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Documentation for the Forest Industry Carbon Assessment Tool (FICAT)

Version 1.4

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About the Forest Industry Carbon Assessment Tool (FICAT)

The Forest Industry Carbon Assessment Tool™ (FICAT™) was developed by NCASI with financial support from the International Finance Corporation of the World Bank Group in 2008. Based on the Confederation of European Paper Industries (CEPI) Carbon Footprint Framework, FICAT assists in the development of cradle-to-gate or cradle-to-grave carbon footprints of forest-based companies. Footprints developed using FICAT include consideration of manufacturing emissions, carbon storage impacts, upstream emissions, and end of life effects.

About NCASI

NCASI (National Council for Air and Stream Improvement, Inc.) is a non-profit environmental research organization that seeks to create credible scientific information required to address the environmental information needs of the forest products industry in North America. NCASI conducts surveys, performs field measurements, undertakes scientific research, and sponsors research by universities and others to document the environmental performance of industry facility operations and forest management, and to gain insight into opportunities for further improvement in meeting sustainability goals.

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1.0 INTRODUCTION

The Forest Industry Carbon Assessment Tool™ (FICAT™) was developed by NCASI with financial support from the International Finance Corporation of the World Bank Group in 2008. Based on the Confederation of European Paper Industries (CEPI) Carbon Footprint Framework, FICAT assists in the development of cradle-to-gate or cradle-to-grave carbon footprints of forest-based companies. Footprints developed using FICAT include consideration of manufacturing emissions, carbon storage impacts, upstream emissions, and end of life effects.

This document includes documentation for FICAT Version 1.4, updated in 2023. The following material includes default values and calculation methods used in the model.

Updates to FICAT 1.4 included:

- Ability to use the most recent global warming potentials (GWPs)
- Updated country specific electricity emission factors
- Updated transportation emission factors
- Updated default emission factors for use in estimating manufacturing emissions
- Updated permanently sequestered carbon value for coated solid unbleached kraft board
- Added deinked market pulp to product type options
- Improved compatibility with modern Microsoft Windows operating systems
- Modernized software security certificate to include the highest level of security

Questions about this document can be directed to NCASI at info@ncasi.org.

2.0 THE FICAT FRAMEWORK

2.1 The Forest Products Value Chain

The forest products value chain begins in the forest and encompasses all subsequent activities related to production use, reuse, and end-of-life of forest products. The connections between climate change issue and the forest products value chain are perhaps more complex than for any other industry. The forests that supply the industry's raw material remove carbon dioxide from the atmosphere and store the carbon - not only in trees, but also below ground in soils and root systems, and ultimately in forest products. These forests and their carbon sequestration potential are affected by management practices, climate, and by the rise in atmospheric CO_2.

Although the forest products industry obtains much of its energy from biomass, most of the industry's manufacturing facilities require fossil fuels that generate greenhouse gases when burned. In addition, fossil fuels are often used in the manufacture of raw materials used by the industry. The industry's raw materials, intermediate, and final products, require transport, which usually results in the use of fossil fuels. The end-of-life management options for forest products, ranging from recycling to landfilling and burning for energy, have important but complex greenhouse gas and carbon implications. All these aspects of the forest products industry value chain are addressed in FICAT.

2.2 The Boundary Conditions in FICAT

Modeling the greenhouse gas emissions of the forest products value chain is similar to performing a life cycle study of a forest product. The boundaries used in FICAT for cradle-to-grave and cradle-to-gate assessments are described in Table 1 and Table 2.

Table 1. General Description of FICAT Cradle-to-Grave Boundary Conditions

Element	Temporal Boundaries	Geographic Boundaries	Process Included and Excluded
Land Based Carbon	Begins and ends at times corresponding to the Pre-Project and Post-Project conditions, respectively.	Area from which the project obtains wood. May also include land owned by the company but not used for wood.	Includes all forest ecosystem carbon pools that are affected by the wood demand from the operation(s) being studied. These include above and below ground biomass, litter, and soil carbon. The calculations do not include fine woody debris or other dead wood pools.
Carbon in Products	For products in use, a 100-year period following production. For products or mill wastes in landfills, maximum degradation period.	All locations where products are produced, used, and disposed.	Calculations include carbon in products in use, and products and mill waste in landfills. Carbon in by-products is only included if these can be modeled as separate products of the system, with the user entering information associated with the value chains of these additional products.
Emissions - Manufacturing	Annual emissions during the period of interest in the analysis, normally one year.	All forest product manufacturing locations where primary products (e.g., pulp) intermediate products (e.g., rolls of paper) and final products (e.g., newspapers) are made.	Includes fossil-fuel related emissions of CO_2, CH_4 and N_2O and biomass-fuel related emissions of CH_4 and N_2O. Exports of CO_2, imports of CO_2, and emissions of HFCs and PFCs may be included as additional information but do not influence the calculations. Emissions of methane from company owned landfills are included in the end-of-life element of the model. Methane emissions from wastewater treatment are not included. CO_2 from biomass combustion is reported for information purposes only.
Emissions – Wood Production	Annual average emissions over a growth cycle.	Area from which the project obtains wood and other fiber.	Includes estimated fossil fuel CO_2 emissions associated with thinning and harvesting, CH_4 from burning, fossil fuel CO_2 and N_2O associated with fertilizing, and upstream emissions from fertilizers and herbicides. Upstream emissions for processing recovered fiber are assumed to be zero and can be changed by the user. Other potential emissions are not included in the defaults but can be added by the user.
Emissions – Other Raw Material/Fuels	Based on average annual amounts of fuels and other non-fiber inputs used during the period of interest.	Includes operations making fossil fuels used in the facilities described in the "Emissions-Manufacturing" element and operations making non-fiber inputs used in the products described in the "Carbon in products" element.	Includes upstream emissions for fossil fuels and other non-fiber inputs. User may select default emissions representing bundled emissions for a representative recipe for each major product type, or the user may enter the specific types and quantities of chemicals being used. The default bundled values address only inputs for products entered in "Carbon in products." Does not include emissions associated with inputs to downstream manufacturing operations unless entered manually.
Emissions – Purchased Electricity, Steam & Heat	Based on average annual amounts of purchased electricity, steam, and heat.	Includes all operations supplying electricity, steam, and heat to the facilities included in the "Emissions-Manufacturing" calculations.	Includes fossil fuel-derived CO_2, CH_4 and N_2O. The default emission factors do not include upstream emissions associated with fossil fuel production and transport to electricity producers, or transmission losses; the user may enter factors that reflect these emissions.
Emissions-Transportation	Time adequate to include all significant transport elements throughout the value chain.	All locations where raw materials, intermediate products, final products, or employees are transported.	Includes transport of major raw materials, intermediate and final products (as determined by the user), and employees. The user is relied upon to provide comprehensive coverage of transport operations within the boundaries of the analysis. Recovered fiber is considered a raw material for the purpose of transport emissions calculations.
Emissions - Product Use	Time during which products are used or 100 years, whichever is shorter.	Locations where products are used.	Includes only CH_4 and N_2O emissions associated with burning biomass energy products. Emissions associated with a different party's burning of the user's by-products are not included unless these are modeled as separate products of the system.
Emissions - End-of-Life	Time adequate to allow maximum degradation under disposal conditions.	All locations where products are disposed.	Includes methane from municipal solid waste and company owned landfills. Does not include CH_4 and N_2O from products burned at the end of life or from methane combustion. Does not include composting or other end-of-life options. Does not include emissions associated with operation of end-of-life facilities.
Emissions - Avoided	Varies by type of avoided emission.	Varies by type of avoided emission.	Varies by type of avoided emission. These are reported separately from value chain emissions.

Table 2. General Description of FICAT Cradle-to-Gate Boundary Conditions

Element	Temporal Boundaries	Geographic Boundaries	Process Included and Excluded
Land Based Carbon	Begins and ends at times corresponding to the Pre-Project and Post-Project conditions, respectively.	Area from which the project obtains wood. May also include land owned by the company but not used for wood.	Includes all forest ecosystem carbon pools that are affected by the wood demand from the operation(s) being studied. These include above and below ground biomass, litter, and soil carbon. The calculations do not include fine woody debris or other dead wood pools.
Carbon in Products	Carbon stored indefinitely in mill landfills is considered to be a permanent removal from the atmosphere.	All locations where products are produced.	Calculations include increases in carbon stocks in mill wastes in landfills. The carbon transferred downstream in products is calculated but not shown as a removal from the atmosphere because its fate is not known.
Emissions - Manufacturing	Annual emissions during the period of interest in the analysis, usually one year.	All forest product manufacturing locations where primary products (e.g., pulp) intermediate products (e.g., rolls of paper) and final products (e.g., newspapers) are made.	Includes fossil-fuel related emissions of CO_2, CH_4 and N_2O and biomass-fuel related emissions of CH_4 and N_2O. Exports of CO_2, and imports of CO_2, and emissions of HFCs and PFCs may be included as additional information but do not influence the calculations. Emissions of methane from company owned landfills are included in the end-of-life element of the model. Methane emissions from wastewater treatment are not included. CO_2 from biomass combustion is reported for information purposes only.
Emissions – Wood Production	Annual average emissions over a growth cycle.	Area from which the project obtains wood and other fiber.	Includes estimated fossil fuel CO_2 emissions associated with thinning and harvesting, CH_4 from burning, fossil fuel CO_2 and N_2O associated with fertilizing, and upstream emissions from fertilizers and herbicides. Upstream emissions for processing recovered fiber are assumed to be zero and can be changed by the user. Other potential emissions are not included in the defaults but can be added by the user.
Emissions – Other Raw Material/Fuels	Based on average annual amounts of fuels and other non-fiber inputs used during the period of interest.	Includes operations making fossil fuels used in the facilities described in the "Emissions-Manufacturing" element and operations making non-fiber inputs used in the products described in the "Carbon in products" element.	Includes upstream emissions for fossil fuels and non-fiber inputs. User may select default emissions representing bundled emissions for a representative recipe for each major product type, or the user may enter the specific types and quantities of chemicals being used. The default bundled values address only inputs for products entered in "Carbon in products." Does not include emissions associated with inputs to downstream manufacturing operations since these are beyond the "gate."
Emissions – Purchased Electricity, Steam & Heat	Based on average annual amounts of purchased electricity, steam, and heat.	Includes all operations supplying electricity, steam and heat to the facilities included in the "Emissions-Manufacturing" calculations.	Includes fossil fuel-derived CO_2, CH_4 and N_2O. Does not include upstream emissions associated with fossil fuel production and transport to electricity producers or transmission losses unless reflected in the factors entered by the user.
Emissions-Transportation	Time adequate to include all significant transport elements throughout the cradle-to-gate portion of the value chain.	All locations where raw materials and intermediate products are transported.	Includes transport of major raw materials and intermediate products (as determined by the user), and employees. The user is relied upon to provide comprehensive coverage of transport operations within the boundaries of the analysis. Recovered fiber is considered a raw material for purposed of transport emissions calculations.
Emissions - Product Use	Not considered.	None.	Not considered.
Emissions - End-of-Life	Emissions from mill landfills included. End-of-life for products not included.	All locations where mill wastes are disposed.	Includes methane from mill waste landfills. Does not include end-of-life processes for discarded or recovered products.
Emissions - Avoided	Varies by type of avoided emission.	Varies by type of avoided emission.	Varies by type of avoided emission. These are reported separately from value chain emissions.

3.0 LAND-BASED CARBON

3.1 Using Element 1 in FICAT

FICAT calculations for land-based carbon are screening values only when they are based on default values. The tool includes carbon stocks in above and below ground biomass, litter, and soil carbon. The calculations are based on IPCC default tables for Tier 1 estimates (the least accurate allowed by IPCC) and may be inappropriate for many circumstances. The user is encouraged to modify the defaults returned by the model wherever more appropriate values are available.

With one exception (organic soils), FICAT estimates the effects of forest ecosystem carbon in the atmosphere by estimating carbon stocks on the land in both pre-project and post-project conditions and calculates the difference. This is converted into an emission or sequestration rate by dividing by a user-specified project life. The project life is selected by the user based on the objectives of the assessment. Where the user is interested in looking at actual year-to-year (or other period) changes in carbon storage based on user-supplied carbon data, the project period will be one year (or some other period that is associated with the pre- and post-project carbon stock data entered by the user). Otherwise, the shortest period the user should consider is the time required for the post-project condition to become established. The longest period is frequently 100 years, the time used to characterize the significance of carbon in products. An intermediate project life might be the period over which the land-based carbon impacts would be expected to remain in a post-project condition given the investment involved.

It is important to understand that the carbon stock change represented by the difference between the pre-project and post-project condition will be "consumed" over time as amounts are reported on the annual inventory calculated by FICAT. When the total cumulative amount shown on annual inventories is equal to the total stock change, there is no more to report and from that point forward the pre-project and post-project conditions should be the same unless another action is taken that causes another stock change to occur. If a company is reporting year-to-year stock changes based on actual inventory data, then the effects of harvesting, and other factors that impact year-to-year stock changes, also need to be included.

The pre-project and post-project conditions can be idealized, steady-state representations. For instance, if the project involves planting a new plantation forest, the post-project condition will be the long-term average biomass stocks across the entire plantation, a condition reasonably represented by the average carbon stocks over a rotation. Accordingly, the model ignores the effects of natural disturbances. If the user knows these to be important, the data inputs should be adjusted accordingly.

Companies using FICAT, particularly those owning or managing forests, may want the inventory to reflect impacts of one-year changes in forest carbon stocks (instead of long-term average conditions). To do this, the forest-related parameters entered into FICAT would represent the beginning and end of the one-year period of interest.

The following sections contain the IPCC tables and descriptions of how they are used. Annex 1 includes IPCC's descriptions of the climatic regions and ecological zones referred to in the following tables. There are many situations that are not addressed in the IPCC Tier 1 tables. In these cases, the user must select the best choice available, overriding the default values as needed.

3.2 Forest Carbon

3.2.1 Above-ground biomass

IPCC provides tables showing average values (and, in some cases, ranges) for above-ground biomass for natural and plantation forests. These are shown in Table 3 and Table 4 below.

IPCC indicates that the term "forest" is usually defined by national governments but lacking such a definition, IPCC observes the following.

> "Forest is a minimum area of land of 0.05 – 1.0 hectares with tree crown cover (or equivalent stocking level) of more than 10 – 30 per cent with trees with the potential to reach a minimum height of 2 – 5 metres at maturity in situ. A forest may consist either of closed forest formations where trees of various storeys and undergrowth cover a high portion of the ground or open forest. Young natural stands and all plantations which have yet to reach a crown density of 10 – 30 per cent or tree height of 2 – 5 metres are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest."

