



Four-Storey Wood School Design in British Columbia: Life Cycle Analysis Comparisons

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1 Scope

Climate change is one of the largest threats facing the planet today. The construction industry accounts for 11% of global carbon emissions, playing a significant part in the climate crisis. To determine the best solution for future school buildings, not only does practicability, economy and constructability play a part, so does sustainability.

In order to better understand the embodied carbon emissions associated with the construction of new school buildings in British Columbia, the embodied carbon content associated with the four framing systems examples in the companion report, *An Analysis of Structural System Cost Comparisons* (costing study), was assessed. The purpose of this study is to allow the embodied carbon associated with these systems to become an important factor when choosing a viable scheme.

Embodied carbon is the carbon footprint of a material or product. To determine the embodied carbon of a building you must consider the quantity of greenhouse gases associated with the building. The most effective way to measure this is through Life Cycle Analysis (LCA), a study which determines the embodied carbon from cradle to grave (material extraction to building demolition). Consequently, an LCA was conducted for each of the four schemes presented in the costing study. Additionally, for wood-frame Options A and B, WoodWorks online carbon calculator was used to determine the potential carbon savings associated with carbon sequestering.

2 Life Cycle Analysis

2.1 Methodology

The Athena Impact Estimator for Buildings was used to conduct this LCA. This software accounts for the following environmental impacts associated with a given building:

- + Material manufacturing, including resource extraction and recycled content
- + Related transportation
- + On-site construction
- + Regional variation in energy use, transportation and other factors
- + Building type and assumed lifespan
- + Maintenance and replacement effects
- + Demolition and disposal

Global warming potential is the most accepted LCA comparison measure used to determine the embodied carbon associated with a building for all life cycle phases, with results given in kg or tonnes of CO₂ equivalent.

Carbon dioxide is the common reference for global warming or greenhouse gas effects. All other greenhouse gases are referred to as having a “CO₂ equivalence effect” which is simply a multiple of the greenhouse potential (heat trapping capability) of carbon dioxide.

$$\text{CO}_2 \text{ equivalent kg} = \text{CO}_2 \text{ kg} + (\text{CH}_4 \text{ kg} \times 28) + (\text{N}_2\text{O kg} \times 265)$$

Typically, global warming potential results are assessed for each of the following life cycle phases:

1. Production: CO₂ equivalent for the manufacturing and associated transportation of building materials.
2. Construction: CO₂ equivalent for the installation and associated transportation for given construction typologies.
3. Use: CO₂ equivalent associated with replacement manufacturing (refurbishment), replacement transportation, and operational energy use over the building’s life.
4. End of Use: CO₂ associated with demolition, transportation to landfill and disposal.

For the purpose of this LCA, Phase 3 was excluded from analysis. Phase 3 strongly relates to the operational embodied carbon associated with the building (mechanical and building envelope design). Since the purpose of this LCA is to provide a basis of comparison for the various structural framing systems, the Phase 3 impacts are assumed to be relatively consistent / comparable across all four options.

