

## CARBON CALCULATOR: References & Notes

### General Information

The WoodWorks Carbon Calculator tool estimates the total wood mass in a building and the associated carbon impacts. Carbon impacts refer to both the amount of carbon stored in the wood building materials and the amount of greenhouse gas emissions (GHGs) avoided by choosing wood instead of another more GHG-intensive, non-wood material. Specific instructions are provided on each input tab. This background note provides an overview of the underlying assumptions, limitations and calculation methodology behind the carbon calculator. Users are asked to enter nominal wood volume information and the tool then performs the necessary volume conversions and makes corrections for moisture content to arrive at a total mass figure of oven-dry wood contained in the building. Total dry mass is then used for the two carbon calculations.

This tool is an estimator—results are approximate, not exact. This applies in particular to the calculation for avoided emissions. By definition, a calculation based on “what-if” scenarios is uncertain. Important factors in this calculation include 1) assurance that the building would have logically been built with a non-wood material; 2) the exact type of alternate material(s); and 3) fate of the wood materials at the end of the building’s service life. Averages have been used in the calculation of avoided emissions which may not apply to the specific application being studied by the user of this tool. Please see further notes on this topic below, in the section titled, ‘CO<sub>2</sub> Avoided – Displacement Factors.’

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 whole building or product level carbon footprint or global warming potential and are not intended to replace an in-depth life cycle assessment (LCA) study. A detailed LCA study, conducted in compliance with internationally recognized standards, is necessary to accurately estimate global warming potential and a corresponding carbon footprint. LCA studies and tools which are in compliance with ISO 14025, ISO 14040/44, ISO/TS 14067, ISO 21930 and ISO 21931-1 will provide more complete results which may be used for decision-making purposes.

### Assumptions, Limitations & Equations

#### Lumber

The selection of dimension lumber sizes is based on those perceived as the most common light-frame lumber sizes used in North American low- and mid-rise building construction. If you are using lumber sizes that are not included in the Carbon Calculator, please refer to the Canadian Wood Council’s (CWC’s) *Board Foot Calculator*, which will allow you to calculate the volume (in cubic meters) of lumber sizes that are not included in the Carbon Calculator. The volume of lumber calculated using the Board Foot Calculator can subsequently be input into the Carbon Calculator as a bulk lumber volume. All conversions from board feet to cubic meters were based on the values provided by Nielson et al (1985).

### **Panels**

Similar to lumber, the selection of wood panel sheathing thicknesses is based on those perceived as the most common light-frame sizes used in North American low- and mid-rise building construction. This list of panel sizes is expected to cover most wall and floor sheathing thicknesses currently available and commonly used in wood-frame construction. For both oriented strand board (OSB) and plywood, the volume of 'Panel thickness unknown' was calculated using a simple average thickness compiled from all the panel sizes listed in the 'Panels' section.

### **Engineered Wood Products (EWP)**

EWP considered in the Carbon Calculator include I-joists, laminated veneer lumber (LVL), laminated strand lumber (LSL), oriented strand lumber (OSL), parallel strand lumber (PSL) and glued-laminated timber (glulam). All EWP are required to be entered into the calculator on a volumetric basis except engineered wood I-joists, which can be entered in either linear feet or board feet and are assumed to have a depth of 14.2 inches. The average weight and depth of wood I-joists are assumed to be 6 kg/m and 14.2 inches, respectively, which are simple averages taken from the range of weights and depths given by the CWC (2016). The conversion of wood I-joists from board feet to linear feet was derived by McKeever et al (2003). The cross-sectional area of wood I-joists is considered to consist of 70% flange and 30% web material by cross-sectional area, with the flanges and web being manufactured from LVL and OSB, respectively.

### **Exterior Decking and Siding/Roofing**

Exterior lumber decking is assumed to have a 6 mm gap between adjacent boards, in order to provide for adequate drainage. If 'Thickness unknown' is selected, the average thickness of decking board was assumed to be 1.5 inches. Only wood siding and roofing materials (shakes and shingles) are considered to be manufactured from Western red cedar, whereas decking can be manufactured from a variety of species. For both siding and roofing, the volume of 'Thickness unknown' was calculated using a simple average thickness compiled from all the shake and shingle thicknesses listed in the 'Siding & Roofing' section.