IPCC defines "natural forest" as "a forest composed of indigenous trees and not classified as a plantation."

IPCC defines a forest plantation as "forest stands established by planting and/or seeding in the process of afforestation or reforestation. They are either of introduced species (all planted stands), or intensively managed stands of indigenous species, which meet all the following criteria: one or two species at planting, even age class, and regular spacing."

Table 3. Natural Forest (IPCC 2006a, Vol. 4, Table 4.7)

Domain	Ecological Zone	Continent	Above-Ground Biomass (tonnes d.m./ha)		
			Avg	Min	Max
Tropical	Tropical rain forest	Africa	310	130	510
		North and South America	300	120	400
		Asia (continental)	280	120	680
		Asia (insular)	350	280	520
	Tropical moist forest	Africa	260	160	430
		North and South America	220	210	280
		Asia (continental)	180	10	560
		Asia (insular)	290		
	Tropical dry forest	Africa	120	120	130
		North and South America	210	200	410
		Asia (continental)	130	100	160
		Asia (insular)	160		
	Tropical shrubland	Africa	70	20	200
		North and South America	80	40	90
		Asia (continental)	60		
		Asia (insular)	70		
	Tropical mountain systems	Africa	115	40	190
		North and South America	145	60	230
		Asia (continental)	135	50	220
		Asia (insular)	205	50	360
Subtropical	Subtropical humid forest	North and South America	220	210	280
		Asia (continental)	180	10	560
		Asia (insular)	290		
	Subtropical dry forest	Africa	140		
		North and South America	210	200	410
		Asia (continental)	130	100	160
		Asia (insular)	160		
	Subtropical steppe	Africa	70	20	200
		North and South America	80	40	90
		Asia (continental)	60		
		Asia (insular)	70		
	Subtropical mountain systems	Africa	50		
		North and South America	145	60	230
		Asia (continental)	160	50	220
		Asia (insular)	205	50	360
Temperate	Temperate oceanic forest	Europe	120		
		North America	660	80	1200
		New Zealand	360	210	430
		South America	180	90	310
	Temperate continental forest	Asia, Europe (<20 yr)	20		
		Asia, Europe (>20 yr)	120	20	320
		North and South America (<20 yr)	60	10	130
		North and South America (>20 yr)	130	50	200
	Temperate mountain systems	Asia, Europe (<20 yr)	100	20	180
		Asia, Europe (>20 yr)	130	20	600
		North and South America (<20 yr)	50	20	110
		North and South America (>20 yr)	130	40	280
Boreal	Boreal coniferous forest	Asia, Europe, North America	50	10	90
	Boreal tundra woodland	Asia, Europe, North America (<20 yr)	3.5	3	4
		Asia, Europe, North America (>20 yr)	17.5	15	20
	Boreal mountain systems	Asia, Europe, North America (<20 yr)	13.5	12	15
		Asia, Europe, North America (>20 yr)	45	40	50

Table 4. Plantation Forests (IPCC 2006a, Vol. 4, Table 4.8)

Domain	Ecological Zone	Continent	Above-Ground Biomass (tonnes d.m./ha)		
			Avg	Min	Max
Tropical	Tropical rain forest	Africa broadleaf >20 yr	300		
		Africa broadleaf <20 yr	100		
		Africa Pinus sp. >20 yr	200		
		Africa Pinus sp. <20 yr	60		
		Americas Eucalyptus sp.	200		
		Americas Pinus sp.	300		
		Americas Tectona grandis	240		
		Americas other broadleaf	150		
		Asia broadleaf	220		
		Asia other	130		
	Tropical moist forest	Africa broadleaf >20 yr	150		
		Africa broadleaf <20 yr	80		
		Africa Pinus sp. >20 yr	120		
		Africa Pinus sp. <20 yr	40		
		Americas Eucalyptus sp.	90		
		Americas Pinus sp.	270		
		Americas Tectona grandis	120		
		Americas other broadleaf	100		
		Asia broadleaf	180		
		Asia other	100		
	Tropical dry forest	Africa broadleaf >20 yr	70		
		Africa broadleaf <20 yr	30		
		Africa Pinus sp. >20 yr	60		
		Africa Pinus sp. <20 yr	20		
		Americas Eucalyptus sp.	90		
		Americas Pinus sp.	110		
		Americas Tectona grandis	90		
		Americas other broadleaf	60		
		Asia broadleaf	90		
		Asia other	60		
	Tropical shrubland	Africa broadleaf	20		
		Africa Pinus sp. >20 yr	20		
		Africa Pinus sp. <20 yr	15		
		Americas Eucalyptus sp.	60		
		Americas Pinus sp.	60		
		Americas Tectona grandis	50		
		Americas other broadleaf	30		
		Asia broadleaf	40		
		Asia other	30		
	Tropical mountain systems	Africa broadleaf >20 yr	105	60	150
		Africa broadleaf <20 yr	70	40	100
		Africa Pinus sp. >20 yr	65	30	100
		Africa Pinus sp. <20 yr	25	10	40
		Americas Eucalyptus sp.	75	30	120
		Americas Pinus sp.	115	60	170
		Americas Tectona grandis	80	30	130
		Americas other broadleaf	55	30	80
		Asia broadleaf	95	40	150
		Asia other	52.5	25	80

Table continued

Table 4. Plantation Forests (Continued)

Domain	Ecological Zone	Continent	Above-Ground Biomass (tonnes d.m./ha)		
			Avg	Min	Max
Subtropical	Subtropical humid forest	Americas Eucalyptus sp.	140		
		Americas Pinus sp.	270		
		Americas Tectona grandis	120		
		Americas other broadleaf	100		
		Asia broadleaf	180		
		Asia other	100		
	Subtropical dry forest	Africa broadleaf >20 yr	70		
		Africa broadleaf <20 yr	30		
		Africa Pinus sp. >20 yr	60		
		Africa Pinus sp. <20 yr	20		
		Americas Eucalyptus sp.	110		
		Americas Pinus sp.	110		
		Americas Tectona grandis	90		
		Americas other broadleaf	60		
		Asia broadleaf	90		
		Asia other	60		
	Subtropical steppe	Africa broadleaf	20		
		Africa Pinus Sp. >20 yr	20		
		Africa Pinus sp. <20 yr	15		
		Americas Eucalyptus sp.	60		
		Americas Pinus sp.	60		
		Americas Tectona grandis	50		
		Americas other broadleaf	30		
		Asia broadleaf >20 yr	80		
		Asia broadleaf <20 yr	10		
		Asia coniferous >20	20		
		Asia coniferous <20	110	100	120
	Subtropical mountain systems	Africa broadleaf >20 yr	105	60	150
		Africa broadleaf <20 yr	70	40	100
		Africa Pinus sp. >20 yr	65	30	100
		Africa Pinus sp. <20 yr	25	10	40
		Americas Eucalyptus sp.	75	30	120
		Americas Pinus sp.	115	60	170
		Americas Tectona grandis	80	30	130
		Americas other broadleaf	55	30	80
		Asia broadleaf	95	40	150
		Asia other	52.5	25	80
Temperate	Temperate oceanic forest	Asia, Europe, broadleaf >20 yr	200		
		Asia, Europe, broadleaf <20 yr	30		
		Asia, Europe, coniferous >20 yr	200	150	250
		Asia, Europe, coniferous <20 yr	40		
		North America	175	50	300
		New Zealand	250	150	350
		South America	105	90	120
	Temperate continental forest and mountain systems	Asia, Europe, broadleaf >20 yr	200		
		Asia, Europe, broadleaf <20 yr	15		
		Asia, Europe, coniferous >20 yr	175	150	200
		Asia, Europe, coniferous <20 yr	27.5	25	30
		North America	175	50	300
		South America	105	90	120
Boreal	Boreal coniferous forest and mountain systems	Asia, Europe >20 yr	40		
		Asia, Europe <20 yr	5		
		North America	45	40	50
	Boreal tundra woodland	Asia, Europe >20 yr	25		
		Asia, Europe <20 yr	5		
		North America	25		

These values for above-ground biomass are intended for use by national governments if they have no better information and are subject to considerable uncertainty.

3.2.2 Below-ground biomass

The information in the tables above is used to estimate below ground biomass by using IPCC root-to-shoot ratios. IPCC's values for root-to-shoot ratio are shown in Table 5.

Table 5. Ratio (R) of Below-Ground to Above-Ground Biomass (IPCC 2006a, Vol. 4, Table 4.4)

Domain	Ecological Zone	Above-Ground Biomass	R (tonne root d.m./tonne shoot d.m.)		
			Avg	Min	Max
Tropical	Tropical rainforest		0.37		
	Tropical moist forest	<125 tonnes/ha	0.2	0.09	0.25
		>125 tonnes/ha	0.24	0.22	0.33
	Tropical dry forest	<20 tonnes/ha	0.56	0.28	0.68
		>20 tonnes/ha	0.28	0.27	0.28
	Tropical shrubland		0.4		
	Tropical mountain systems		0.27	0.27	0.28
Subtropical	Subtropical humid forest	<125 tonnes/ha	0.2	0.09	0.25
		>125 tonnes/ha	0.24	0.22	0.33
	Subtropical dry forest	<20 tonnes/ha	0.56	0.28	0.68
		>20 tonnes/ha	0.28	0.27	0.28
	Subtropical steppe		0.32	0.26	0.71
	Subtropical mountain systems		*		
Temperate	Temperate oceanic forest, Temperate continental forest, Temperate mountain systems	conifers <50 tonnes/ha	0.4	0.21	1.06
		conifers 50-150 tonnes/ha	0.29	0.24	0.5
		conifers >150 tonnes/ha	0.2	0.12	0.49
		Quercus spp. >70 tonnes/ha	0.3	0.2	1.16
		Eucalyptus spp. <50 tonnes/ha	0.44	0.29	0.81
		Eucalyptus spp. 50-150 tonnes/ha	0.28	0.15	0.81
		Eucalyptus spp. >150 tons/ha	0.2	0.1	0.33
		other broadleaf <75 tonnes/ha	0.46	0.12	0.93
		other broadleaf 75-150 tonnes/ha	0.23	0.13	0.37
		other broadleaf >150 tonnes/ha	0.24	1.17	0.44
Boreal	Boreal coniferous forest, Boreal tundra woodland, Boreal mountain systems	<75 tonnes ha	0.39	0.23	0.96
		>75 tonnes/ha	0.24	0.15	0.37

*FICAT uses the same value here as for tropical mountain systems.

3.2.3 Forest biomass carbon

The above- and below-ground biomass are summed and multiplied by 0.5 to yield total forest carbon in biomass.

3.2.4 Forest litter

IPCC provides a default table for estimating carbon stocks in forest litter. This table is reproduced in Table 6 below. Note that this table does not include woody debris or other dead wood pools. IPCC defines litter as, "all non-living biomass with a size greater than the limit for soil organic matter (suggested 2mm) and less than the minimum diameter chosen for dead wood (e.g., 10cm), lying dead, in various states of decomposition above or within the mineral or organic soil. This includes the litter layer as usually defined in soil typologies. Live fine roots above the mineral or organic soil (of less than the minimum diameter limit chosen for below-ground biomass) are included in litter where they cannot be distinguished from it empirically" (IPCC 2006a).

Table 6. Forest Litter Carbon Stocks (IPCC 2006a, Vol. 4, Table 2.2)

Region	Climate	Tree Type	Litter Carbon Stocks of Mature Forests (tonnes C/ha)		
			Avg	Min	Max
Boreal	Dry	Broadleaf deciduous	25	10	58
		Needleleaf evergreen	31	6	86
	Moist	Broadleaf deciduous	39	11	117
		Needleleaf evergreen	55	7	123
Cold Temperate	Dry	Broadleaf deciduous	28	23	33
		Needleleaf evergreen	27	17	42
	Moist	Broadleaf deciduous	16	5	31
		Needleleaf evergreen	26	10	48
Warm Temperate	Dry	Broadleaf deciduous	28.2	23.4	33
		Needleleaf evergreen	20.3	17.3	21.1
	Moist	Broadleaf deciduous	13	2	31
		Needleleaf evergreen	22	6	42
Subtropical	All	Broadleaf deciduous	2.8	2	3
		Needleleaf evergreen	4.1		
Tropical	All	Broadleaf deciduous	2.1	1	3
		Needleleaf evergreen	5.2		

3.2.5 Total forest non-soil carbon

The total forest carbon, not including soil carbon, is estimated by adding the forest biomass carbon and litter carbon determined above. This does not include fine woody debris, or dead wood because IPCC does not provide default estimates for these, as explained in the following text from the IPCC 2006 guidelines.

> "While it is the intent of these IPCC Guidelines to provide default values for all variables used in Tier 1 methodologies, it is currently not feasible to provide estimates of regional defaults values for litter (including fine woody debris < 10 cm diameter) and dead wood (> 10 cm diameter) carbon stocks. Litter pool estimates (excluding fine woody debris) are provided in Table 2.2. Tier 1 methodology only requires the estimates in Table 2.2 for lands converted from Forest Land to any other land-use category (carbon losses) and for lands converted to Forest Land (carbon gains). Tier 1 methods assume that litter and dead wood pools are zero in all non-forest categories and therefore transitions between non-forest categories involve no carbon stock changes in these two pools."

Soil carbon is discussed later in this document.

3.3 Cropland Carbon

IPCC's default values for cropland biomass are in several locations in the 2006 inventory guidelines. Table 7 shows the defaults available from IPCC.

IPCC indicates that Cropland includes all annual and perennial crops as well as temporary fallow land (i.e., land set at rest for one or several years before being cultivated again). Annual crops include cereals, oils seeds, vegetables, root crops and forages. Perennial crops include trees and shrubs, in combination with herbaceous crops (e.g., agroforestry) or as orchards, vineyards and plantations such as cocoa, coffee, tea, oil palm, coconut, rubber trees, and bananas, except where these lands meet the criteria for categorization as Forest Land. Arable land which is normally used for cultivation of annual crops, but which is temporarily used for forage crops or grazing as part of an annual crop-pasture rotation (mixed system) is included under cropland. The biomass carbon values calculated by FICAT for crops assume a root to shoot ratio of 0.5 and a biomass carbon content of 50%. The table below does not include soil carbon, which is addressed later in this document.

3.4 Grassland Carbon

IPCC provides the following values (Table 8) for biomass carbon on grassland. IPCC indicates that grassland includes rangelands and pastureland that are not considered Cropland. It also includes systems with woody vegetation and other non-grass vegetation such as herbs, brushes, and trees that fall below the threshold values used in the Forest Land category. The category also includes all grassland from wild lands to recreational areas as well as agricultural and silvi-pastural systems, consistent with national definitions.