2.2 Assumptions

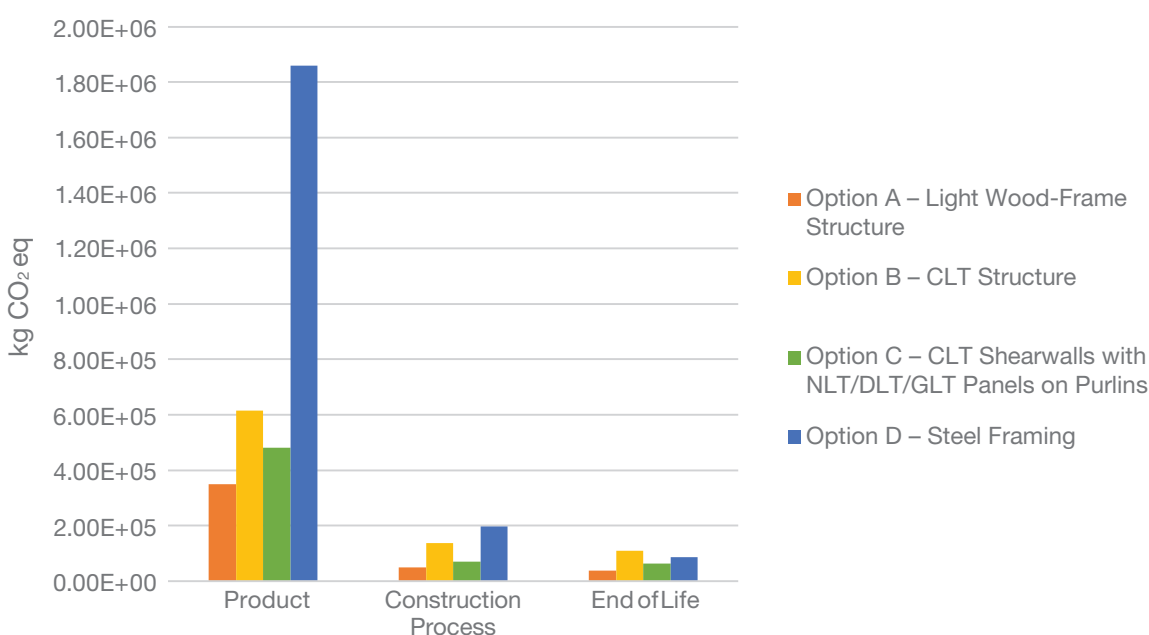
The following assumptions were incorporated into the LCA conducted for this study:

- + An 80-year design life was taken for each of the buildings.
- + Vancouver was selected as the location within British Columbia to run the analysis, influencing building stock data selected within the software.

- + A storey height of 4.25 meters was used for each of the four floors. This determines the overall height of the building. This affects lifting potential energy of cranes and plays a part in the embodied carbon associated with the building's construction and demolition.
- + Only the carbon content associated with the structural framing systems was considered. Architectural finishes and mechanical systems are assumed to be consistent across all four options and are therefore not pertinent when comparing the structural framing systems.
- + Foundations were not included in the study, since it was assumed that the type and sizes of foundations will be similar for each of the four schemes, resulting in a similar quantity of embodied carbon.

2.3 Results

The image below summarizes the global warming potential per life cycle phase for each of the four schemes

