LCAs) so that the results are comparable among products of similar types, such as building insulation. An EPD "quantifies environmental information on the life cycle of a product to enable comparisons between products fulfilling the same function."[7]

Industry-average EPDs gather data from multiple manufacturers and produce a single GWP factor to represent an average of the results from the participating manufacturers. Product-specific EPDs are created by a single manufacturer and the GWP factor is unique to that product.

The building insulation market currently has a mix of these two types of EPDs representing the common product options. Some product types, such as cellulose and EPS foam, have industry-average EPDs. Other product types, such as fiberglass and XPS foam, have product-specific EPDs. Others, such as mineral wool, have both industry-average and product-specific EPDs. Currently, this mix of EPD types enables broad comparisons between product types, with product-specific results being averaged to reflect all available data in the category. As more manufacturers produce product-specific EPDs, building designers and constructors will be able to select products based on their actual carbon footprint.

In this study, Table 1 shows material carbon emissions for cellulose insulation based on both the industry average EPD (produced by the Cellulose Insulation Manufacturers Association) and a third party verified life cycle assessment (LCA, the precursor to publishing an EPD) for SANCTUARY(R) by Greenfiber Insulation.

Accounting for biogenic carbon content

EPDs are currently inconsistent in dealing with biogenic carbon storage in products, despite the importance of durable carbon storage in meeting climate targets.[8] There are three accepted pathways recognized by the current ISO rules for life cycle assessment: biogenic carbon can be ignored, it can be treated as neutral (called -1/+1 because it calculates biogenic carbon in the raw material but assumes that the full carbon content will be released at the end of a product's life), or it can be shown as biogenic carbon storage (a negative number) in the A1 phase and attribute a reasonable amount of carbon release in the C phase at end of life, based on anticipated disposal methods. This type of accounting for biogenic material more accurately reflects the actual climate impact of biogenic materials, as they prevent CO2 from accumulating

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[7] ISO 14025:2006(en): Environmental labels and declarations — Type III environmental declarations — Principles and procedures. https://www.iso.org/obp/ui/#iso:std:iso:14025:ed-1:v1:en

[8] IPCC, What Transitions Could Enable Limiting Global Warming to 1.5C?. https://www.ipcc.ch/sr15/faq/faq-chapter-4/

in the atmosphere for the duration of time the product is in the building, and perhaps beyond.[9] It is likely that this will become the accepted methodology as the development of carbon storage methodologies and markets begins to expand, such as the recent release of carbon removal certificates for building materials by Puro.Earth[10] on the NASDAQ exchange and the standard development work of Aureus Earth.[11]

Carbon Accounting for Buildings: BEAM

GWP factors from EPDs provide important data, but this does not translate into comparable carbon footprint information for actual buildings. Because performance levels (in the case of insulation, the R-value per inch) are different for each product, it will take a unique quantity of material to achieve a particular performance level in a building.

LCA software programs are able to convert GWP factors into actual carbon footprint for a specific quantity of material in a building design.

The Building Emissions Accounting for Materials (BEAM) software was developed by Builders for Climate Action to provide comparative material assessment for low- and mid-rise residential designers and builders. BEAM includes industry-average and product-specific EPDs and shows users which type of EPD was used to generate the results visible in the software. BEAM also provides the carbon storage value for products with biogenic carbon content and applies a consistent methodology for all such products to ensure comparability.[12]

This study uses BEAM to generate comparisons of emissions associated with different product types and assemblies, ensuring that each comparison reflects comparable accounting for material quantities for the stated performance level.

Insulation Comparison

As insulation levels in buildings increase to meet higher and higher energy efficiency requirements, choosing insulation products based on their embodied carbon is crucial. In this study, BEAM was used to assess the comparative carbon footprint of a range of common insulation products, using 100 square feet of coverage area and an R-value of 10 as the performance criteria. Table 1 summarizes the results of this analysis.