The values in the following table do not include soil carbon, which is discussed later in this document.

Table 7. Crop Biomass and Carbon (IPCC 2006a, Vol. 4, Tables 5.2, 5.3 and 5.9)

System type	Region	Eco-Region	Above-Ground Biomass tonne/ha	Root to Shoot Ratio*	Carbon** tonnes/ha
Annual cropland	Any	Any			5
Perennial cropland	Temperate	Any			2.1
	Tropical	Dry			1.8
		Moist			2.6
		Wet			10
Agrosilvicultural	Africa	Humid tropical high	41	0.5	30.75
	S America	Humid tropical low	70.5	0.5	52.875
		Dry lowlands	117	0.5	87.75
	SE Asia	Humid tropical	120	0.5	90
		Dry lowlands	75	0.5	56.25
Silvopastoral	Australia	Humid tropical	39.5	0.5	29.625
	N America	Humid tropical high	143.5	0.5	107.625
		Humid tropical low	151	0.5	113.25
		Dry lowlands	132.5	0.5	99.375
	N Asia	Humid tropical low	16.5	0.5	12.375
Oil palm	SE Asia	Any	136	0.5	102
Mature rubber	SE Asia	Any	178	0.5	133.5
Young rubber	SE Asia	Any	48	0.5	36
Young cinnamon (7 yr)	SE Asia	Any	68	0.5	51
Coconut	SE Asia	Any	196	0.5	147
Improved fallow 2-r	E Africa	Any	35	0.5	26.25
Improved fallow 1-yr	E Africa	Any	12	0.5	9
Improved fallow 6-yr	SE Asia	Any	16	0.5	12
Alley cropping	SE Asia	Any	2.9	0.5	2.175
Jungle rubber	SE Asia	Any	304	0.5	228
Gmelina-cacao	SE Asia	Any	116	0.5	87

* Root-to-shoot ratio of 0.5 was assumed to allow total biomass to be estimated.

**Except for “Annual Cropland” and “Perennial Cropland,” an assumption for fraction biomass carbon was required. It was assumed that this fraction is 50%.

Table 8. Biomass on Grassland After Conversion (IPCC 2006a, Vol. 4, Table 6.4)
Note: Values assume steady state stocks within one year after conversion.

Land Type	Climate Zone	Total Non-Woody Biomass tonnes d.m./ha	Fraction C *	Total Non-Woody Biomass Carbon tonnes C/ha
Grassland	Boreal - dry and wet	8.5	0.5	4.25
Grassland	Cold Temperate - dry	6.5	0.5	3.25
Grassland	Cold Temperate - wet	13.6	0.5	6.8
Grassland	Warm Temperate - dry	6.1	0.5	3.05
Grassland	Warm Temperate - wet	13.5	0.5	6.75
Grassland	Tropical – dry**	8.7	0.5	4.35
Grassland	Tropical - moist and wet**	16.1	0.5	8.05

* FICAT assumes grassland biomass is 50% carbon.

** Also used for subtropical grasslands in FICAT.

3.5 Settlements

IPCC's Tier 1 assumption is that biomass carbon in settlements is zero. FICAT uses this same default.

3.6 Soil Carbon

IPCC's guidelines, as well as FICAT, use different calculation frameworks for mineral and organic soils. As a result, if a mineral soil is used in the pre-project condition, the post-project condition must also use a mineral soil. Likewise, if an organic soil is used in the pre-project condition, the post-project condition must also use an organic soil.

3.6.1 Mineral soils

For mineral soils, IPCC guidelines provide defaults for "soil organic carbon reference values" and a series of adjustment factors to account for "land use," "management," and "input." IPCC describes these factors as follows.

> "The stock change factors are very broadly defined and include:
> 1) a land-use factor that reflects C stock changes associated with type of land use,
> 2) a management factor representing the principal management practice specific to the land-use sector (e.g., different tillage practices in croplands), and
> 3) an input factor representing different levels of C input to soil. … [A disturbance factor] is substituted for [the land use factor] in Forest Land to account for the influence of natural disturbance regimes."

A review of the factors by NCASI suggests that, for purposes of a screening tool like FICAT, many of the factors are close enough to 1.0 to be ignored. In addition, since it is the intent of FICAT to look at forests over time frames that tend to reduce the influence of natural disturbances, FICAT does not adjust soil carbon (or any other carbon pool) to account for natural disturbances.

For purposes of FICAT, it was determined that, with one exception, the only factor that varied from 1.0 by enough to make it important was the "land use" or "disturbance" factor. The exception was grassland where the management factors for non- or moderately degraded soils were very different from the factors for severely degraded soil, so both were included.

The mineral soil organic carbon reference values (SOCref) and the adjustment factors selected for FICAT are shown in Table 9 and Table 10.

Table 9. Mineral Soil Reference Values (SOCref) (IPCC 2006a, Vol. 4, Table 2.3)

Climate Region	Default Reference (Under Native Vegetation) Soil Organic C Stocks (SOCref) for Mineral Soils* (tonnes C/ha to 30 cm)					
	HAC Soil	LAC Soil	Sandy Soils	Spodic Soils	Volcanic Ash	Wetland Soils**
Boreal	68		10	117	20	146
Cold temperate, dry	50	33	34		20	87
Cold temperate, moist	95	85	71	115	130	87
Warm temperate, dry***	38	24	19		70	88
Warm temperate, moist***	88	63	34		80	88
Tropical, dry	38	35	31		50	86
Tropical, moist	65	47	39		70	86
Tropical, wet	44	60	66		130	86
Tropical, montane	88	63	34		80	86

* IPCC provides the following definitions for the various types of mineral soils:

HAC Soil: Soils with high activity clay (HAC) minerals are lightly to moderately weathered soils which are dominated by 2:1 silicated clay minerals (in FAO classification included Vertisols, Chernozems, Phaezems, Luvisols.

LAC Soil: Soils with low activity clay (LAC) minerals are highly weathered soils dominated by 1:1 clay mineral and amorphous iron and aluminum oxides (in FAO classification includes Acrisols, Nitosols, Ferrasols).

Sandy soil: A soil classification Including all soils (regardless of taxonomic classification) having > 70% sand and < 8 % clay (based on standard textural measurements (in FAO classification includes Arenosols, sandy Regosols.

Spodic soil: Soils exhibiting strong podzolization (in FAO classification includes many Podzolic groups).

Volcanic ash: IPCC offers no definition, but these soils consist primarily of volcanic ash.

****Wetland soil:** This includes soil on land that is covered or saturated by water for all or part of the year (e.g., peatland) and that does not fall into the forest land, cropland, grassland, or settlements categories. Note: FICAT does not model organic soils like peat using these factors, but rather by using the approach discussed later in this document.

*** Also used for subtropical soils in FICAT.

Table 10. Factors Used in FICAT to Convert SOCref to Soil Carbon

Land type	Temperature Regime	Moisture Regime	Land Use or Disturbance Factor	Source in Vol. 4 of IPCC's 2006 Guidelines
Forest	All	All	1	Bottom page 4.23, Tier 1 approach
Cropland - long term cultivated*	Temperate/boreal	Dry	0.8	Table 5.5
Cropland - long term cultivated*	Temperate/boreal	Moist	0.69	Table 5.5
Cropland - long term cultivated*	Tropical	Dry	0.58	Table 5.5
Cropland - long term cultivated*	Tropical	Moist/wet	0.48	Table 5.5
Cropland - long term cultivated*	Tropical/montane	All	0.64	Table 5.5
Cropland - rice paddy	all	All	1.1	Table 5.5
Cropland - perennial/tree crop	all	All	1	Table 5.5
Cropland - set aside <20 yrs	Temperate/boreal/tropical	Dry	0.93	Table 5.5
Cropland - set aside <20 yrs	Temperate/boreal/tropical	Moist/wet	0.82	Table 5.5
Cropland - set aside <20 yrs	Tropical montane	All	0.88	Table 5.5
Grassland - non- or moderately degraded	All	All	1	Table 6.2
Grassland - severely degraded	All	All	0.7	Table 6.2 - Note, this includes the "management factor" for severely degraded lands because it is not near zero
Settlements	All	All	1	Section 8.3.3.2 recommendation for turfgrass

* FICAT associates these values with annual cropland in the biomass tables.

Using the information in these two tables, the stocks of carbon per hectare in mineral soils are estimated for both the pre-project and post-project conditions and the difference is divided by the project life to yield an annualized emission or sequestration rate.

3.6.2 Organic soils

IPCC uses a different method to characterize the carbon in organic soils. Instead of providing factors to estimate stocks of carbon, IPCC provides information on the rate of loss of carbon from drained organic soils. For this reason, instead of calculating pre- and post-project carbon stocks, FICAT assumes that the carbon emissions for undrained organic soils are zero while those for drained organic soils are those suggested by IPCC.

Because IPCC's methodology for organic soils is not based on carbon stock changes, the "pools and parameters" screen in FICAT does not include soil carbon when organic soils are selected.

The carbon emission rates for organic soils used in FICAT are shown in the following table (Table 11).

Table 11. Emission Factors for Organic Soils (IPCC 2006a, Vol. 4, Table 4.6, 5.6 and 6.3)

Soil Condition	Land Type	Climate	Emission Factor (tonnes C/ha)/yr
Un-drained	All	All	0.0
Drained	Forest	Tropical	1.36*
Drained	Forest	Temperate	0.68
Drained	Forest	Boreal	0.16
Drained	Cropland	Boreal	5
Drained	Cropland	Cool Temperate	5
Drained	Cropland	Warm Temperate	10
Drained	Cropland	Tropical/Sub-Tropical	20
Drained	Grassland	Boreal	0.25
Drained	Grassland	Cool Temperate	0.25
Drained	Grassland	Warm Temperate	2.5
Drained	Grassland	Tropical/Sub-Tropical	5
Drained	Settlements	Boreal	5
Drained	Settlements	Cool Temperate	5
Drained	Settlements	Warm Temperate	10
Drained	Settlements	Tropical/Sub-Tropical	20

* Also used in FICAT for subtropical forest soils

The difference between the pre- and post-project emission factors is used to calculate the emissions associated with the change which is added to the stock-change-based changes estimated in other parts of FICAT.

4.0 CARBON IN PRODUCTS

Except for the carbon that is transformed into products, all the carbon removed from the forest during harvesting is assumed to return to the atmosphere in the year of harvest.

In cradle-to-grave inventories, FICAT estimates the fraction of carbon that is stored in products-in-use for 100 years. For products that do not remain in use for 100 years, FICAT estimates the net additions to carbon stocks in products in landfills (the methane attributable to products in landfills is addressed in Element 9 of FICAT). If the product of interest is a biomass energy product, the model does not calculate carbon storage or methane emissions from landfills for used products.

In cradle-to-gate studies, the net additions to carbon stocks in products-in-use are not calculated since they are outside of the assessment boundaries. Likewise, net additions to carbon stocks in products in landfills and greenhouse gas emissions attributable to products in landfills are not included in cradle-to-gate inventories. The amount of carbon in the products themselves is shown in cradle-to-gate inventories to facilitate efforts by downstream entities to complete the footprint. The impacts of carbon storage in, and methane emissions from, landfills receiving manufacturing wastes from mills are included in both cradle-to-grave and cradle-to-gate inventories.

To provide transparency regarding the internal consistency of the carbon accounting, FICAT asks the user to estimate the fraction of the wood used to manufacture products entered in the "carbon in products" element (not including recovered fiber) that comes from land areas entered in the "land-based carbon" element of FICAT. Ideally, the areas entered in "land-based carbon" would be supplying 100% of the wood (not including recovered fiber) needed to produce the products described in the "carbon in products" element. To enter this value, the user clicks on "product/wood percentage" in the upper left of the data entry window. It can also be entered from the summary screen.

FICAT considers additions to two pools of product-derived carbon: products in use and products in landfills.

4.1 Products in Use (Only Calculated in Cradle-to-Grave Inventories)

IPCC's national inventory method is not well suited to entity-level accounting of carbon in products. FICAT, therefore, uses two approaches that are better suited to entity-level and product-level inventories. These methods are the 100-year end point method, sometimes simply called the "100-year method", and the "100-year weighted average method."

As used in FICAT, both the 100-year end point method and the 100-year weighted average method use generally accepted time-in-use information from IPCC or other sources, and a first order mathematical relationship to estimate the amount of carbon that will still be in use over time. In the case of the 100-year end point method, the net additions to carbon stocks in products-in-use are equal to the amount remaining in use after 100 years. In the 100-year weighted average method, net additions to carbon stocks in products in use are equal to the weighted average carbon storage over the 100-year period, which is a fraction of the original carbon equal to the area under the time-in-use distribution, from zero to 100 years, divided by 100. The net additions to carbon stocks in products in use are accounted for as removals from the atmosphere.

FICAT uses IPCC's default first order half-lives for products in use; 30 years for wood products, and 2 years for paper products (IPCC 2006a, Vol. 4, Table 12.2). The model also uses IPCC's default assumption that most products are 50% carbon by weight[1] (IPCC 2006a Vol. 4). These can be changed by the user, however.

For the 100-year end point method, the amount of carbon remaining in use after 100 years is calculated as follows.

*Quantity of carbon remaining In-Use at end of 100 years = (Quantity of Product) * (Biomass carbon content) * EXP(-100 * LN(2)/Half-life in years)*

For the 100-year weighted average method, the net additions to carbon stocks in products in use are calculated as follows.

*Weighted average quantity of carbon Remaining In-Use for 100 years = (Quantity of Product) * (Biomass carbon content) **

*((EXP((-(LN(2)/(Half-life in years)) * 100))-1)/((-(LN(2)/(Half-life in years)) * 100)*

The results from these two equations are converted into CO_2 equivalents by multiplying by 44/12 and shown as carbon storage in products in the FICAT summary for carbon in products in use.

4.2 Products in Landfills

After use, a certain fraction of used material will often be sent to landfills. Studies have shown that because modern landfills contain low amounts of oxygen (i.e., are essentially anaerobic), some of the carbon in forest products is non-degradable. Lignin is non-degradable under anaerobic conditions. FICAT uses current data on the ultimate fate of carbon in landfills for different types of forest products to identify the fraction of carbon that can be considered permanently stored in landfills. The calculation approach is as follows.

The user enters information indicating the fraction of used product that is placed in landfills when that product is removed from use. The user also indicates the general type of landfill to estimate the extent that landfill contents will be under anaerobic conditions, which determines the methane correction factor (MCF) used in the calculations as shown in Table 12.