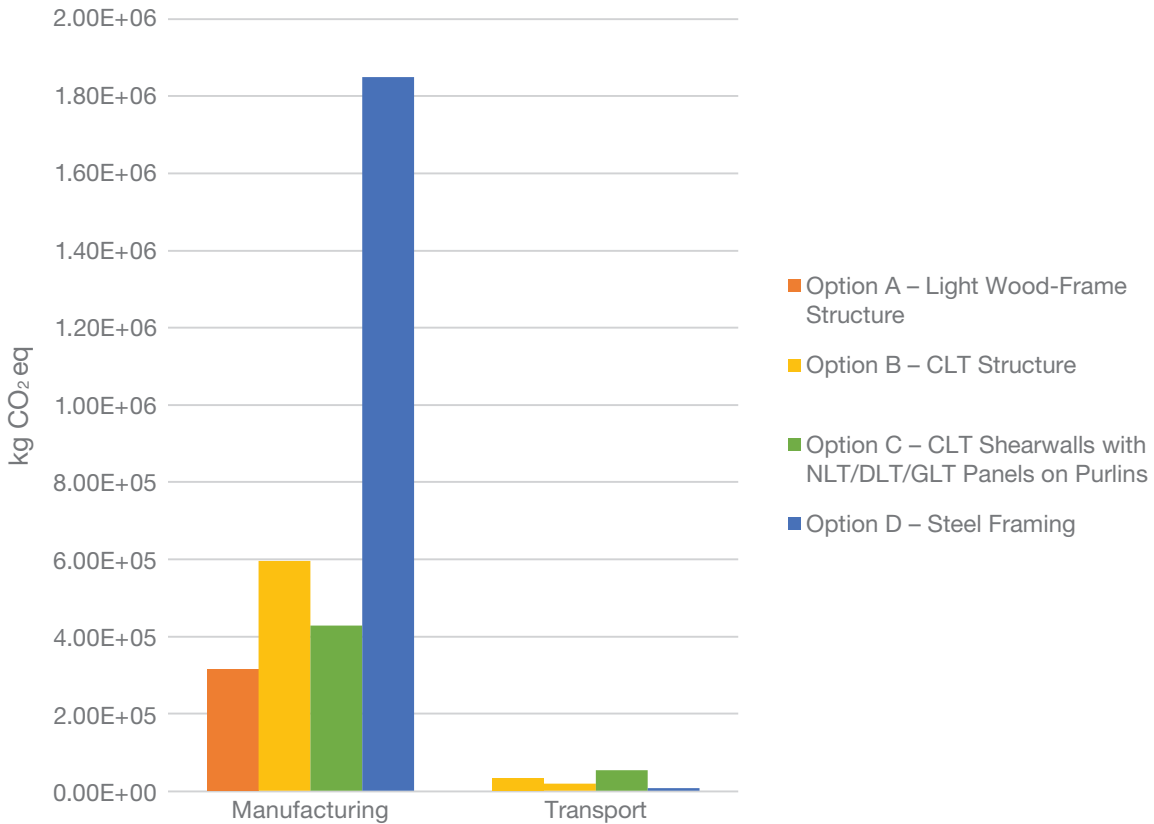


Global Warming Potential Comparison for the Four Structural Framing Options

Global warming potential associated with steel construction is greater than the wood options for all life cycle phases. For the steel scheme, total global warming potential is 2140000 kg of CO₂. This is approximately 2.5 times greater than Option B (the greatest of the wood options), which totals 862000 kg of CO₂.

For all four of the framing options assessed, the greatest quantity of CO₂ is associated with the production phase of the building life cycle.

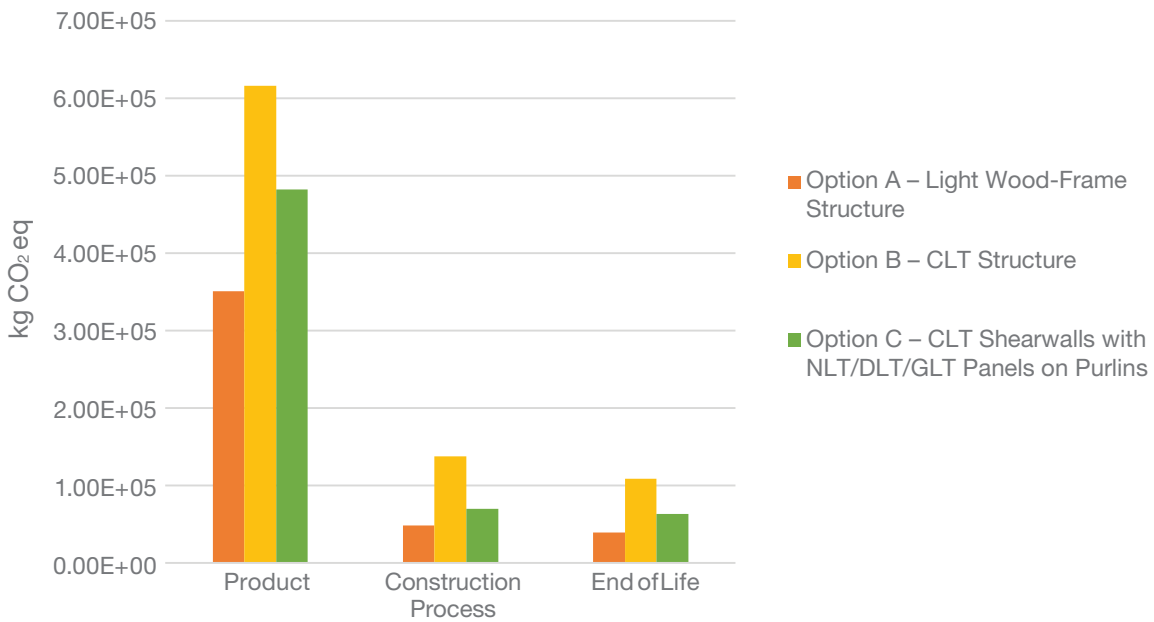
During production phases, the steel build produces 1860000 kg of CO₂ equivalent. This equates to 87% of the total CO₂ throughout the steel building's life cycle. In this phase, the CO₂ associated with the steel build vastly exceeds any of the three wood options, while at construction and end-of-life phases becomes more comparable. The following table provides a more detailed breakdown of the production phase assessment for the four framing options.