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[9] Liz Marshall and Alexia Kelly, “The Time Value of Carbon and Carbon Storage: Clarifying the Terms and Policy Implications of the Debate,” World Resources Institute, November, 2010,, MPRA paper no. 27326.
[10] Puro Standard Bio-based Construction Materials Methodology. https://connect.puro.earth/biobased-construction-materials-carbon-removal
[11] A Methodology for Building-based Embodied Carbon Offsetting. https://www.aureusearth.com/documents
[12] BEAM Methodology. https://www.buildersforclimateaction.org/beam-estimator.html

Comparison of cavity fill insulation products @ 100 ft^2 and R-10		
Product type	EPD type	GWP value kg CO2e
Closed cell polyurethane spray foam, HFC	Industry avg.	**215**
Closed cell polyurethane spray foam, HFO	Industry avg.	**68**
Mineral wool batt	BEAM avg. of products	**28**
Mineral wool loose fill	Industry avg.	**26**
Fiberglass loose fill	BEAM avg. of products	**16**
Fiberglass batt	BEAM avg. of products	**11**
Hemp wool batt	Nature Fibre	**-9 (28)***
Cellulose loose fill	Industry avg.	**-17 (8)***
Cellulose dense packed (3.5 lb/ft^3)	Industry avg.	**-35 (16)***
Cellulose loose fill	Applegate-Greenfiber LCA[13]	**-21 (4)***
Cellulose dense packed (3.5 lb/ft^3)	Applegate-Greenfiber LCA	**-43 (8)***
*Value in parentheses indicates emissions from product before biogenic carbon storage value subtracted		

Table 1. GWP values of insulation types

Cellulose insulation has the lowest carbon footprint of all the insulation types prior to the inclusion of carbon storage value. With carbon storage attributed, this type of insulation provides the highest degree of net carbon storage in the study.

It is important to note that individual products with specific EPDs will have values higher and lower than the averages shown in this comparison. Owens Corning Eco-Touch Pink fiberglass batt has a product-specific result of 8 kg CO2e, which is the lowest product specific result available in the BEAM tool. Even this result is significantly higher than the results for cellulose insulation.

[13] Life Cycle Assessment (LCA) of SANCTUARY(R) Insulation by GreenfiberI, Sustainable Minds, October 2022

Assembly comparison

Greenfiber Insulation provided the research team with six (6) home building assemblies (including wall framing, structure and insulation and roof insulation) that reflect current practice in the home building sector (see Appendix 1 for details of each assembly). The BEAM tool was used to model each of these assemblies, and the results are shown in Figure 1.

All the assemblies are based on typical wood frame construction, and the carbon footprint for the framing (13 kg CO2e) and structural sheathing (29 kg CO2e) are the same across all the samples. The differences between each sample arise entirely from the type of insulation specified.

Each assembly is represented with two different bars in the chart. The gray bars represent the net carbon footprint results (carbon emissions minus carbon storage) and the colored bars represent the contribution of each material in the assembly to the net total. Colored areas below the zero line represent carbon storage and those above the zero line represent emissions.