FICAT then uses information on the non-degradable fraction of different types of products under anaerobic conditions to estimate the quantity of carbon remaining in long-term storage in the landfill, shown in Table 13.

Mapping is required in many cases to connect specific products to the appropriate product-in-use and landfill parameters. The mapping is shown in 4.

[1] Table 12.4 in Vol. 4 of IPCC 2006a indicates that the carbon fraction of dry weight is 50% for roundwood, industrial roundwood, sawnwood, other industrial roundwood, pulpwood, chips, particles, wood fuel, wood residues, paper and paperboard, pulp, recovered fibre pulp, and recovered paper. The carbon fraction of wood panels is indicated to be 0.468 and that of charcoal, 0.85. In FICAT, the defaults for all, however, are 0.5.

The calculations for carbon storage in products in landfills are as follows.

*Quantity of carbon permanently stored in landfills = [(Quantity of product manufactured – Quantity of product remaining in use calculated using the simple 100-year method or the 100-year weighted average method)] * (Fraction of used product landfilled)] * MCF * (Fraction carbon in product) * (Fraction of carbon permanently stored under anaerobic conditions)*

*Quantity of carbon in CO_2 equivalents stored in landfills = Quantity of carbon permanently stored in landfills * 44/12.*

Table 12. Methane Correction Factors (IPCC 2006b, Vol. 5, Table 3.1)

Type of Site	MCF	Comments
Managed - anaerobic	1.0	
Managed - semi-aerobic	0.5	
Unmanaged - deep (>5 m)	0.8	Also pertains to sites with high water table
Unmanaged - shallow (<5 m)	0.4	
Uncategorized SWDS	0.6	

The definitions for these landfill types are as follows (IPPC 2006 guidelines):
Anaerobic managed: These must have controlled placement of waste (i.e., waste directed to specific deposition areas, a degree of control of scavenging and a degree of control of fires) and will include at least one of the following: (i) cover material; (ii) mechanical compacting; or (iii) levelling of the waste.
Semi-aerobic: These landfills must have controlled placement of waste and will include all the following structures for introducing air to waste layer: (i) permeable cover material; (ii) leachate drainage system; (iii) regulating pondage; and (iv) gas ventilation system.
Unmanaged deep: Deep and/or with high water table landfills: All SWDS not meeting the criteria of managed SWDS and which have depths of greater than or equal to 5 meters and/or high-water table at near ground level. Latter situation corresponds to filling inland water, such as pond, river, or wetland, by waste.
Unmanaged shallow: All SWDS not meeting the criteria of managed SWDS and which have depths of less than 5 meters.
Uncategorized: Select only if user cannot categorize their SWDS according to the other four categories of managed and unmanaged SWDS.

Table 13. Storage of Forest Product Carbon in Anaerobic Landfills

Product Type	Fraction of Carbon Permanently Stored Under Anaerobic Conditions
Solid Wood Products (lumber, panels, etc.)	0.77*
Newsprint and other non-coated mechanical grades	0.84**
Corrugated boxes, OCC, unbleached linerboard, Semi-chem, and other unbleached chemical grades	0.61***
Office papers (recycled and virgin) and other bleached chemical grades	0.12****
Coated mechanical paper grades	0.79*****

*From U.S. EPA (2020b), Annex 3, Table A-226.
EPA (2020) "Inventory of U.S. Greenhouse Gas Emissions and Sink 1990-2018, EPA 430-R-20-002, Annex 3, Table A-226.
**From NCASI (2004), Table 6.1, pg. 41. It its waste reduction model (WARM), U.S. EPA (2020a), Exhibit 3-28, uses a consistent value of 0.41 kg C/kg newspaper or 0.85 kg C/kg C.
*** From NCASI (2004). U.S. EPA (2020a) WARM (2020) has a similar value of 0.26 kg C/kg corrugated containers or approximately 0.55 kg C/kg C.
****From NCASI (2004). U.S. EPA (2020a) includes the same value.
*****From NCASI (2004). U.S. EPA (2020a) has a similar value of 0.28 kg C/kg coated papers or about 0.82 kg C/kg C.

Table 14. Mapping Product Types to In-Use and Landfill Parameter Values

Product Descriptions			Product Groupings for In-Use and In-Landfill Calculations				
Product Groups	Product Sub-Groups	Product Grades	Coated Mechanical Paper Grades	Corrugated Boxes, OCC, Unbleached Linerboard, Semi-Chemical, and Other Unbleached Chemical Grades	Newsprint and Other Non-Coated Mechanical Grades	Office Papers (Recycled and Virgin) and Other Bleached Chemical Grades	Wood Products
Paperboard	Containerboard	Recycled corrugating medium		X			
Paperboard	Containerboard	Semichemical corrugating medium		X			
Paperboard	Containerboard	Recycled linerboard		X			
Paperboard	Containerboard	Kraft linerboard		X			
Paperboard	Containerboard	Uncoated solid unbleached kraft board		X			
Paperboard	Containerboard	Coated solid unbleached kraft board		X			
Paperboard	Containerboard	Coated bleached kraft board				X	
Paperboard	Containerboard	Uncoated bleached kraft board				X	
Paperboard	Recycled boxboard	Coated recycled boxboard		X			
Paperboard	Recycled boxboard	Uncoated recycled boxboard		X			
Paper	Newsprint	Newsprint, 0% DIP			X		
Paper	Newsprint	Newsprint, 100% DIP			X		
Paper	Packaging paper	Uncoated unbleached kraft paper		X			
Paper	Packaging paper	Coated Unbleached kraft paper		X			
Paper	Printing and Writing	Coated mechanical grades	X				
Paper	Printing and Writing	Coated woodfree - integrated				X	
Paper	Printing and Writing	Coated woodfree - nonintegrated				X	
Paper	Printing and Writing	Uncoated mechanical grades			X		
Paper	Printing and Writing	Supercalendered mechanical grades			X		
Paper	Printing and Writing	Uncoated woodfree - integrated				X	
Paper	Printing and Writing	Uncoated woodfree - nonintegrated				X	
Paper	Tissue and Toweling	Tissue and Toweling, 0% DIP				X	
Paper	Tissue and Toweling	Tissue and Toweling, 100% DIP				X	
Market pulp	Deinked market pulp	Deinked market pulp				X	

Table continued

Table 15. Mapping Product Types to In-Use and Landfill Parameter Values (Continued)

Product Descriptions			Product Groupings for In-Use and In-Landfill Calculations				
Product Groups	Product Sub-Groups	Product Grades	Coated Mechanical Paper Grades	Corrugated Boxes, OCC, Unbleached Linerboard, Semi-Chemical, and Other Unbleached Chemical Grades	Newsprint and Other Non-Coated Mechanical Grades	Office Papers (Recycled and Virgin) and Other Bleached Chemical Grades	Wood Products
Market pulp	Bleached market pulp	ECF market pulp				X	
Market pulp	Bleached market pulp	TCF market pulp				X	
Market pulp	Unbl. market pulp	Unbleached kraft market pulp				X	
Wood product	Manufactured lumber	Glue laminated timber, indoor use					X
Wood product	Manufactured lumber	Glue laminated timber, outdoor use					X
Wood product	Manufactured lumber	Laminated timber element, outdoor use					X
Wood product	Panels	Three layered laminated board					X
Wood product	Panels	Particle board, indoor use (680 kg/m3)					X
Wood product	Panels	Particle board, outdoor use (680 kg/m3)					X
Wood product	Panels	OSB (650 kg/m3)					X
Wood product	Panels	Cement-bonded particleboard (1200 kg/m3)					X
Wood product	Panels	Fiberboard, MDF (300 kg/m3)					X
Wood product	Panels	Fiberboard, MDF (780 kg/m3)					X
Wood product	Panels	Fiberboard, MDF (900 kg/m3)					X
Wood product	Panels	Plywood, indoor use (500 to 800 kg/m3)					X
Wood product	Panels	Plywood, outdoor use (500- 800 kg/m3)					X
Wood product	Panels	Wood wool insulation board, cement bonded (450 kg/m3)					X
Wood product	Sawn timber	Sawn timber					X

4.3 Mill Wastes in Landfills

In the manufacturing process, some of the biomass from the forest is lost as waste material and some of this waste material may be landfilled. In landfills, this material both stores carbon and decomposes to a mix of CO_2 and methane. The physical and chemical phenomena are the same as for products in landfills and are described above.

Because the amounts of carbon stored in landfills contribute relatively little to the value chain profile, they may be estimated without great precision. Accordingly, in FICAT, the amounts of mill waste are assumed to be 5% of the amount of pulp, paper, or paperboard product manufactured, and 25% of the quantity of wood products manufactured. These can be changed by the user, as can the biomass carbon content.

Note that the wood product "waste" factor is large because it includes sawdust, chips, and other materials that may be wastes but are more often co-products or by-products frequently used as fuel or raw materials by other facilities. Normally, only a small fraction of the residuals from wood products plants is waste and the value entered in this field should be only waste material. Co-products and by-products should be entered as separate products in the "Carbon in products" element. For materials that are waste, the user indicates the fraction of the waste that is disposed of in landfill, and the type of landfill, which determines the MCF (i.e., the fraction of the landfilled waste experiencing anaerobic conditions). The fraction of non-degradable carbon is assumed to be the same as in the parent product from which it was derived.

The calculations are shown below.

*Quantity of mill waste = (waste generation factor) * quantity of product*

Where the default for (waste generation factor) is 0.05 for pulp, paper, and paperboard products, and 0.25 for wood products.

*Quantity of mill waste carbon permanently stored in landfill = (quantity of mill waste) * (fraction carbon in mill wastes) * (fraction of mill waste landfilled) * (mill landfill MCF) * (Fraction of carbon in parent product permanently stored under anaerobic conditions)*

4.4 Total Carbon in Long-Term Storage

For cradle-to-grave studies, the total amount of carbon in long-term storage is the sum of carbon stored in products in use, carbon stored in products in landfills, and carbon stored in mill wastes in landfills. In cradle-to-gate studies, the total storage is unknown because the fate of the carbon in products is not known. Instead, the storage accomplished up to the point of sale is reported and the amount of carbon contained in the product is reported so that entities down the value chain can continue the footprint calculations.

The amounts of carbon stored are multiplied by 44/12 to calculate the CO_2 equivalents of this storage, representing an equivalent net removal of CO_2 from the atmosphere.

5.0 EMISSIONS - MANUFACTURING

Emissions from manufacturing operations include direct emissions from fuels combusted at forest products industry manufacturing facilities. Imports or exports of CO_2 or emissions of other GHGs can be included as additional information. Carbon dioxide that is captured and exported/sold, rather than emitted, is not included in direct emission totals and is reported separately as additional information. Emissions of methane from the decomposition of manufacturing wastes are calculated in the end-of-life section of the model.

To understand the profile of the value chain, it is necessary to include emissions associated with the following manufacturing activities.

- Primary manufacturing (e.g., the production of pulp, paper and paperboard, lumber, panels, etc.) Primary manufacturing may be followed by intermediate manufacturing if, for example, a mill buys market pulp (primary manufacturing) to make rolls of paper (intermediate manufacturing).

- Secondary manufacturing, sometimes called converting (the conversion of primary products into final products e.g., boxes, cartons, newspapers, magazines, furniture, houses, etc.).

The user should include facilities that are owned/controlled as well as those that are not. For instance, if the user manufactures book paper from purchased pulp, in addition to emissions associated with the fuels burned by the user, the user must include the upstream emissions associated with fuel used by the pulp manufacturer and the emissions associated with fuel required for printing and book production. Default factors are provided in Table 16 below to assist in estimating these when they are not known to the user.

The model allows the user to differentiate between direct and indirect emissions based on the ownership or control of the sources.

5.1 Fuel Combustion

Emissions from fuel combustion comprise the majority of emissions from forest product industry manufacturing operations. In FICAT, these emissions are based on calculation methodologies from the World Resources Institute and World Business Council for Sustainable Development Greenhouse Gas Protocol (www.ghgprotocol.org) which are essentially the same as those used by IPCC (Tier 1 values). Emissions of carbon dioxide, methane, and nitrous oxide are included. The forest products industry relies on biomass fuels to satisfy a significant portion of its energy needs. Consistent with guidance from the Greenhouse Gas Protocol and IPCC, biomass combustion CO_2 emissions are not included with fossil fuel-derived CO_2, but are estimated and reported separately as additional information. However, methane and nitrous oxide from biomass combustion are included with the direct emissions estimates. The global warming potentials used in FICAT for CH_4 and N_2O are selected by the user, with the choices being those from IPCC's 1996, 2001, 2006, 2013, or 2021 inventory guidelines. Some default information included in FICAT were derived using the 2006 GWPs i.e., 25 for CH_4 and 298 for N_2O.

Emissions are calculated based on fuel consumption quantities and emission factors. The emission factors incorporated in FICAT were drawn from the Greenhouse Gas Protocol, which in turn are based on IPCC guidance, Tier I, Vol. 2, Table 2.3 (IPCC 2006). The table below presents the emission factors incorporated into FICAT. The user selects the fuels consumed from a drop-down list of options (which will link to the appropriate emission factors) and enters the quantity of fuel combusted per year. It is important that the user enter fuel consumption for the entire manufacturing operation, even sub-operations that might occur at facilities outside their control (e.g., a user operating a converting operation that manufactures envelopes from roll stock must enter total fuel consumed during production of the envelopes and during production of the roll stock). Users can use the default emission factors listed in Table 15 or enter other factors if more appropriate information is available. The user identifies the emissions as direct or indirect, reflecting ownership or control of the source.

In addition, the user can enter the CO_2 emissions per year for a given source directly into the table after creating the source. This will be useful in cases where the emissions must be estimated from default values because the source is not owned or controlled by the entity using FICAT. It may also be useful where the company has already estimated these emissions.

Table 16. Emission Factors for Fuel Combustion

Fuel Type	kg CO_2/GJ LHV	kg CH_4/GJ LHV	kg N_2O/GJ LHV
Gasoline / petrol	69.3	0.003	0.0006
Kerosene	71.9	0.003	0.0006
Distillate fuel oil and diesel	74.1	0.001	0.0006
Residual fuel oil (No.5, No.6 fuel oil)	77.4	0.003	0.0006
LPG	63.1	0.001	0.0001
Natural gas (dry)	56.1	0.001	0.0001
Anthracite	98.3	0.01	0.0015
Bituminous coal	94.6	0.01	0.0015
Sub-bituminous coal	96.1	0.01	0.0015
Lignite	101.0	0.01	0.0015
Peat	106.0	0.001	0.0015
Coking coal	94.6	0. 01	0.0015
Petroleum coke	97.5	0.003	0.0006
Coke oven / gas coke*	107.00	0.01	0.0015
Brown coal briquettes	97.50	0.01	0.0015
Lubricants	73.30	0.003	0.0006
Coal tar	80.70	0.01	0.0015
Waste oils	73.30	0.03	0.004
Municipal solid waste (MSW)	91.7	0.03	0.004
Tires and tire derived fuel†	85.78	0.032	0.0042
Wood and wood waste	112‡	0.03	0.004
Pulping liquors	95.3‡	0.003	0.002

SOURCE: IPCC (2006b, Vol. 2, Chapter 2, Table 2.3)

*For coke oven and gas coke, the IPCC emission factors are the same but CH_4 and N_2O are different. In FICAT, the two have been merged into a single fuel type and the worst CH_4 and N_2O emission factors are shown as defaults.