### **Wood Species and Density**

Wood species information was used to calculate density, which in turn was used to calculate oven-dry wood mass. The user input of the relative percentage of each species type in each product category was used to calculate a weighted average density for each wood product category. Default wood densities were used for several products, including I-joists, OSB, siding and roofing (shakes and shingles). Wood densities were obtained from several reference sources, including Neilson et al (1997), CANPLY (2010), US Forest Products Lab (2010), Canadian Standards Association (2014), National Design Specification (NDS) for Wood Construction (2015), and CWC (2016).

All wood species densities were converted to oven-dry density, using the following formula:

$$P_{OD} = P_D / (1 + MC/100)$$

Where:

$P_{OD}$	=	Oven-dry density (kg/m) <sup>3</sup>
$P_D$	=	Reference density (kg/m) <sup>3</sup>
$MC$	=	Reference moisture content (%)

Oven-dry density is then used to find the dry mass of wood:

$$m_{wood} = V_{wood} \times P_{OD}$$

Where:

$m_{wood}$	=	Mass of dry wood (kg)
$V_{wood}$	=	Volume of wood (m <sup>3</sup> )
$P_{OD}$	=	Oven-dry density (kg/m) <sup>3</sup>

### Carbon Stored

The mass of carbon stored in wood products was calculated based upon the assumption that the amount of carbon contained in wood fiber was 50% by dry weight (Sathre O'Connor 2010). After the mass of carbon in the wood products was determined, the carbon was converted to CO<sub>2</sub> based on molecular weight ratio. The final value provided in the carbon calculator is an estimate of the mass of carbon dioxide removed from the atmosphere during the growth of the tree and stored as carbon in the chemical structure of the wood building products.

The following is a general equation for the mass of CO<sub>2</sub> equivalents contained within wood fiber:

$$m_{CO_2} = \left(\frac{M_{CO_2}}{M_C}\right) \times m_{wood} \times 0.5$$

Where:

$m_{CO_2}$	=	Mass of CO <sub>2</sub> equivalents (kg)
$M_{CO_2}$	=	Molecular mass of CO <sub>2</sub> (44 g/mol)
$M_C$	=	Molecular mass of carbon (12 g/mol)
$m_{wood}$	=	Mass of oven-dry wood (kg)

### Construction Type & Displacement Factors – CO<sub>2</sub> Avoided

Wood-framed buildings typically have a smaller embodied GHG footprint than equivalent buildings made with non-wood materials (Sathre O'Connor 2010). In other words, there are fewer GHG emissions associated with the manufacturing of a wood-frame building than other buildings. This difference can be quite large and can be taken as a carbon credit for the amount of CO<sub>2</sub> emissions that were avoided (displaced) by choosing wood over other materials.

Building construction type was used to select an appropriate displacement factor for the avoided emissions calculation. Four construction types and associated displacement factors were selected, including light-frame (low- or mid-rise), post and beam (low- or mid-rise), mass timber (low-, mid- or high-rise) and combination. Displacement factors of 3.9, 3.9, 0.71, 3.01 and 0.25 were used for light-frame, post and beam, mass timber, decking and siding, respectively. A weighted average of displacement factors, based on wood volumes, was used for the combination option. All displacement factors were measured in units of metric tons of CO<sub>2</sub> equivalent avoided per metric tons of oven-dry wood. A further explanation of displacement factor calculation methodology and reference sources is provided below.

The meta-analysis in Sathre & O’Connor (2010) provides an average displacement of 3.9 metric tons of CO<sub>2</sub> avoided per metric ton of oven-dry wood. This average is derived from numerous world studies looking at different products, different substitute materials and using different assumptions. This variety is advantageous when using the displacement factor on a broad basis (e.g., across a large population of examples) as it captures the variety of circumstances in a large group. To apply that average number to any particular single building is difficult and the result should be considered a rough estimate.