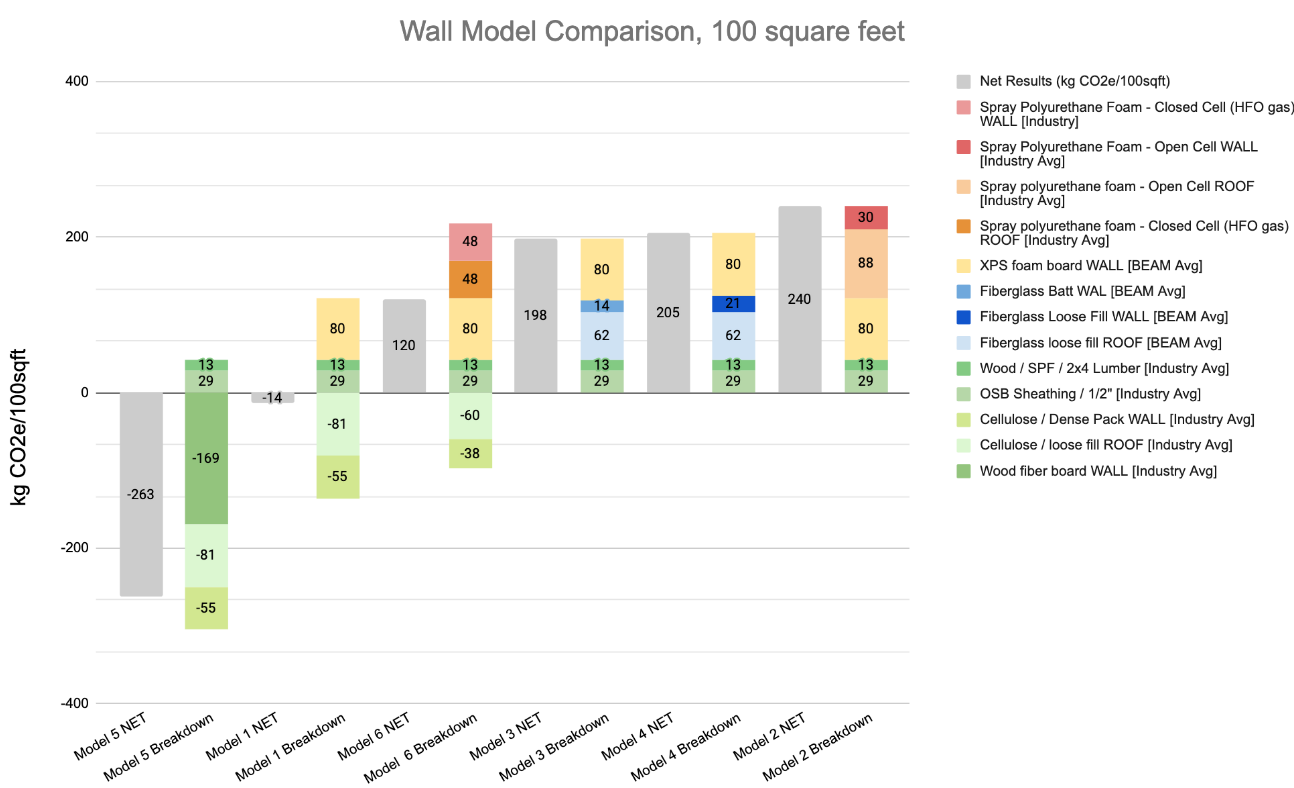

Figure 1. Carbon footprint comparison chart of six assemblies

Assembly 5 is shown to have the lowest net carbon footprint, at -263 kg CO2e. This assembly combines two biogenic insulation materials, with cellulose used in wall and roof cavities and wood fiberboard used as a continuous exterior wall insulation. This result is 210 percent better than the assembly with the highest carbon footprint, which is a typical assembly using XPS and spray foam insulation products.

The second best result is found in Assembly 1. This assembly uses the same quantities of cellulose insulation in the wall and roof cavities, but uses XPS foam board as the continuous exterior insulation. The carbon storage provided by the cellulose insulation offsets all of the emissions from the other materials in this assembly, with a net result of -14 kg CO2e.

The results demonstrate that insulation choices can have a dramatic impact on the carbon footprint of an entire assembly, and therefore an entire house. Table 2 shows the percentage reduction from the assembly with the highest example.

Comparison of Carbon Footprint for Different Assemblies				
Assembly	Wall R-value	Roof R-value	kg CO2e per 100 ft^2	Percentage reduction
#2 Open cell spray foam in cavities with XPS continuous wall insulation	23	38	240	0%
#4 Fiberglass loose fill in cavities with XPS continuous wall insulation	23	38	205	15%
#3 Fiberglass batt in cavities with XPS continuous wall insulation	23	38	198	18%
#6 Close cell spray foam and dense-packed cellulose in cavities with XPS continuous wall insulation	26*	35*	120	50%
#1 Cellulose in cavities with XPS continuous wall insulation	23	38	-14	106%
#5 Cellulose in cavities with wood fiberboard continuous wall insulation	23	38	-263	210%
*Slight variation in R-values due to combining two insulation types in cavities				

Table 2. Percentage reduction in carbon footprint from baseline model.