†Factors for tire derived fuel are from U.S. EPA (2009, Table C-1 and C-2 of Subpart C). Factors from this source were converted to SI units, and converted from HHV basis to LHV basis using IPCC recommendations:

Emission factor (LHV) = Emission factor (HHV) / 0.95 for solid/liquid fuels

Emission factor (LHV) = Emission factor (HHV) / 0.90 for gaseous fuels

‡ CO_2 emission factors for biomass are used to estimate biomass-derived CO_2 emissions, which are reported separately from CO_2 from fossil fuel combustion.

In some instances, the user may not have data on fuel consumption at facilities outside their control. In these cases, the user can calculate the manufacturing-related emissions to enter in the model by using the default direct emission CO_2 emission intensities for a variety of primary products, shown in Table 16. These default CO_2 intensity values were developed by NCASI from data on energy consumption by forest product facilities in North America. While these values are within the ranges suggested by the various datasets used, they are significantly higher than the average intensities to discourage users from using these values instead of values better reflecting their actual situations.

Table 17. Direct Emissions CO_2 Intensity Values for Primary Product Categories

Production Category	Fossil Direct CO_2 Intensity (mt CO_2/admt)
Chemical market pulp mill	0.31
Integrated bleached chemical pulp and paper/paperboard mill	0.55
Integrated unbleached chemical pulp and paper/paperboard mill	0.36
Integrated mechanical pulp and paper	0.13
Recycled paperboard or containerboard mill	0.26
Non-integrated paper/paperboard mill using primarily purchased pulp	0.66
Deinked market pulp	1.07
Lumber – not dried	0
Lumber – dried	0.01
Structural panels (e.g., plywood and OSB)	0.05
Non-structural panels (e.g., particleboard and MDF)	0.3

Where the user is lacking information on the emissions associated with secondary manufacturing or converting operations (i.e., operations required to convert intermediate products, like rolls of paper, into final products, like magazines), one option is for the user to assume that the emissions from secondary manufacturing or converting operations are 15% of those from primary manufacturing. This is within the range found in the literature.

5.2 Waste Management

The calculations for methane emissions associated with landfilled mill wastes are discussed in the sections on Carbon in Products and End-of-Life emissions. Greenhouse gas emissions from aerobic wastewater treatment plants (which are commonly used in the forest products industry) are not included because research has demonstrated that these are very small. In unusual circumstances, however, where companies are operating anaerobic wastewater treatment plants without methane recovery, the greenhouse gas emissions can be significant, should be estimated, and entered separately by the user.

5.3 Imports and Exports of CO_2

Some forest products facilities import CO_2 for use in the manufacturing process, e.g., for pH control. While not an emission if the CO_2 is consumed during use rather than released, FICAT provides a place for the user to document imports of CO_2. Imports of CO_2 are not added to, or subtracted from, emission totals, but rather are included as additional information because it is not known how much of the import is released as an emission.

Some facilities export CO_2 for use in manufacturing products such as precipitated calcium carbonate (PCC). The most common example of this within the forest products sector is capture of flue gases from kraft mill lime kilns. Carbon dioxide that is captured and exported or sold rather than released to the atmosphere is not an emission for the company exporting and selling the CO_2. Entries of CO_2 exports are not subtracted from direct emissions totals due to uncertainties on the value chain effects of these exports.

The user may also enter imports of gases used in cooling systems (e.g., PFCs and HFCs).

None of these aspects discussed in this section (1.13) affect the emissions calculations.

6.0 EMISSIONS: WOOD PRODUCTION

Fiber represents most of the raw material needed to produce forest products. Therefore, in FICAT, these upstream emissions are estimated separately from other upstream emissions associated with raw materials and fuels. The emissions estimated in this element of the profile do not include transport-related emissions, which are estimated elsewhere. In FICAT, the user divides these emissions into direct and indirect emissions reflecting the degree of ownership/control the user has over the emissions sources.

Although this element is titled “wood production,” it allows the user to enter information in upstream emissions associated with producing recovered fiber and non-wood fiber.

6.1 Virgin Wood Fiber: Default Generic Emission Factors

In many cases, these emissions will be relatively minor compared to other emissions in the value chain, and it is reasonable to estimate them based on factors from the literature. For users with detailed information on the use of fuels, fire, and chemicals in forest management, however, FICAT allows users to enter data to develop a highly accurate site-specific emission factor for harvested wood.

The generic emission factors in FICAT are differentiated according to management intensity. Three levels of intensity are used in FICAT, described as high, medium, and low intensity. Low management intensity refers to operations where the only significant management is harvesting, which includes thinning. Medium intensity management allows for the use of fire as a management tool and/or chemicals in forest management, but in moderate amounts compared to high intensity management. High intensity management describes the management activities associated with, for instance, eucalyptus pulpwood plantations.

For the generic emission factors, NCASI has relied primarily on information in Sonne (2006). The paper by Sonne finds that almost all the management- and harvest-related emissions can be attributed to three activities: harvesting, burning and fertilization.

The generic emission factors for harvesting, fire use, and chemicals used in FICAT are shown in Table 17. The factors are based on a baseline emission for harvesting (including thinning) of 1,500 kg CO_2 eq./100 m3. The factors are increased to reflect the relative importance of other factors compared to harvesting, as reported by Sonne (see Tables 8 and 9 in Sonne 2006). In addition, information from Kulay et al. (2006), personal communications with Kulay, and from Markewitz (2006), has been used to estimate the upstream emissions associated with herbicides used in forest management. Information from Kulay (2006) suggests an application rate for intensively managed eucalyptus plantations of 0.273 kg herbicide (of several different types) per oven-dried (OD) metric ton (tonne) of wood harvested. Markewitz (2006) provides information suggesting that the upstream emissions associated with herbicides can be 1.5 to 8.6 kg C per kg of herbicide. From these values, it can be estimated that upstream emissions associated with herbicides could be 2 to 9 kg CO_2 eq. per tonne of wood. For the calculations in this model, 5 kg CO_2 eq. per tonne of wood harvested was added to the emissions associated with fertilizers, reported by Sonne (see above), under the assumption that intensive forest management would often involve both. The emissions are converted to harvesting units of cubic meters assuming a density of 0.5 OD tonne/m^3.

Table 18. Greenhouse Gas Emissions Associated with Forest Management

Type of management practice	kg CO_2 eq. / cubic meter harvested
Only management is harvesting	15
In addition to harvesting, burning is used for site preparation or undergrowth control	24
In addition to harvesting, fertilizers, and herbicides are used on the land	29
In addition to harvesting, management includes burning, fertilizers, and herbicide use	39

In some earlier versions of FICAT, the user selected from these four categories of management practices. In the current version, the old categories which were based on management practices have been converted into three management intensity-based factors that approximately correspond to the original FICAT factors. The management-intensity-based factors are described in the following table. For low management intensity, it was assumed that the only management was harvesting and thinning. For high intensity management, it was assumed that in addition to harvesting and thinning, significant amounts of chemicals and fire were used. The factors for medium intensity were arbitrarily selected to represent intermediate levels of use of chemicals and fire.

Table 19. Default Generic Forest Management Emission Factors Used in FICAT

Management intensity	Emission factors, kg CO_2 eq. per cubic meter harvested			
	Fossil fuel consumption	Use of fire for management	Use of chemicals (fertilizers and herbicides)	Total
Low	15	0	0	15
Medium	15	5	5	25
High	15	10	10	35

More recent information (Milota and Puettmann 2017, Oneil and Puettmann 2017), provide estimates in the same order of magnitude of the defaults presented in Table 17 and Table 18.

6.2 Virgin Wood Fiber: Site-Specific Emission Factors

In cases where companies have information on the amounts of fossil fuel used in forest management, the extent to which fire is used as a management tool (e.g., in site preparation), and the types and amounts of chemicals used, these can be entered directly into FICAT with the result being a site-specific emission factor reflecting emissions from forest management. Depending on the context for undertaking the carbon profile, the data entered into FICAT can either reflect the activity averaged over a rotation (e.g., average kg chemical used per year over the rotation), or an actual year-by-year estimate based on what is done in a single year.

Where companies enter data on fuels, fire, and chemicals used in forest management, these are converted into emissions estimates using the following information.

Emissions associated with fossil fuels used in forestry: The default values in the calculator for fossil fuel use in forestry are the average values across all management intensities from the data generated under the CORRIM program, as contained in the U.S. LCI database in 2008 (NREL 2008). Fossil fuel use is converted into emissions using physical-unit-based emissions factors (e.g., GHGs per liter of petrol) from WRI/WBCSD GHG Protocol, although the user may enter different emission factors (WRI/WBCSC, 2009).

Emissions associated with the use of fire in forest management: Emissions associated with fire are estimated using methods from IPCC as shown in Table 19.

Table 20. Emission Factors for Open Burning of Biomass (IPCC 2006a, Vol 4., Table 2.5)

	Emissions factors, kg GHG/tonne burned	
	CH_4	N_20
Savannah and grassland	2.3	0.21
Agricultural residues	2.7	0.07
Tropical forest	6.8	0.2
Other Forest	4.7	0.26
Biofuel burning	6.1	0.06

The tonnes burned (usually over a rotation) are calculated using the following equations.

*Non-merchantable above ground biomass = (cubic meters harvested) * (merchantable wood density, dry tonnes/m^3) * (1 - (fraction of above ground biomass that is merchantable wood)) / (fraction of above ground biomass that is merchantable wood)*

The default value for wood density is 0.5 dry tonnes/m^3, which is within the range found in IPCC 2006 guidelines (IPCC 2006a, Vol. 4, Table 4.14). This value can be changed by the user.

The default value for the fraction of above ground biomass that is merchantable wood is 0.7, which is reasonable given the values in IPCC 2006 guidelines (IPCC 2006a, Vol. 4, Tables 4.5 and 4.14).

The user enters a value for the fraction of non-merchantable above ground biomass that is burned on-site, and the emission factors in the table above are then applied to estimate the methane and nitrous oxide emissions associated with the burning.

Emissions associated with the use of chemicals in forest management: There are upstream emissions associated with the production of fertilizers, herbicides, and other chemicals used in some forest operations. In addition, nitrogen-based fertilizers release nitrous oxide after they have been applied. These greenhouse gas emissions can be accounted for by using emission factors from public databases. FICAT has default emission factors developed primarily from the ecoinvent lifecycle database (Swiss Centre for Life Cycle Inventories. (2010). Dubendorf, Switzerland: Swiss Federal Laboratories for Materials Testing and Research) and the U.S. LCI database (USDOE. (2010). U.S. Life-Cycle Database.).

FICAT's default upstream emission factors, which are calculated assuming that electricity is provided from an electricity grid representing the global average grid, are shown in Table 20.

Table 21. Emission Factors for Chemicals Used in Forestry

Chemical	kg CO_2 eq./ dry kg of chemical	Data source
Ammonium nitrate phosphate, as N	4.869	ecoinvent modified for world grid
Ammonium nitrate phosphate, as P_2O_5	1.108	ecoinvent modified for world grid
Ammonium nitrate, as N	8.187	ecoinvent modified for world grid
Ammonium sulphate, as N	2.419	ecoinvent modified for world grid
Calcium ammonium nitrate, as N	8.242	ecoinvent modified for world grid
Calcium nitrate, as N	3.479	ecoinvent modified for world grid
Diammonium phosphate, as N	2.527	ecoinvent modified for world grid
Diammonium phosphate, as P_2O_5	1.433	ecoinvent modified for world grid
Lime, algae	0.158	ecoinvent modified for world grid
Lime, from carbonation	0.009	ecoinvent modified for world grid
Monoammonium phosphate, as N	2.519	ecoinvent modified for world grid
Monoammonium phosphate, as P_2O_5	1.453	ecoinvent modified for world grid
Potassium chloride, as K_2O	0.368	ecoinvent modified for world grid
Potassium nitrate, as K_2O	0.687	ecoinvent modified for world grid
Potassium nitrate, as N	15.417	ecoinvent modified for world grid
Potassium sulphate, as K_2O	1.152	ecoinvent modified for world grid
Single superphosphate, as P_2O_5	2.291	ecoinvent modified for world grid
Stone meal	0.014	ecoinvent modified for world grid
Thomas meal, as P_2O_5	0.619	ecoinvent modified for world grid
Triple superphosphate, as P_2O_5	1.855	ecoinvent modified for world grid
Urea ammonium nitrate, as N	5.533	ecoinvent modified for world grid
Urea, as N	3.127	ecoinvent modified for world grid
[sulfonyl]urea-compounds (e.g., metsulfuron methyl, sulfometuron methyl)	9.400	ecoinvent modified for world grid
2,4-D	3.148	ecoinvent modified for world grid
Glyphosate	16.855	ecoinvent modified for world grid
Pesticide/Herbicide unspecified	7.928	ecoinvent modified for world grid
Triazine-compounds (e.g., hexizinone)	7.936	ecoinvent modified for world grid
Super absorbent polymer (SAP), sometimes used to hold water around newly planted trees	3.120	https://lifecycleinitiative.org/wp-content/uploads/2021/03/UNEP-D003-Nappies-Report_lowres.pdf

For all nitrogen-containing chemicals, except [sulfonyl]urea-compounds and triazine-compounds, an emission factor was also developed to account for the emission of nitrous oxide after use. The factor was based on the IPCC assumption that 1% of the nitrogen is released as nitrous oxide (IPCC 2006a, Vol. 4, Table 11.1). The nitrous oxide emissions were then converted to CO_2 equivalents by multiplying by 298, the global warming potential of nitrous oxide in the 2006 IPCC Fourth Assessment Report (IPCC 2007). The resulting factors are shown in Table 21.

The user enters information on the quantities of these chemicals used and FICAT calculates the emissions using the emission factors in these two tables.