Global Warming Potential Comparison for the Production Phase of the Four Structural Framing Options

Based on the above charts, it is evident that the manufacturing process of steel causes a large increase in global warming potential. All four schemes include concrete topping, however, in the steel framing system the composite deck associated with the scheme greatly increases quantities of CO₂ associated with the manufacturing phase. Cement production contributes 8% of global carbon emissions. The complex process of limestone calcination performed during cement production releases large quantities of CO₂ into the atmosphere. Concrete used, even in small quantities, will have a large impact on the buildings embodied carbon.

Since the significantly higher global warming potential of the steel framing option skews the overall comparison of the four options presented in this study, the following image summarizes the global warming potential per life cycle phase for the three wood-frame options.



Global Warming Potential Comparison for the Timber Framing Options

Of the three timber framing options, light wood-frame has the lowest impact on global warming potential, while the CLT structural system has the highest; the kg of CO₂ associated with the flat panel scheme is 70% greater than the panels-on-purlins system, and 220% greater than the light wood-frame system. This is, however, directly proportional to the difference in wood fibre volume associated with each scheme. The CLT structural system uses 230% more wood fibre than the light wood-frame system.

3 WoodWorks Carbon Calculator

3.1 Methodology

WoodWorks Wood Product Council provides an online tool to measure the total volume of wood and carbon associated with timber construction. This tool considered the following for a given timber framing system:

- + Wood regrowth time
- + Carbon stored and sequestered in wood building materials
- + Greenhouse gases avoided when choosing wood over other building materials

Wood Regrowth Time

The time it takes to grow back the lumber used in construction is estimated using this tool. This is based on North American data from a variety of manufacturing facilities. Several assumptions are made:

- + During manufacture 10% of lumber is wasted
- + Plywood recovery factor for plywood plants in North America is 53.4%
- + Tree growth occurs 365 days a year, 24 hours a day
- + Losses due to fire, insects and disease is built into analysis

Overall, the estimate given is conservative due to the varying seasonal growth rates of trees, however it does give an idea of the benefits of sourcing timber sustainably.

Carbon Stored and Sequestered

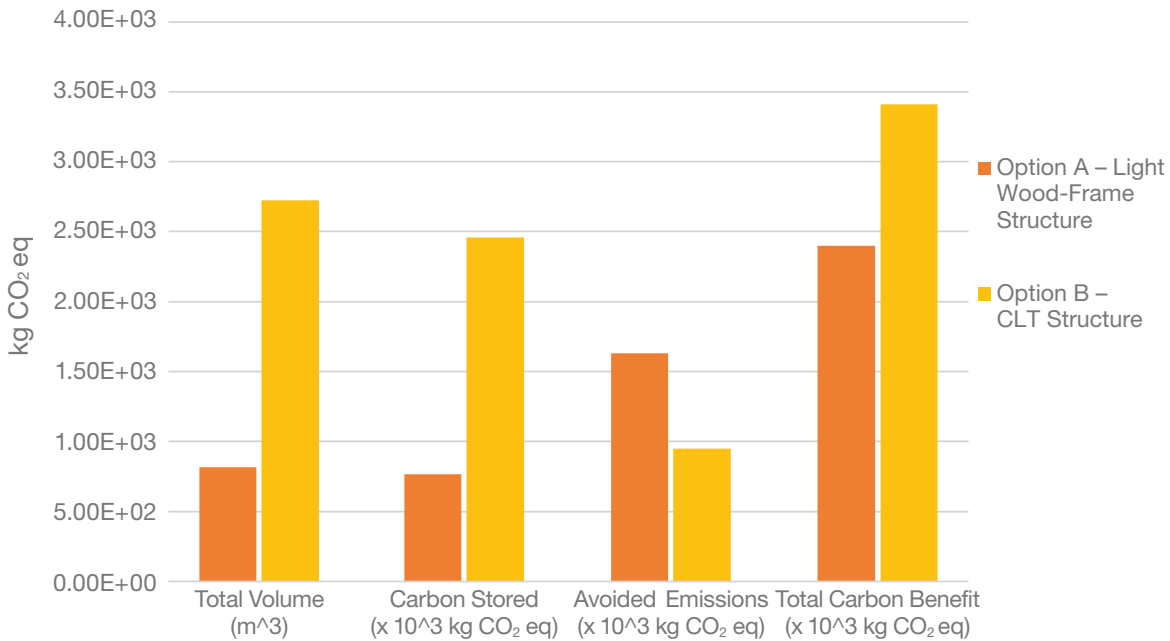
The tool assumes the carbon stored within the wood is 50% of its dry weight, then converted into kg of CO₂. This estimate is for the CO₂ removed from the atmosphere during the growth of the tree, which is then stored and preserved as carbon in the wood building.