The studies covered in Sathre & O’Connor (2010) have a high proportion of scenarios that include aggressive biomass recovery activities. For example, very high displacement factors are achieved if a study assumes fuel recovery from harvest slash, stumps, and the wood products themselves at end of life; these displacement scenarios are included in the Sathre & O’Connor (2010) average but may not yet be common practice in North America.

In North America, many wood products currently go to landfill at end of life, where decomposition into CO<sub>2</sub> and methane can (and does) occur. If methane is not captured at the landfill, this situation can lead to very low or even negative displacement factors for wood. However, the displacement calculation is looking ahead into the future when considering the ultimate fate of wood installed in a building today. Today’s waste management practices are changing, with more methane recovery and increased diversion of wood from landfill, either for recycling or for energy recovery.

For mass timber, there is very little comparative LCA data. Mass timber must have a lower displacement factor than traditional wood framing systems because it uses far more wood than traditional systems while still offsetting the same amount of greenhouse gas emissions; as such, it offsets less emissions than light or heavy timber framing. Muter & O’Connor (2009) simply reduced the 3.9 figure by an estimate of the percentage difference in wood volume between cross-laminated timber (CLT) and light framing. Mahalle & O’Connor (2010) roughly estimate displacements for two European mid-rise CLT buildings. All three numbers were averaged for the figure used here, 0.71.

For decking and siding, the data reported in Mahalle O’Connor (2009) is used to derive displacement factors.

The general equation for the mass of GHG emissions avoided is as follows:

$$GHG = m_{wood} \times D_f$$

Where:

- GHG* = Greenhouse gas avoided (kg CO<sub>2</sub> equivalents)
- m<sub>wood</sub>* = Mass of dry wood (kg)
- D<sub>f</sub>* = Displacement factor (kg CO<sub>2</sub> equivalents/kg oven-dry wood)

### GHG Equivalencies

The calculations that equate the amount of carbon stored in a building and greenhouse gas emissions avoided by not using non-wood materials to the emissions that result from driving passenger vehicles or from the energy used to operate an average home are derived from the US Environmental Protection Agency’s Greenhouse Gas Equivalencies Calculator (<https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator>).

The Greenhouse Gas Equivalencies Calculator uses the Emissions & Generation Resource Integrated Database (eGRID) US annual non-baseload CO<sub>2</sub> output emission rate to convert reductions of kilowatt-hours into avoided units of carbon dioxide emissions. Please note that periodic updates to the data behind the US EPA calculator may result in slight differences in results with the WoodWorks carbon calculator. Additional information on the US EPA calculations can be found at <https://www.epa.gov/energy/ghg-equivalencies-calculator-calculations-and-references>.

### Forest Growth Rates

The forest growth rates calculation is a conservative estimate for the time taken to grow the volume of wood products as calculated elsewhere in the Carbon Calculator model. The input to the estimate is the volume of wood products, which is then converted into a volume of logs needed to produce the products using average lumber and panel recovery factors from manufacturing facilities. The volume of logs is then converted to a volume of trees needed after accounting for volume left in the forest as woody debris, which is important for soil productivity, conservation of biodiversity and other forest management considerations.

The calculation uses 10% as the volume adjustment factor for woody debris (WD) (tree to log) which is based on the Metafore (2006) study which stated, “More than 90% of every tree harvested in Canada and the United States is utilized (10% remains in the forest as woody debris).” Figures from the US Forest Service for logging residue range from 6 to 18%.

The average lumber recovery factor (LRF) for dimension mills in North America was 266 fbm/m<sup>3</sup> in Spelter et al (2005). The LRF nominal was converted to m<sup>3</sup> using the dimensional conversion factors in the model from Nielson et al (1985).

$$0.266 \text{ Mfbm/m}^3 \times 1.61 \text{ m}^3 / \text{Mfbm} = 42.8 \text{ m}^3_{\text{lumber}} / \text{m}^3_{\text{log}} \text{ or } 42.8\%$$

The average plywood recovery factor for plywood plants in North America was 53.54% in Spelter et al (2006). A weighted average recovery factor (RF) for lumber and plywood mills in North America was calculated using an 85%/15% split lumber/plywood log consumption resulting in an average recovery factor of 44.4%. This factor was estimated from Oswalt et al (2014), which estimated log use from US growing stock at 85% lumber and 15% veneer, the BC Ministry of Forests (2015) stated average primary log use in BC of 89% lumber and 11% veneer, and Metafore (2006) figures for Canada and US of 78% lumber and 22% veneer. It was assumed that other wood products (e.g., LVL) would have similar recovery factors.