Table 22. Nitrous Oxide (N_2O) Emissions Associated with Chemicals Sometimes Used in Forestry Operations

Chemical	N_2O emissions kgCO_2 eq./kg chemical
Ammonium nitrate phosphate, as N	9.37
Ammonium nitrate phosphate, as P2O5	1.44
Ammonium nitrate, as N	9.37
Ammonium sulphate, as N	9.37
Calcium ammonium nitrate, as N	9.37
Calcium nitrate, as N	9.37
Diammonium phosphate, as N	9.37
Diammonium phosphate, as P2O5	3.66
Lime, algae	0.00
Lime, from carbonation	0.00
Monoammonium phosphate, as N	9.37
Monoammonium phosphate, as P2O5	1.98
Potassium chloride, as KCl	0.00
Potassium nitrate, as K2O	0.00
Potassium nitrate, as N	9.37
Potassium sulphate, as K2O	0.00
Single superphosphate, as P2O5	0.00
Stone meal	0.00
Thomas meal, as P2O5	0.00
Triple superphosphate, as P2O5	0.00
Urea ammonium nitrate, as N	9.37
Urea, as N	9.37
[sulfonyl]urea-compounds (e.g., metsulfuron methyl, sulfometuron methyl)	0.00
2,4-D	0.00
Glyphosate	0.00
Pesticide/Herbicide unspecified	0.00
Triazine-compounds (e.g., hexizinone)	0.00
Super absorbent polymer (SAP)	0.00

6.3 Recovered Fiber

Transport-related emissions, emissions associated with collection and sorting, and emissions associated with virgin manufacturing operations, are the main emissions associated with producing recovered fiber. In FICAT, transport-related emissions are dealt with in a separate part of the tool and, consistent with the GHG Protocol Scope 3 Standard for corporate GHG inventories (WRI and WBCSD 2011), a simplifying default assumption is made that virgin manufacturing emissions are not passed through to the user of recovered fiber. Collection and sorting emissions are neglected. Therefore, emissions related to the production of recovered fiber are assumed to be zero, although this can be changed by the user.

In some, but not many, life cycle studies, a fraction of the loads associated with the original production of the virgin fiber is assigned to the recovered fiber in recognition of the fact that recovered fiber is a raw material just like other raw materials and has upstream loads associated with its production. Recovered fiber is a useful raw material only because a virgin mill expended the mechanical and chemical energy needed to convert the tree into individual fibers. To simplify the calculations, FICAT allocates zero loads from virgin manufacturing to recovered fiber, but this should not be interpreted as a general endorsement of this approach. If the user has an emission factor reflecting the pass-through of the recovered fiber's share of virgin production emissions, this factor can be entered by the user. If this is done, the user may want to adjust the emissions associated with virgin fiber production to reflect emissions that are "exported" with used paper that is recovered for reuse elsewhere in FICAT.

6.4 Non-Wood Fiber

Companies will need to develop their own emission factors for non-wood fibers if non-wood fibers are used as a significant fiber source.

7.0 EMISSIONS: OTHER RAW MATERIALS/FUELS

Although most of the mass of raw materials used in forest products manufacturing is wood fiber, other raw materials are also often used. These materials, as well as fossil fuels, are associated with their own upstream emissions. These emissions are assumed to be indirect in FICAT.

7.1 Fossil Fuels

All upstream CO_2 emission factors associated with fossil fuels were obtained from the Argonne National Lab GREET.NET model (2021) except for coal which was obtained from the U.S. LCI Database (NREL 2021). The factors used in FICAT are shown Table 22. Emissions are calculated by multiplying these factors by the amounts of fuel entered by the user in the "Emissions – Manufacturing" element of FICAT. It is important to note that in cases where the user directly enters emissions quantities in this element of FICAT, FICAT cannot calculate upstream emissions associated with fossil fuels because the amounts of specific fuels are not known. Therefore, the upstream emissions associated with directly entered combustion emissions from fossil fuels are estimated from the upstream emissions associated with fuels entered in the model. The combustion related emissions entered directly (without specifying fuels) are multiplied by a factor equal to the upstream emissions from fuels entered in the model divided by the combustion related emissions from those fuels. In cases where the user has entered no fuels, FICAT calculates fuel-related upstream emissions assuming a ratio of upstream emissions to combustion-related emissions equal to that for natural gas. Because upstream emissions are subject to high uncertainty, with CH_4 and N_2O representing relatively small contributions that are also subject to high uncertainty, the factors in the table below represent CO_2 emissions only. The omission of CH_4 and N_2O in these factors will have an inconsequential impact on

FICAT results given the conservative methodology approach FICAT uses to estimate combustion related emissions, as discussed above.

Table 23. Upstream (Pre-Combustion) Emission Factors for Fossil Fuels Used in FICAT

Fuel	Pre-Combustion Emission Factor (kg CO_2 eq./GJ LHV)	Also used for
Pulping liquors	0.00 [a]	Municipal solid waste (MSW), Wood and wood waste
Coal	6.10[b]	All coals (incl. lignite), coal tar, coal coke, coke gas, peat
Natural gas	4.14[c]	
Distillate oil	12.28 [c]	Including low-sulfur diesel, gasoline, kerosene)
Kerosene	8.43 [c]	Jet fuel
Gasoline / petrol	11.97 [c]	Blend-stock gasolines
Residual fuel oil	9.34 [c]	Including No.5 and No.6 fuel oil, lubricants, Waste oils, Tires and tire derived fuel
LPG	9.30 [c]	Propane
Petroleum coke	9.86 [c]	

[a]These materials are considered waste for purposes of upstream emissions and use the cutoff method to assign no upstream emissions when upcycled for energy production. [b]0.161 kg CO_2 eq./kg, assuming 26.4 GJ LHV/tonne (API 2009, Table 3-8). [c]Factors from Argonne National Labs GREET.NET 2021 model.

7.2 Other Raw Materials

The user is given a choice between (1) using a FICAT default emission factor to represent the upstream emissions associated with a typical recipe of chemical inputs, and (2) developing a product-specific factor reflecting the actual chemical usage associated with the manufacture of the company's product.

7.2.1 Default emission factors for generic product types

To estimate the upstream emissions associated with non-fiber, non-fuel inputs, NCASI developed lists of the amounts of various inputs used in paper, paperboard, market pulp and panel production. The lists for paper, paperboard and market pulp were supplied by Fisher International, based on their proprietary database (Fisher International 2008). The lists included all non-fuel non-fiber inputs representing at least 1% of total the total mass of all mill inputs. In several cases, these lists were lengthened to include additional chemicals, based on expert judgment and consultation of the ecoinvent life cycle database (Swiss Center for Life Cycle Inventories 2010). The inputs to panel manufacturing (primarily resins), and the upstream greenhouse gas emissions for the lists of inputs for pulp, paper, market pulp, and panel manufacturing were obtained from the ecoinvent database. The were obtained from the ecoinvent database. From this, an emission factor was derived expressed in units of kg CO_2 eq. per tonne of product. In a few instances, NCASI relied on information from other sources to derive these factors. Given the large uncertainty associated with applying these factors to specific products, the factors were rounded to one significant figure.

Emissions are estimated by multiplying the factors listed in Table 23 by the amounts of each product entered by the user in the "Carbon in Products" element of FICAT. Upstream emissions associated with chemicals used to make downstream products not listed in the "Carbon in Products" element of FICAT are not included in the calculations. This may occur where FICAT is used by a market pulp mill because in this case the upstream emissions associated with chemicals used to make paper from the market pulp will not be included.

The emission factors in FICAT for upstream emissions associated with non-fiber, non-fuel raw materials are shown in the following table. Note that the user must enter values for tissue and toweling.

If the user has other sources of information on the total upstream emissions associated with non-fiber, non-fuel inputs to manufacturing (for example, from a previous life cycle study), a different value may be substituted for the FICAT default. If the user knows the inputs to manufacturing, this information may be used to develop an accurate product-specific factor as described below.

[Note: In earlier versions of FICAT, the upstream emissions associated with market pulp were bundled into the emission factors for non-integrated paper and paperboard production. To prevent double counting, the market pulp-related emissions have been removed from these bundled factors in versions 1.3 and later of FICAT. Where market pulp is used, market pulp emissions should be accounted for by entering market pulp as one of the products in Element 2, and entering market pulp related emissions in Elements 3, 5 and 6.]

7.2.2 Product-specific factors reflecting actual chemicals used in each product

Where the user has information on the types and amounts of chemicals used in manufacturing, it is far better to develop a product- or mill-specific emission factor reflecting actual chemical usage. To accomplish this in FICAT, the user selects chemicals from a drop-down window, indicates how much is used per year, and FICAT multiplies this by an emission factor to calculate the annual emissions associated with producing those chemicals. If the user has an emission factor for a specific chemical input, it may be used in place of the default values in FICAT, which are from ecoinvent, adjusted to reflect electricity from a global average grid (Swiss Centre for Life Cycle Inventories. (2010). ecoinvent lifecycle database. Dubendorf, Switzerland: Swiss Federal Laboratories for Materials Testing and Research). The chemicals and emission factors in FICAT are shown in Table 24.

Table 24. Generic Upstream Emissions Associated with Non-Fiber, Non-Fuel Raw Materials

Product Type	Specific Product	Upstream emissions, $kgCO_2$/tonne product
Poles	Poles	0
Preserved poles	Poles treated with creosote	700
Sawn Timber	Sawn timber	0
Preserved timber	Timber treated with preservative (not creosote)	50
Engineered wood	Glue laminated timber, indoor	100
Engineered wood	Glue laminated timber, outdoor	200
Engineered wood	Laminated timber element, outdoor	400
Engineered wood	Three layered laminated board	200
Panel	Particle board, indoor (680 kg/m3)	200
Panel	Particle board, outdoor (680 kg/m3)	300
Panel	OSB (650 kg/m3)	200
Panel	Cement-bonded particleboard (1200 kg/m^3)	500
Panel	Fiberboard, MDF (300 kg/m^3)	200
Panel	Fiberboard, MDF (780 kg/m^3)	200
Panel	Fiberboard, MDF (900 kg/m^3)	200
Panel	Plywood, indoor (500 to 800 kg/m^3)	100
Panel	Plywood, outdoor (500 to 800 kg/m^3)	200
Panel	Wood wool insulation board, cement bonded (450 kg/m^3)	400
Market pulp	Deinked market pulp	200
Market pulp	ECF market pulp	200
Market pulp	TCF market pulp	100
Market pulp	Unbleached kraft market pulp (assumed to be the same as linerboard)	20
Market pulp	Deinked	400
Paper	Coated mechanical grades	200
Paper	Coated woodfree - integrated	300
Paper	Coated woodfree – nonintegrated (not including market pulp-related emissions)	200
Paper	Uncoated mechanical grades	60
Paper	Supercalendered mechanical grades	80
Paper	Newsprint, 0% DIP	60
Paper	Newsprint, 100% DIP	90
Paper	Unbleached kraft paper, coated and uncoated	20
Paper	Uncoated woodfree - integrated	100
Paper	Uncoated woodfree – nonintegrated (not including market pulp-related emissions)	200
Paperboard	Recycled corrugating medium	40
Paperboard	Semichemical corrugating medium with virgin fiber	40
Paperboard	Recycled linerboard	30
Paperboard	Kraft linerboard	20
Paperboard	Recycled boxboard, coated and uncoated	50
Paperboard	Solid unbleached kraft board, coated and uncoated	90
Paperboard	Bleached kraft board, coated and uncoated	200
Tissue and Toweling	All	User entered

SOURCE: These emission factors were developed by NCASI using a variety of data sources.
NOTE: These emission factors were not updated in FICAT 1.4. Hence, they are likely conservative.

Table 25. Upstream Emissions Associated with Chemicals Used in Manufacturing

Chemical Name	kg CO_2 eq./ dry kg	Data Source
AKD sizer	2.5207383	ecoinvent modified for world grid
Aluminum sulphate	0.51968319	ecoinvent modified for world grid
Ammonia, liquid	2.019467	ecoinvent modified for world grid
Biocides, unspecified	4.0797121	ecoinvent modified for world grid
Carbon dioxide	0.80113844	ecoinvent modified for world grid
Carboxymethyl cellulose (CMC)	4	Adapted from ecoinvent
DAS-1, fluorescent whitening agent triazinylaminostilben type	11	Adapted from ecoinvent
Fluorescent whitening agent distyrylbiphenyl type	22	Adapted from ecoinvent
Coating powder	7.5606471	ecoinvent modified for world grid
Deinking emulsion	0.81876753	ecoinvent modified for world grid
Optical brighteners	16.44233	ecoinvent modified for world grid
Pigments, unspecified	0.10851527	ecoinvent modified for world grid
Pitch despergents	1.0583126	ecoinvent modified for world grid
Printing colour, offset, solvent-based	1.7323197	ecoinvent modified for world grid
Printing colour, rotogravure, solvent-based	2.6556722	ecoinvent modified for world grid
Retention aids	2.7224289	ecoinvent modified for world grid
Rosin size	1.5663534	ecoinvent modified for world grid
Toner, black, powder	6.0730739	ecoinvent modified for world grid
Toner, black, including the cartridge	48.040019	ecoinvent modified for world grid
Toner, colour, powder	6.3309584	ecoinvent modified for world grid
Toner, colour, including cartridge	45.423137	ecoinvent modified for world grid
DTPA	4.8107386	ecoinvent modified for world grid
EDTA	4.8107386	ecoinvent modified for world grid
Fatty acids	2.0368063	ecoinvent modified for world grid
Ground calcium carbonate (GCC)	0.020447049	ecoinvent modified for world grid
Hydrochloric acid (HCl)	0.85656868	ecoinvent modified for world grid
Hydrogen peroxide (H_2O_2)	1.1279307	ecoinvent modified for world grid
Isopropanol (isopropyl alcohol)	1.7946732	ecoinvent modified for world grid
Kaolin (clay)	0.21924275	ecoinvent modified for world grid
Latex	2.63	ecoinvent modified for world grid
Limestone, at mine	0.001784901	ecoinvent modified for world grid
Methanol	0.74732397	ecoinvent modified for world grid
Nitric acid	3.1018956	ecoinvent modified for world grid
Oxygen, liquid	0.48166558	ecoinvent modified for world grid
Phosphoric acid	1.2903253	ecoinvent modified for world grid
Quicklime (lime, CaO)	1.0064599	ecoinvent modified for world grid
Sulfur dioxide	0.39873842	ecoinvent modified for world grid
Soap	1.6880499	ecoinvent modified for world grid
Borax	1.7064562	ecoinvent modified for world grid
Sodium carbonate (Na_2CO_3)	1.0975214	ecoinvent modified for world grid
Sodium chlorate (NaClO3)	3.6563215	ecoinvent modified for world grid
Sodium hydroxide (NaOH)	1.2012639	ecoinvent modified for world grid
Sodium dithionite (hydrosulfite, $Na_2S_2O_4$)	3.5629278	ecoinvent modified for world grid
Sodium hypochlorite (NaOCl)	0.88764455	ecoinvent modified for world grid
Sodium silicate (Na2SiO3)	1.5295925	ecoinvent modified for world grid
Sodium sulfate (Na2SO4)	0.47696278	ecoinvent modified for world grid
Starch, corn	1.2120825	ecoinvent modified for world grid
Starch, potato	0.71171688	ecoinvent modified for world grid
Sulfuric acid	0.089763527	ecoinvent modified for world grid
Talc	0.030415572	ecoinvent modified for world grid
Titanium dioxide (TiO2)	4.6024953	ecoinvent modified for world grid
Urea, as N	3.127482	ecoinvent modified for world grid
Wood adhesives	5.9	CPM database
Purchased precipitated calcium carbonate (PCC)	0.322	Estimated based on mass/energy balances
Wax	0.543	U.S. LCI database, data gaps filled using ecoinvent
Varnish, water-based		ecoinvent modified for world grid
Varnish, solvent-based	3.7	http://www.sveff.se/Branschinformation/LCA_eng.pdf
Wood preservative, creosote	1.6	ecoinvent modified for world grid
Wood preservative, inorganic salt, chrome-containing	2.62	ecoinvent modified for world grid
Wood preservative, organic salt, chrome-free	3.23	ecoinvent modified for world grid

8.0 EMISSIONS - PURCHASED ELECTRICITY AND STEAM

This element of FICAT addresses greenhouse gas emissions associated with purchased electricity and steam. These emissions are, by definition, indirect emissions: i.e., they are released from sources that you do not own or control. Because these purchases almost always involve electricity or steam, only these are mentioned in the material below, but the concepts apply to purchased heat and hot or chilled water as well.