Green House Gases Avoided

The tool assesses the quantity of greenhouse gases avoided during manufacture compared to other building materials. Building construction type whether it is CLT frame or light wood frame has an associated displacement factor and a formula is used to work out avoided greenhouse gases.

3.2 Results

The chart below summarizes the results of the WoodWorks Carbon Calculator.



Carbon Summary for Light Wood-Frame and CLT Structure Options

Notably, of the three wood-frame options the light wood-frame system has the lowest wood fibre volume, the smallest carbon footprint, and the shortest timeframe required to replenish timber stock. These factors could become significant when assessing various timber schemes based on their overall carbon impact.

It is valuable to compare LCA results to the WoodWorks carbon calculator. LCA results for Option B estimates 615000 kg of CO₂ is produced during the building's life cycle, however, WoodWorks estimates 2458000 kg of CO₂ is stored in the wood before it is cut down and used in construction. The amount of carbon stored is four times the amount emitted. The same can be seen for Option A – light wood frame. LCA results for Option B estimates 191000 kg of CO₂ is produced during the building's life cycle, however, WoodWorks estimates 767000 kg is stored in the wood. Again, the amount of carbon stored is four times greater than the amount emitted.

4 Conclusion

The aim of this study is to present options for reducing the embodied carbon associated with school buildings in British Columbia. By reducing embodied carbon during a building's life cycle construction can have a more positive impact on the environment, reducing contributions to global warming.

The greatest quantity of CO₂ is associated with the production phase for all options. At all phases assessed under LCA the steel frame option produces vast amounts of CO₂ in comparison to the wood options. Under LCA the light wood-frame option sees the lowest impact on global warming potential.

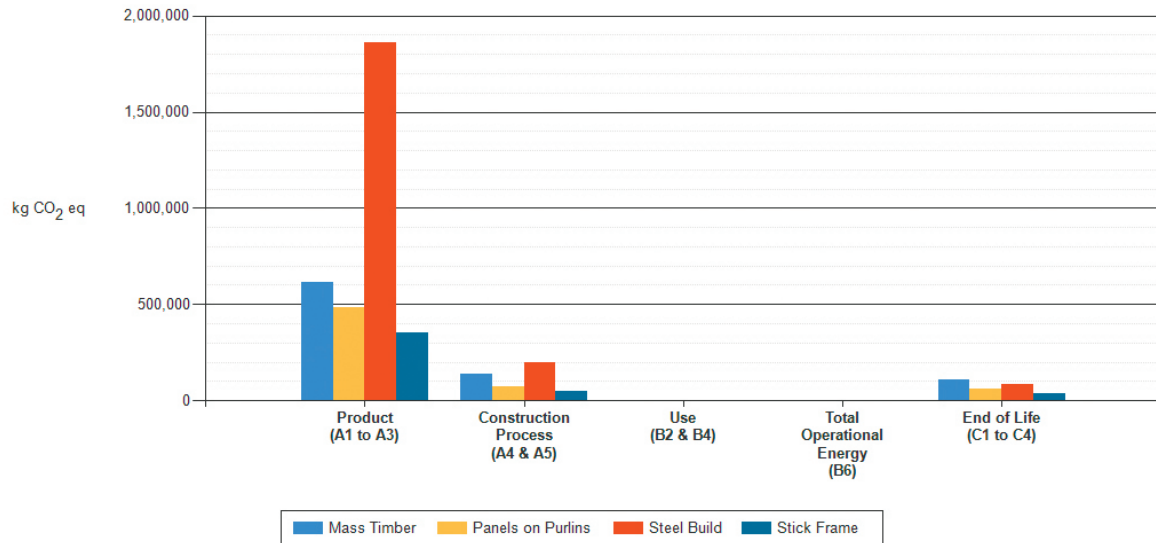
The Wood *WORKS!* study presented the benefits of sourcing wood from sustainable forests. By sourcing wood sustainably, the sequestering potential of wood can be assessed. The carbon stored in wood during its life span can serve to mitigate the carbon associated with production, construction and demolition of a building.