The elements included in the assembly study do not represent the full range of materials that could be used in each assembly. In particular, continuous exterior insulation products were limited to just two options in the study. However, a designer/builder can select from a range of different options that would impact the carbon footprint of any of these assemblies. Table 3 provides BEAM results for all of the continuous insulation options in the tool.

MATERIAL	NET EMISSIONS ($kg\ CO_2e$)	CARBON EMISSIONS ($kg\ CO_2e$)	CARBON STORAGE ($kg\ CO_2e$)
XPS foam board / DuPont / Styrofoam / Reduced GWP	597	597	0
XPS foam board / [BEAM Avg | US & CA]	80	80	0
Mineral wool board - light density / [Industry Avg | N.America]	54	54	0
Vacuum Insulated Panel / Porextherm / Vacupor	122	122	0
EPS foam board / Type II / [Industry Avg | US & CA]	62	62	0
EPS foam board with graphite / BASF / Neopor / Type II	45	45	0
Polyisocyanurate / Wall Boards / [Industry Avg | US & CA]	67	67	0
Cork board insulation / Amorim / Isolamentos / R4/inch	-112	49	160
Wood fiberboard / [Industry Avg | US & CA]	-169	174	343

Table 3. BEAM results for continuous insulation products

Additional materials would be required to complete the construction of a wall assembly for a whole house. Appendix 2 includes BEAM results for other key material components of a wall assembly, including cladding and drywall options.

Conclusions

Cellulose insulation provides the lowest carbon footprint and the highest amount of net carbon storage of any insulation product in this comparison. The use of cellulose insulation can reduce the carbon footprint of an assembly – and a whole house. Used in combination with other low-carbon and carbon-storing materials, cellulose insulation can play an important role in bringing the overall carbon footprint of new homes down to zero, or even into the range of net carbon storage.

The wide availability of cellulose insulation and its compliance with all residential building codes offers home builders with an immediately accessible pathway to dramatically reducing the carbon footprint of a new home. The use of cellulose insulation is among the most valuable strategies for achieving large reductions in emissions from home building materials.

Appendices

Appendix 1: Assembly details

MAIN ASSEMBLIES ***Based on 100sqft of wall and roof area**												
Assembly	**Framing**	**Framing Factor**	**R-Value**	**Continuous Insulation**	**Sheathing**	**R-Value**	**Insulation Cavity**	**R-Value**	**Insulation Attic**	**Attic Type**	**Roof Pitch**	**TOTAL kg CO2e**
5	2x4 @ 16' OC	25%	R-10	Fiber board	7/16th OSB	R-13	Dense pack cellulose	R-38	Loose fill cellulose	Flat	4:12	-263
1	2x4 @ 16' OC	25%	R-10	XPS	7/16th OSB	R-13	Dense pack cellulose	R-38	Loose fill cellulose	Flat	4:12	-14
6	2x4 @ 16' OC	25%	R-10	XPS	7/16th OSB	R-7	Closed cell spray foam	R-7	Closed cell spray foam 1” thick	Flat	4:12	120
						R-9	Dense-pack cellulose	R-28	Loose fill cellulose			
3	2x4 @ 16' OC	25%	R-10	XPS	7/16th OSB	R-13	Fiberglass batts	R-38	Loose fill fiberglass	Flat	4:12	198
4	2x4 @ 16' OC	25%	R-10	XPS	7/16th OSB	R-13	Loose fill fiberglass (BIBS)	R-38	Loose fill fiberglass	Flat	4:12	205
2	2x4 @ 16' OC	25%	R-10	XPS	7/16th OSB	R-13	Open cell spray foam	R-38	Open-cell spray foam	Flat	4:12	240

Appendix 2: Wall model comparison graph