To account for value chain emissions, the user needs to include emissions associated with purchased electricity and steam used by the following manufacturing activities.

- Purchased electricity or steam used in primary and intermediate manufacturing (e.g., the production of pulp, paper and paperboard, lumber, panels, etc.)
- Purchased electricity or steam used in secondary manufacturing, sometimes called converting (the conversion of primary products into final products, e.g., boxes, cartons, newspapers, magazines, furniture, houses, etc.)

The user should include facilities that are owned/controlled and those that are not. For instance, if the user manufactures book paper from purchased pulp, in addition to emissions associated purchased electricity, the user must include the upstream emissions associated with electricity purchased by the pulp manufacturer and the emissions associated with electricity required for printing and book production.

Emissions associated with electricity or steam purchases at facilities owned or controlled by the user are Scope 2 emissions and emissions associated with electricity purchases at other facilities are Scope 3 emissions as defined by the WRI/WBCSD GHG Protocol Corporate Accounting and Reporting Standard (WRI and WBCSD 2004).

For sources where the user has information on electricity or steam purchases, FICAT can calculate the emissions for the user. This is done by selecting the tab labeled “Indirect Emissions from Electricity and/or Steam Imports” and then entering the type of energy purchased.

For purchased steam, the user can use the drop-down menu in the “Country generated” box to retrieve a default emission factor for that country. The default factors are from “IEA (2021), Emission Factors” by International Energy Agency Data Services. Alternatively, the user can use an emission factor obtained from the seller of the steam or one calculated using the CHP calculator or custom emission factor calculator based on fuels and technologies used to generate the purchased steam. The user inserts the emission factor in the “CO_2 emissions factor” box in the upper right of the screen. Where the steam is purchased from a combined heat and power (CHP) system, the calculator on the “CHP Emissions Allocation Tool” tab may be helpful in developing this emission factor. See below for more information on these tools.

For purchased electricity, the user may use the drop-down menu in the “Country generated” box to retrieve a default emission factor for that country. The default factors are from “IEA (2021), Emission Factors” by International Energy Agency Data Services . The user may enter a different value, however, if the emission factor associated with the purchased electricity is known. Where electricity is purchased from a CHP system, the calculator on the “CHP Emissions Allocation Tool” tab may be helpful in developing an emission factor for this purchased electricity. The CHP Emissions Allocation Tool is discussed in more detail below.

The calculations are as follows.

*Emissions due to imported electricity or steam in CO_2 eq/yr = Amount imported * Emission factor associated with imported energy*

Where

Amount imported is the amount of electricity or steam that is imported in MWh/yr

Emission factor associated with imported energy, in kg CO_2 eq/MWh, is provided by the user, although default emission factors for different countries are provided via a drop-down window. The default factors are from “IEA (2021), Emission Factors” by International Energy Agency Data Services*.*

Where the user is lacking information on the purchased electricity required in primary manufacturing, the following defaults can be used to estimate purchased electricity and manually entered into the tool.

Table 26. Default Electricity Intensity per Product Category

Production Category	Net Electricity Intensity (MWh/admt)
Chemical market pulp mill	-0.01
Integrated bleached chemical pulp and paper/paperboard mill	0.36
Integrated unbleached chemical pulp and paper/paperboard mill	0.26
Integrated mechanical pulp and paper	1.30
Recycled paperboard or containerboard mill	0.62
Non-integrated paper/paperboard mill using primarily purchased pulp	0.68
Deinked market pulp	1.26
Lumber – not dried	0.3
Lumber – dried	0.3
Structural panels (e.g., plywood and OSB)	0.4
Non-structural panels (e.g., particleboard and MDF)	1
* These values are larger than for most facilities in these categories and have been selected to give the user incentive to obtain actual emissions data from emissions sources.	

If the user is lacking data on purchased electricity used in secondary manufacturing, one can assume that it is 15% of the purchased electricity required in primary manufacturing. This assumption, however, is based on studies of the emissions associated with secondary manufacturing and it is not known if it applies specifically to purchased electricity.

The CHP Emissions Allocation Tool

In some cases, steam that is generated for electricity production is also used as a source of process heat. Such systems are called combined heat and power (CHP, sometimes called cogeneration) systems. Most commonly in CHP systems, the steam is passed through a turbine to produce electricity and then used in manufacturing or district heating. Pulp mills are among the leaders in the use of CHP. In most cases, the pulp mill uses all the steam and electricity that is produced by CHP systems so there is no need to divide the emissions between the steam and the electricity since the mill reports all the emissions as direct emissions. A situation where it is necessary to divide the emissions between the electricity and the steam arises when the mill is purchasing only part of the energy output of a CHP system owned by another entity. A typical example would be an electrical power generation plant that sells most of its electricity to the grid but also sells steam and electricity to a nearby mill. In such a case, the mill needs to know the emission factor to apply to the steam and electricity it purchases. Another case where the user will need to allocate CHP emissions is when the mill is exporting electricity from a CHP system; a situation discussed in the "Emissions – Avoided" element of FICAT.

There are several methods for allocating emissions to the various energy outputs of CHP systems. FICAT uses the efficiency method. This method is the default method in the WRI/WBCSD GHG Protocol Calculation Tools for Pulp and Paper Mills. It allocates emissions to electricity and steam by estimating how much fuel was required to produce each, based on assumptions about the relative efficiencies associated with steam and electricity production.

To use the Tool, the user first enters the total fuel input to the CHP system, the steam output, the electricity output of the CHP system, and the total emissions from the CHP system. The Tool then calculates the range of values possible for the ratio = heat production efficiency/electricity production efficiency. The tool includes a default ratio of 2.3, which corresponds to a heat production efficiency of 80% and an electricity production efficiency of 35%. The user may enter any ratio that falls within the acceptable range shown in the Tool. The emission factors shown in the Tool for steam production and electricity production can then be used on the tab labeled "Indirect Emissions from Electricity and/or Steam Imports."

The calculations are as follows:

User enters; *CHP Heat output (district heat, process heat, other steam), MWh/yr*

CHP Power output (electricity), MWh/yr

Total Fuel input, MWh/yr

Total emissions from CHP facility, tonnes CO_2 eq. /yr

This information establishes an energy balance around the CHP system that constrains the calculations by limiting the ratio of the efficiencies of production of heat and electricity that can be used in the rest of the calculations. The calculator shows the user the minimum and maximum values allowed for the value; Heat production efficiency/Electricity production efficiency. The minimum and maximum values are calculated as follows.

Minimum value for (Heat production efficiency/Electricity production efficiency) = CHP Heat output / (Total Fuel input – CHP Power output)

Maximum value for (Heat production efficiency/Electricity production efficiency) = (Total Fuel input - CHP Heat output) / CHP Power output

The user then enters a "S*elected value for (Heat production efficiency/Electricity production efficiency*" from within this range. In the following calculation, this is simply called "*Selected value*."

The resulting emission factors for heat (e.g., steam) production and electricity production are then calculated as follows.

*Emission factor for heat production (kg CO_2/MWh) = (Total emissions from CHP facility * 1000) / (CHP Heat output + (CHP Power output * Selected value))*

*Emission factor for electricity production (kg CO_2/MWh) = [Total emissions from CHP facility- (Total emissions from CHP facility * (CHP Heat output/ (CHP Heat output+ (CHP Power output * Selected value))))] * (1000/ CHP Power output)*

These values are manually entered where needed in the "Emissions – Electricity, steam and heat" calculations and the "Emissions – Avoided" calculations as needed.

9.0 EMISSIONS: TRANSPORTATION

This element of FICAT estimates the emissions associated with the transport of raw materials (e.g., wood and recovered paper), intermediate materials (e.g., large rolls of paper), final products to users (normally, retail outlets), and employees.

The model calculates emissions based on the distance material is transported. If the transport vehicle returns empty the user should include the return trip in the miles entered in the calculation. This will yield an estimate of emissions that is biased high because the fuel use for an empty vehicle is less than for a fully loaded vehicle.

The emission factors used in FICAT are shown in

Table 27. These factors are multipled by the weight of product, or number of passengers, per year, and transport distance entered by the user. Version 1.4 of FICAT includes some updated factors from publicly available data.

In FICAT, the user indicates whether the transport-related emissions are direct or indirect.

The emissions are grouped by raw materials, intermediate products and final products.

Table 27. Transportation Activity GHG emission factors in FICAT Version 1.4

Transport description	Emission factor Kg CO_2/(km*tonnes) or Kg CO_2/(km*persons)
Coal Locomotive (from FICAT 1.2.0.3)	0.026
Diesel Locomotive	0.0117‡
Electric Locomotive (from FICAT 1.2.0.3)	0.040
Freight: Air – Domestic Freight	0.5404‡
Freight: Air - Long Haul Freight	0.5404‡
Freight: Air - Short Haul Freight	1.439
Freight: Rail Freight	0.0117‡
Freight: Road Freight	0.0715‡
Freight: Watercraft - Large RoPax Ferry	0.384
Diesel Barge Inland Shipping by Water	0.0085‡
Ocean Container Marine shipping	0.008‡
Passenger: Air - Long Haul - Business Class	0.255
Passenger: Air - Long Haul - Economy Class	0.088
Passenger: Air - Long Haul - Economy+ Class	0.141
Passenger: Air - Long Haul - First Class	0.352
Passenger: Air - Short Haul - Economy Class	0.102
Passenger: Air - Short Haul - First/Business Class	0.153
Passenger: Bus	0.066
Passenger: Large RoPax Ferry	0.115
Passenger: Taxi	0.143
Passenger: Train	0.101
Passenger: Watercraft - Freight Vessel	0.055
Diesel Semi-Trailer Road Freight	0.0715‡

‡Emission factors are updated in this aversion of FICAT, are derived from the Argonne National Lab's GREET.NET model (2021), and include fossil-based CO_2, CH_4, and N_2O. CO_2 equivalents for these factors are calculated using GWPs from IPCC's sixth Assessment Report (IPCC AR6). These updated factors should be preferentially used when possible. All other factors are from the WRI/WBCSD Greenhouse Gas Protocol Calculation Tool Spreadsheet: Mobile Combustion Tools (versions 1.3, 2.0) and are kept in FICAT at this time to allow backward compatibility of previous versions of the tool.

10.0 PRODUCTS IN USE

The emissions during product use are almost always zero for forest products. It takes no energy to use a piece of paper. When a shipping container is transported, the transport vehicle is the emitting source. Even in the case of wood products used in housing, energy consumption and emissions are not assigned to the individual building products but rather to the entire structure or to the energy-using appliances associated with the structure.

There is one type of product, however, that emits greenhouse gases during use: biomass energy products. Although the CO_2 released during biomass combustion is not included in greenhouse gas totals, the CH_4 and N_2O released in the combustion of biomass are included in greenhouse gas emission totals. FICAT estimates these emissions as follows.

*Emissions from burning Biomass Energy Products (tonnes CO_2 eq./yr) = Dry tonnes of Biomass Energy Product sold per year * 0.03 [Note: This value changes slightly depending on the GWPs selected by the user.]*

This factor (0.03) has been developed based on the following assumptions.

Product heating value = 15.6 GJLHV/tonne (assumed equal to wood; from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Volume 2 Energy, Chapter 1)

Emission factor of 1.94 kg CO_2 equivalents in CH_4 and N_2O emissions per GJ LHV, which is taken from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Volume 2 Energy, Chapter 2 Stationary Combustion. This value changes, however, to reflect the GWPs selected by the user.

In FICAT, the user divides these emissions into direct and indirect emissions reflecting the degree of ownership/control the user has over the emissions sources.

Also, the user is asked whether these emissions have been entered elsewhere in FICAT. This may occur, for instance, if a biomass energy product is used by a facility elsewhere in the value chain so that the emissions are reported under manufacturing-related emissions.

These emissions are not included in cradle-to-gate inventories.

11.0 EMISSIONS: END-OF-LIFE

In cradle-to-grave inventories, this element of FICAT displays the results of estimates of greenhouse gas emissions associated with the end-of-life of the forest products and the manufacturing waste described in the “Carbon in Products” element of the model. In cradle-to-gate inventories, only the emissions associated with manufacturing wastes are shown.

To change any of the parameters affecting end-of-life calculations, the user must return to the “Carbon in Products” element. There are no end-of-life emissions calculated for biomass energy products although emissions from manufacturing wastes associated with biomass energy products (e.g., pellet production) are included where appropriate. The only parameter entered in this part of FICAT is selection of whether the emissions are direct or indirect, reflecting the ownership/control of the sources by the user.

At the end of its useful life, wood fiber (and manufacturing waste) is usually either recycled, burned, or landfilled. The burning of used products releases biogenic CO_2 that is not included in greenhouse gas emission totals. Biomass burning releases CH_4 and N_2O, but the amounts are small relative to other emissions addressed in this model, so they are not included in the end-of-life calculations. (Note: These emissions are estimated, however, for biomass that is produced expressly as a biomass energy product, but these emissions are included in the “Emissions: Product Use” elements of FICAT.)