Embodied carbon can now be compared and weighted against constructability, cost, time frame and other important factors when choosing to design and construct schools in British Columbia.

5 Appendices

5.1 Global Warming Potential Comparison for the Four Structural Framing Options

Comparison of Global Warming Potential by Life Cycle



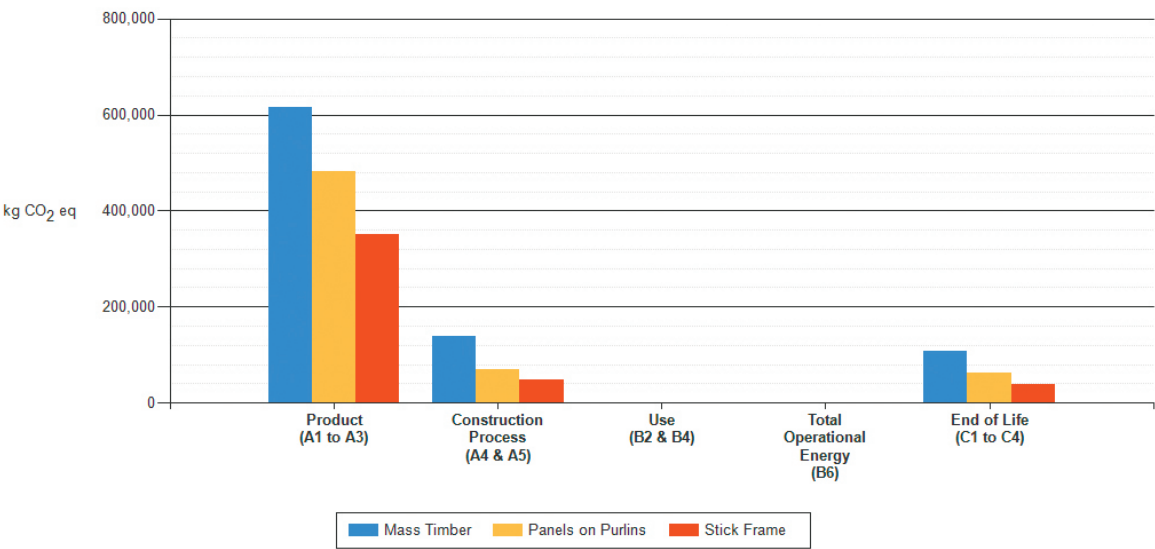
Project Name	Unit	Product (A1 to A3)	Construction Process (A4 & A5)	Use (B2 & B4)	Total Operational Energy (B6)	End of Life (C1 to C4)	Total
CLT Structure	kg CO ₂ eq	6.16E+05	1.38E+05	0.00E+00	0.00E+00	1.09E+05	8.62E+05
Panels on Purlins	kg CO ₂ eq	4.82E+05	6.93E+04	0.00E+00	0.00E+00	6.29E+04	6.14E+05
Steel Framing	kg CO ₂ eq	1.86E+06	1.97E+05	0.00E+00	0.00E+00	8.61E+04	2.14E+06
Light Wood Frame	kg CO ₂ eq	3.51E+05	4.84E+04	0.00E+00	0.00E+00	3.90E+04	4.38E+05
Total	kg CO₂ eq	3.31E+06	4.53E+05	0.00E+00	0.00E+00	2.97E+05	4.06E+06

