Athena Sustainable Materials Institute

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Background Methodology

End-of-Life Carbon Model for BC Wood Products

Prepared for:
Forestry Innovation Investment

By:
Athena Sustainable Materials Institute

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Introduction:
This document outlines the modeling decisions and background data that was used to develop the excel model “End-of-Life Carbon Model for BC Wood Products”. The background data assumed in the model is included in Appendix 1.

Purpose:
This calculator is intended to test and model different end-of-life assumptions for wood. The user enters an amount of a wood product and defines key parameters including: service life, end-of-life disposition, and landfill. A key feature of the tool is that it simultaneously models up to 6 unique landfills that includes specific landfills in BC as well as USEPA and IPCC assumed models.

General approach to analysis:
This tool enables the calculation of related carbon and LCI flows for wood products as they move to and from end uses to end of life (EOL) disposition pools. All calculations are performed on an annual basis and correspond to a single year's production of a wood product at time zero. Recycled wood products are assumed to leave the system boundary (a loss of carbon) as their carbon and related LCI flows will be accounted for by the second use. Possible avoided fossil carbon emissions asociated with combusting wood products with energy recovery or the capture and combustion of landfill gas (LFG) is not accounted for in the tool and therefore, represents a conservative estimate of net global warming impacts.

User Input Data:
The tool user needs to first select the commodity wood product of interest (from the pull down menu) and enter the quantity of the finished product (oven dry kg). Then the user can specify a service life (or leave blank to apply default half-lives) and the expected treatment at end-of-life.

Use Decay Model:

Carbon in products in use is characterized by the flow of carbon into and out of the product in use pool. Carbon flows into the product in use pool only at year zero, the year in which the product is manufactured. Carbon then flows out of the product in use pool as products are removed from service. The rate of product removal from service is described by a first order decay relationship, which is used to calculate annual removals after year 0. The end-use annual removals are calculated for each year into the future out to 500 years after production. The first order decay relationship used to calculate annual product removals from service in year "t" takes the following form:

$$N_p(t-1) - N_p(t) = N_p(0) \times \left[e^{-\frac{\ln(2)(t-1)}{HL}} - e^{-\frac{\ln(2)t}{HL}} \right]$$

Np(t) = Quantity of carbon in the product in use pool at year t

HL = Half life of product in use (referenced default values are provided in the Parameters tab)

The net flow of carbon though the product in use pool is simply flow in minus flow out. Cumulative net flow is the sum of flow in minus sum of flow out from time zero, and represents the quantity of carbon stored (i.e., carbon stocks) in the product in use pool at the time of analysis.

Landfill Model(s):

As products are taken out of use, a portion of the carbon in the product flows into the landfill pool. The tool provides 6 landfill models, each customized based on the assumed % DOCF (decomposable fraction), k-factor (decomposition rate), and assumed landfill gas oxidation and capture.

The flow of carbon out of the landfill corresponds to decay of landfilled product into carbon dioxide and methane. Because the flow of product into the landfill pool is modeled as a discrete annual event, and decay is described by a first order (exponential) relationship (see equation below), the annual flow of carbon out of the landfill pool each subsequent year corresponding to each input of carbon to the landfill pool must be performed separately and then summed for the 500-year period.

$$N_{LF}(t-1) - N_{LF}(t) = \sum_{t_d=1}^{t-1} N_{LF,t_d} \times \left[(f_{an}) \times (1 - f_{nd}) + (1 - f_{an}) \right] \times \left[e^{-k(t-t_d-1)} - e^{-k(t-t_d)} \right]$$

NLF(t) = Quantity of carbon in the landfill pool at time t
NLF,td = Quantity of carbon in the landfill deposit that occurred in year td, at the time of deposit

t = year at which carbon flow is assessed
td = year at which a deposit is made to the landfill pool
fan = fraction of the landfilled material disposed of in anaerobic landfills
fnd = non-degradeable fraction (under anaerobic conditions) of the carbon in the product placed into the landfill pool
k = decay rate constant, year-1

Total net cumulative flow of carbon (CO2 and CH4) through the pool is the sum of cumulative net flow through the product in use pool and the cumulative net flow through the landfill pool, and represents total net storage (carbon stocks) in these pools at 500-years (t=500).