The general equation for the volume of trees to produce the volume of product is:

$$V_{\text{tree}} = V_{\text{wood}} / RF / (1 - WD)$$

Where:

- $V_{\text{tree}}$  = Volume of trees used to manufacture the wood products  $V_{\text{wood}}$  (m<sup>3</sup>)
- $V_{\text{wood}}$  = Volume of wood products (m<sup>3</sup>)
- $RF$  = Average lumber and plywood recovery factor (m<sup>3</sup><sub>product</sub> / m<sup>3</sup><sub>log</sub>)
- $WD$  = Average woody debris left in the forest (%) – converts tree volume to log

The annual growth of growing stock on timberland in the US is taken from Oswalt et al (2014) "Table 34 Net annual growth of growing stock on timberland in the United States by ownership group, region, subregion, and species group, 2011, 2006, 1996, 1986, and 1976." The figure used from the report is 11,442,885,222 ft<sup>3</sup>/yr which represents the net annual growth for softwood in 2006 for all private lands in the US. It was recommended that we not include US public lands due to minimal harvest. This figure was then converted to 324,025,886 m<sup>3</sup>/yr for use in the model.

The annual growth of growing stock on timberland in Canada is taken from The United Nations Economic Commission for Europe (UNECE) (1996) "Table 9 Estimated Potential Annual Growth on Canadian Productive and Available Forest Land" of 262.6 million m<sup>3</sup> of softwood. The estimated losses (net of salvage harvesting) due to fire, insects and disease are 100.9 million m<sup>3</sup> per annum (table 10) for softwood. This implies a net long run sustainable harvest level of 161.7 million m<sup>3</sup> per annum; 262.6 less 100.9 = 161.7 million m<sup>3</sup>/yr.

Therefore the annual net growth for commercial forests in Canada and the US used for the calculations in the model is:

$$161,700,000 \text{ m}^3/\text{yr} + 324,025,886 \text{ m}^3/\text{yr} = 485,725,886 \text{ m}^3/\text{yr}$$

The time to grow calculation assumes that the forests of Canada and the US grow 365 days/yr, 24 hrs/day. This is clearly not the case as the actual growing season for much of Canada and the US is much shorter. If the actual growing seasons were used, the time would be much shorter. The time to grow is therefore a very conservative estimate.

The general equation for the time taken to grow the volume in trees is:

$$T = V_{tree} / (G_{tree} / 365 \text{ days/yr} / 24 \text{ hr/day} / 60 \text{ min/hr})$$

Where:

- $T$  = Time to grow the volume of trees (minutes)
- $V_{tree}$  = Volume of trees used to manufacture the  $V_{wood}$  (m<sup>3</sup>)
- $G_{tree}$  = Net annual growth of growing stock (m<sup>3</sup>/yr)

### Version 2 Updates

The second version of the Carbon Calculator was released in October 2016 with the following revisions:

- Names of the construction types were altered to provide more clarity to the user for the selection of appropriate displacement factors.
- Several new materials were added including LSL, OSL, PSL and NLT.
- EWPs (using variable displacement factors) may now be selected for use in a mass timber, light-frame/post and beam or combination structural system.
- The CLT displacement factor of 0.71 is now used for all mass timber products.
- Oven-dry densities were updated to reflect the most recent engineering design standards.
- Calculations were aligned with the updates to the USEPA GHG Equivalency Calculator.
- The default unit of measurement for dimension lumber and I-joists was changed from board feet to linear feet.
- Pictures and descriptions were provided as pop-ups for all the wood products.
- Forest growth rate calculations were updated to reflect the most recent USDA data.

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### **Photography**

Product images in the Carbon Calculator were provided by the Wood WORKS! BC program (photos by Photography West), and APA – The Engineered Wood Association.