5.2 Global Warming Potential by Life Cycle Phase

Global Warming Potential		Product (A1 to A3)			Construction Process (A4 & A5)			End of Life (C1 to C4)			Total Effects
LCA Measures	Unit	Manufacturing	Transport	Total	Construction-Installation Process	Transport	Total	De-construction, Demolition, Disposal & Waste Processing	Transport	Total	A to C
CLT Structure	kg CO ₂ eq	5.96E+05	1.94E+04	6.16E+05	4.23E+04	9.53E+04	1.38E+05	8.75E+04	2.11E+04	1.09E+05	8.6E+05
Steel Frame	kg CO ₂ eq	1.85E+06	7.09E+03	1.9E+06	7.64E+04	1.21E+05	2.0E+05	7.18E+04	1.43E+04	8.6E+04	2.1E+06
Light Wood Frame	kg CO ₂ eq	3.16E+05	3.47E+04	3.51E+05	3.10E+04	1.74E+04	4.84E+04	3.00E+04	8.92E+03	3.90E+04	4.38E+05
Panels on Purlins	kg CO ₂ eq	4.28E+05	5.38E+04	4.82E+05	3.16E+04	3.76E+04	6.93E+04	4.99E+04	1.30E+04	6.29E+04	6.14E+05

5.3 Global Warming Potential Comparison for the Timber Framing Options

Comparison of Global Warming Potential by Life Cycle



Project Name	Unit	Product (A1 to A3)	Construction Process (A4 & A5)	Use (B2 & B4)	Total Operational Energy (B6)	End of Life (C1 to C4)	Total
CLT Structure	kg CO ₂ eq	6.16E+05	1.38E+05	0.00E+00	0.00E+00	1.09E+05	8.62E+05
Panels on Purlins	kg CO ₂ eq	4.82E+05	6.93E+04	0.00E+00	0.00E+00	6.29E+04	6.14E+05
Light Wood Frame	kg CO ₂ eq	3.51E+05	4.84E+04	0.00E+00	0.00E+00	3.90E+04	4.38E+05
Total	kg CO ₂ eq	1.45E+06	2.55E+05	0.00E+00	0.00E+00	2.10E+05	1.91E+06

5.4 Carbon Summary for Light Wood Frame

Carbon Summary



Results



Volume of wood products used:
815 cubic meters (28,789 cubic feet)



U.S. and Canadian forests grow this much wood in:
2 minutes



Carbon stored in the wood:
767 metric tons of carbon dioxide



Avoided greenhouse gas emissions:
1631 metric tons of carbon dioxide



Total potential carbon benefit:
2398 metric tons of carbon dioxide

Project Name: Stick Frame
Date: March 12, 2020

Results from this tool are based on wood volumes only and are estimates of carbon stored within wood products and avoided emissions resulting from the substitution of wood products for non-wood products. The results do not indicate a carbon footprint or global warming potential and are not intended to replace a detailed life cycle assessment (LCA) study. Please refer to the References and Notes' for assumptions and other information related to the calculations.

Equivalent to:



507 cars off the road for a year



Energy to operate 253 homes for a year

5.5 Carbon Summary for CLT Panels

Carbon Summary



Results



Volume of wood products used:
2,722 cubic meters (96,126 cubic feet)



U.S. and Canadian forests grow this much wood in:
7 minutes



Carbon stored in the wood:
2458 metric tons of carbon dioxide



Avoided greenhouse gas emissions:
951 metric tons of carbon dioxide



Total potential carbon benefit:
3409 metric tons of carbon dioxide

Project Name: Mass Timber
Date: March 12, 2020

Results from this tool are based on wood volumes only and are estimates of carbon stored within wood products and avoided emissions resulting from the substitution of wood products for non-wood products. The results do not indicate a carbon footprint or global warming potential and are not intended to replace a detailed life cycle assessment (LCA) study. Please refer to the References and Notes' for assumptions and other information related to the calculations.

Equivalent to:



721 cars off the road for a year



Energy to operate 360 homes for a year