Calculator Developer:
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Version: Version 1.0. March 2021

Appendix 1: Background Data

Canada Landfill Characteristics		
	MSW	**Wood Landfill**
DOCf	0.5	0.5
MCF	1	0.8
% Methane	50%	0.5
CH4 from Flare	0.03%	0
Ox Factor	0.1	0.2
% LFG Captured	52%	0
k/yr		0.03

References

Volume 5, Chapter 3, of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006)
https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html
https://ghgprotocol.org/sites/default/files/standards/GHGP_GPC_0.pdf
*Ox Factor given as 10%, Factor Adjusted to Incorporate MCF

US Landfill Characteristics							
EPA WARM 6-1	No LFG Recovery	Flaring	Electricity	% DOCf		OX Rate	
C&D	0.96	0.02	0.02	Lumber	12%	No LFG Recovery	10%
MSW	0.08	0.26	0.66	Flooring	5%	W/ LFG Recovery	20%
				MDF	16%	Covered	30%
EPA WARM 6-2	No LFG Recovery	Flaring	Electricity				
Industrial	0.98	0.02					
Municipal	0.08	0.26	0.66				
	k-Factor		% LFG Recovered				
	Avg. Waste	Lumber	AP-42	Typical/Average	Worst Case	Aggressive	Cali
Dry <20 inches precip.	0.02	0.04	0.75	0.682	0.662	0.686	0.836
Moderate 20-40 inches precip.	0.04	0.08	0.75	0.65	0.613	0.658	0.795
Wet >40 inches precip.	0.06	0.12	0.75	0.641	0.592	0.663	0.774
Bioreactor 40% M.C.	0.12	0.25	0.75	0.606	0.506	0.639	0.729
Nat. Avg	0.052	0.11	0.75	0.648	0.603	0.664	0.788
LFG Recovery Rate/yr* Not Used	0		0.75	0	0	0	0
	1		0.75	0.5	0	0.5	0.5
	2		0.75	0.5	0	0.5	0.8
	3		0.75	0.5	0	0.75	0.8
	4		0.75	0.5	0	0.75	0.8
	5		0.75	0.75	0.5	0.75	0.8
	6		0.75	0.75	0.5	0.75	0.8
	7		0.75	0.75	0.5	0.75	0.8
	8		0.75	0.75	0.5	0.75	0.8
	9		0.75	0.75	0.5	0.75	0.85
	10		0.75	0.75	0.75	0.75	0.85
	11		0.75	0.75	0.75	0.75	0.85
	12		0.75	0.75	0.75	0.75	0.85
	13		0.75	0.75	0.75	0.75	0.85
	14		0.75	0.75	0.75	0.75	0.85
	15		0.75	0.825	0.825	0.825	0.85
	Covered		0.75	0.9	0.9	0.9	0.9
References							
US EPA WARM Model V 15: https://www.epa.gov/sites/production/files/2020-12/documents/warm_management_practices_v15_10-29-2020.pdf							

BC Landfill Characteristics				
Methane Generation Potential				
	m3 CH4/tonne MSW	kg CH4/tonne MSW	% CH4 C of initial C	% LFG C of initial C (DOCf)
Relatively Inert	20	13.57	2.37%	4.73%
Moderately Decomposable	120	81.42	14.20%	28.40%
Decomposable	160	108.56	18.93%	37.87%

BC Specific K-Factors			
Rain /yr at Landfills	mm	in	k/yr
Alberni Valley	1910.7	75.22440945	0.071
Armstrong	410	16.14173228	0.031
Bailey	1515.8	59.67716535	0.071
Bessborough	482.1	18.98031496	0.031
Cache Creek	269	10.59055118	0.031
Campbell Mtn	330	12.99212598	0.031
Campbell River	1605.6	63.21259843	0.071
Central	755.2	29.73228346	0.057
Central Subregion	401.1	15.79133858	0.031
Columbia Regional	424.2	16.7007874	0.031
Comox Valley	1179	46.41732283	0.071
Ecowaste	1277.4	50.29133858	0.071
Foothills	643.9	25.3503937	0.057
Ft. Nelson	451.8	17.78740157	0.031
Ft. St. John	465.8	18.33858268	0.031
Gibraltar	509.8	20.07086614	0.057
Glenmore	380.5	14.98031496	0.031
Hartland	906.2	35.67716535	0.057
Heffley Creek	409	16.1023622	0.031
Knockholt	460.8	18.14173228	0.031
Lower Nicola	322.1	12.68110236	0.031
McKelvey Creek 3	774.9	30.50787402	0.057
Mini's Pit	1875.6	73.84251969	0.071
Mission Flats	279	10.98425197	0.031
Nanaimo	1162.8	45.77952756	0.071
Ootischenia	755.2	29.73228346	0.057
Prince Rupert	2593.6	102.1102362	0.081
Salmon Arm	669.3	26.3503937	0.057
Sechelt	1369.2	53.90551181	0.071
Squamish	2366.8	93.18110236	0.081
Terrace	1160.7	45.69685039	0.071
Thornill	1160.7	45.69685039	0.071
Vancouver	1277.4	50.29133858	0.071
Vernon	445.1	17.52362205	0.031
Average BC (per N.I.R.)	815	32.08661417	0.04

References

https://www2.gov.bc.ca/assets/gov/environment/climate-change/data/ceei/technical_methods_and_guidance_document_for_the_ceei_reports.pdf

0.6785 is the density of methane at standard temperature of 15 deg.C and pressure of 1 atm (kg/m3)

Rainfall amounts and wood is "moderate" per https://www2.gov.bc.ca/assets/gov/environment/waste-management/garbage/lgassessment.pdf