In landfills, a portion of the biomass in forest products (and landfilled waste) decays, primarily into gas. This fraction varies by type of product. Under anaerobic conditions, about one-half of the carbon is converted to biogenic CO_2 while the other half is converted to CH_4. This is important because, originating from a non-fossil source,CH_4 is 27.2 times more potent than CO_2 as a greenhouse gas over a 100-year period (IPCC, 2021). Under aerobic conditions (e.g., in shallow unmanaged landfills) a much smaller fraction of the gas consists of CH_4. FICAT uses the IPCC factors to adjust methane generation to reflect the extent of anaerobic conditions in different types of landfills. (For IPCC's descriptions of these types of landfills, see the section above on "carbon in products."

Table 28. Methane Correction Factors used in FICAT (IPCC 2006a) *

Type of Site	Factor
Managed – anaerobic	1.0
Managed - semi-aerobic*	0.5
Unmanaged - deep (>5 m)	0.8
Unmanaged - shallow (<5 m)	0.4
Uncategorized SWDS	0.6

*Some of the 2006 values were updated in IPCC's 2019 Refinements to the reporting guidelines. The "Managed – semi-aerobic" category is called "Managed well – semi-aerobic" landfills. A new category, "Managed poorly- semi-aerobic, is given an MCF of 0.7. In addition, in 2019 IPCC added two other categories, "Managed well- active aeration" and "Managed poorly – active aeration", having MCFs of 0.4 and 0.7, respectively. (IPCC 2019)

The other key factor influencing the release of landfill methane to the atmosphere is the extent to which CH_4 is oxidized to biogenic CO_2 before exiting the landfill. Even in the absence of systems designed to capture and destroy methane, about 10% of the methane is oxidized as it moves through the surface layers of the landfill (IPCC 2006c). This is used as a default in FICAT. FICAT assumes that landfills are not equipped with cover systems to capture and destroy methane. As a result, the FICAT default is that no methane is captured and destroyed. However, since some landfills have such systems, FICAT allows this assumption to be overridden by the user. In landfills with cover systems to collect and destroy methane by burning, it is often assumed that 75% of the methane is collected and destroyed (e.g., see U.S. EPA 2020c).

The information entered in the "Carbon in Products" element of FICAT determines the parameter values to use in making the estimates shown in this element.

The calculations done to develop the results shown in this element of FICAT are shown below.

<u>Methane emissions associated with used products in landfills</u>

The calculations are as follows.

*Quantity of carbon converted to gas under anaerobic conditions = (Quantity of product manufactured – Quantity of carbon remaining in use for 100 years) * (Fraction of used product landfilled) * (Fraction carbon in product) * (1-Fraction of carbon permanently stored under anaerobic conditions) * MCF*

*Quantity of carbon converted to methane = Quantity of carbon converted to gas under anaerobic conditions * 0.5*

*Quantity of carbon in methane not oxidized naturally in cover systems = Quantity of carbon converted to methane * (1 – fraction uncollected methane oxidized)*

(As noted above, IPCC's default for uncollected methane oxidized in the 2006 guidelines is 0.1)

*Quantity of carbon in methane released to the environment = Quantity of carbon in methane not oxidized naturally in cover systems * (1-Fraction of generated methane that is collected and burned)*

(Note: the *Fraction of generated methane that is collected and burned* is entered by the user and can be estimated off-line by multiplying the fraction of landfills with methane capture systems by 0.75, which, as noted above, is a common default assumption regarding the efficienty of methane capture and combustion systems.)

*Quantity of methane released to the environment = Quantity of carbon in methane released to the environment * 16/12*

*CO_2 equivalents in methane released to the environment = Quantity of methane released to the environment * [user-selected methane GWP]*

<u>Methane from mill wastes in landfills</u>

These calculations are shown below.

*Quantity of mill waste carbon converted to gas under anaerobic conditions = (Quantity of mill waste) * (fraction of carbon in mill waste) * (fraction of mill waste landfilled) * (1-Fraction of carbon in parent product permanently stored under anaerobic conditions) * (mill landfill MCF)*

*Quantity of mill waste carbon converted to methane = Quantity of mill waste carbon converted to gas under anaerobic conditions * 0.5*

*Quantity of mill waste carbon in methane released to the environment = Quantity of mill waste carbon converted to methane * (1 – fraction uncollected methane oxidized)*

(As noted above, the default for uncollected methane oxidized is 0.1. The default in FICAT is that landfills receiving mill waste do not have methane collection and burning systems but this can be overridden by the user.)

*Quantity of mill waste methane released to the environment = Quantity of mill waste carbon in methane released to the environment * 16/12*

*CO_2 equivalents in mill waste methane released to the environment = Quantity of mill waste methane released to the environment * [user-selected methane GWP]*

12.0 EMISSIONS - AVOIDED

In this part of FICAT, the user is shown the estimates of several types of avoided emissions and given the opportunity to enter the results of estimates that may have made of additional avoided emissions.

Avoided emissions are fundamentally different from the emissions, carbon stocks, and flows examined in elements 1 through 9 in FICAT. Elements 1 through 9 involve actual movements of material into and out of the atmosphere or through the value chain. Avoided emissions are different in that they only exist relative to a hypothetical scenario that was avoided due to a particular action. Avoided emissions can be controversial because people may disagree with the validity of the scenario that was claimed to have been avoided.

FICAT estimates only three types of avoided emissions; those associated with (a) recycling, (b) exporting “green” electricity, and (c) burning used products and biomass energy products for energy. These are among the least controversial avoided emissions, although there are elements of the calculations that remain open to debate. These are explored in more detail below.

There are other types of avoided emissions that may be important for specific situations. Wood-based building products, for instance, may displace more greenhouse gas-intensive materials, avoiding emissions in the process. To allow for such situations, FICAT provides a space for users to enter additional avoided emission estimates and descriptions.

In all cases, because avoided emissions are different from the other estimates in FICAT, they are reported separately in FICAT.

12.1 Avoided Emissions Associated with Recycling

Recycling has extremely complex effects on greenhouse gas emissions and carbon sequestration. Among the factors to be considered in estimating avoided emissions attributable to recycling are the following.

- The methane from landfills that is avoided by recycling
- The carbon storage in landfills that is avoided by recycling
- The biomass energy precluded by recycling (i.e., use products not available for biomass energy)
- The difference in GHG intensity of virgin vs. recycled manufacturing
- The differences in processing and transport requirements for virgin vs. recycled fiber
- The impact of increased use of recovered fiber on forest carbon stocks

There is considerable uncertainty with estimating the effects of these factors. The uncertainty in the first five factors is primarily related to incomplete science (e.g., in degradation rates) and incomplete data (e.g., regarding the transport requirements for virgin vs. recovered fiber). The last factor, the effect of recycling on forest carbon stocks, is also subject to considerable market and economic uncertainty because it depends on how landowners will react to a marginal reduction in demand for pulpwood. A landowner might do any number of things including:

- allow "surplus" trees to continue to grow in hopes of the pulpwood market returning
- thin the stand and allow remaining trees to grow into saw timber
- sell the wood into the biomass energy market instead of the pulpwood market
- convert the land to a use that provides higher economic returns (e.g., agriculture)

These different choices have quite different carbon implications. Some might result in carbon benefits while others would result in carbon losses. Due to this uncertainty, FICAT does not address the effects of recycling on forest carbon.

Where the alternative to recycling is landfilling, studies of this question suggest that in addition to forest carbon effects, the most important factors are those related to methane emissions from, and carbon storage in, landfills. (This is evident, for instance, from a deconstruction of the emission factors developed by USEPA in Solid Waste Management and Greenhouse Gases - A Life-Cycle Assessment of Emissions and Sinks, 3rd Edition, September 2006.")

Consequently, FICAT estimates the avoided emissions from recycling only based on (a) the reduced emissions from landfills, and (b) the reduced carbon in sequestration in landfills. The needed parameter values must be entered in the data entry box that appears when you click on the button at the far right of each row. The calculations are identical to those described above for (a) carbon in products that are placed in landfills, and (b) end-of-life methane emissions. The only difference is that the calculations are performed on the quantities recycled, under the assumption that a user-specified fraction of these would be landfilled if they were not recycled. The user must indicate the characteristics of the landfills that would have received the discarded materials had they not been recycled.

12.2 Avoided Emissions Associated with Burning Used Products and Biomass Energy Products

When used products and biomass energy products are burned for energy, the biomass may displace a greenhouse-gas emitting fossil fuel, thus avoiding those emissions. The amount of avoided emission depends primarily on the type of fossil fuel that is assumed to have been displaced. In FICAT, the user is asked to specify this fuel. The model then uses the information on the fate of used products (entered in the "Carbon in Products" element), or the production of biomass fuel products, to estimate the emissions avoided. These are not calculated for cradle-to-gate inventories.

The calculations are as follows.

*Quantity of material burned = Quantity produced * fraction burned*

Where:

"Quantity produced" is the amount of product manufactured, entered by the user in the Carbon in Use calculations in dry tonnes/yr

And

"Fraction burned" is either 1.0 for biomass energy products or the value entered for "fraction burned for energy recovery" in the "Carbon in Products/End of Life" screen.

*Energy in product burned = Quantity of material burned * Energy content of product*

Where; "Energy content of product" defaults to 15.6 GJ LHV/dry tonne but can be changed by the user (Source, IPCC's 2006 National inventory guidelines, Volume 2, Chapter 1)

*Fossil fuel energy avoided = Energy in product burned * (0.6842/Fossil fuel boiler efficiency)*

Where

0.6842 = assumed efficiency of biomass boiler based on LHV

Fossil fuel boiler efficiency depends on fuel (see table below)

*Fossil fuel CO_2 emissions avoided = Fossil fuel energy avoided * Fossil fuel avoided emissions factor*

Where

Fossil fuel avoided emissions factor depends on fuel (see Table 29*)*

Table 29. Avoided Emissions Factors for Exported Electricity and Steam

Fuel	$Efficiency_{LHV}$	Avoided emission factor kgCO2 eq/GJ LHV*
Anthracite	0.8842	96.490
Bituminous Coal	0.8842	92.790
Sub-Bituminous Coal	0.8842	94.290
Lignite	0.8842	99.190
Residual Oil	0.8632	75.206
Natural Gas	0.8889	53.634

Note: these are different than the combustion factors for each fuel because they have been adjusted to reflect (a) the relative efficiency of burning these fuels compared to biomass and (b) the different emission factors for CH_4 and N_2O when comparing the fuels to biomass. In specific, each fossil fuel emission factor, in terms of CO_2 equivalents, has subtracted from it, the following quantity: 1.94*(Eff for fossil fuel above)/0.6842

Where 1.94 is the CO_2 equivalents in CH_4 and N_2O emissions for biomass fuels *(Source, IPCC's 2006 National inventory guidelines, Volume 2, Chapter 2)* and 0.6843 is the assumed efficiency of biomass boilers in terms of LHV.

FICAT does not estimate the avoided emissions associated with using landfill methane to displace fossil fuels. NCASI has used the U.S.E.P.A. Waste Reduction Model to examine the potential significance of this type of avoided emission and has found that, in the U.S., 88% of the benefit of capturing and burning methane to displace fossil fuel in electricity production is due to the capture and destruction of the methane, a benefit already included in FICAT calculations. The use of methane to displace fossil fuel contributes only 12% of the benefit. It is possible, however, to calculate this benefit off-line and enter it as an additional avoided emission.

12.3 Avoided Emissions Associated with Exports of "Green" Electricity and Steam

Increasingly, mills are investing in electrical generation capacity that allows them to export excess electricity to the grid. In many cases, the greenhouse gas-intensity of this electricity is lower than the electricity it is assumed to displace on the grid. In addition, in northern climates, mills may export steam for use in district heating systems. The lower emissions-intensity of mill-produced electricity or steam can be due to the use of biomass and to the use of CHP systems.

To estimate the avoided emissions associated with exports of electricity or steam the user must have the following information.

- The quantity of electricity or steam exported
- The greenhouse gas intensity of that electricity or steam.
- The greenhouse gas intensity of the electricity or steam that is assumed to have been displaced, although default values are supplied representing the GHG intensity of the grid in different countries.

The calculations are as follows.

*Avoided emissions due to exported electricity or steam in CO_2 eq/yr = Amount exported * Emission factor associated with exported energy/Emission factor associated with the displaced energy)*

Where:

Amount exported is the amount of electricity or steam that is exported in MWh/yr

Emission factor associated with exported energy, in kg CO_2 eq/MWh, is provided by the user

Emissions factor associated with displaced energy, in CO_2 eq/MWh, is provided by the user, although default emission factors for different countries are provided via a drop-down window. The default factors are from "IEA (2021), Emission Factors" by International Energy Agency Data Services.

Features are included that will assist the user in developing greenhouse gas intensity values for the electricity or steam that is exported, or for estimating intensities of electricity or steam that is displaced (along with a set of country-specific utility grid emission factors that can be used if energy is exported to the grid). Another tool within FICAT assists in developing intensity values for combined heat and power systems (CHP, also known as cogeneration) in which both electricity and steam are produced from the same fuel stream. The explanation of the CHP tool is included in the section on "Emissions – Electricity, Steam and Heat" above, and in FICAT, the CHP tool is included in this section of the model.

13.0 SUMMARY

The results of FICAT calculations are summarized on this screen.

If the user has failed to enter text in any of the "notes" boxes, the missing notes are highlighted in red. In addition, the user will be alerted if there is no value for the fraction of the wood used to manufacture products entered in the "carbon in products" element that come from land areas entered in the "land-based carbon" element of FICAT. It is not possible to generate a report without having text in all the notes boxes and answering the "fraction of wood" question.

Options for generating output in FICAT are accessed by clicking on "produce output" at the top of the screen.

14.0 UNCERTAINTY

FICAT is considered a screening-level model when the user relies primarily on default values for carbon stocks and emissions. By examining IPCC documents and other sources, it is possible to suggest uncertainty ranges associated with the use of the default values in FICAT. The uncertainty ranges, like the estimates themselves, are subject to considerable uncertainty but they will help the user interpret the estimates generated by the model. The uncertainty factors for the 10 elements of FICAT, and the methods used to derive them, are described below. Where the user overrides the defaults values in the model, the user should also consider whether the uncertainty factors used in the model should be changed (an option in the model).

14.1 Forest and Other Land-Based Carbon

The 2006 IPCC Guidelines for national inventories of greenhouse gas emissions and sinks contain minimum and maximum values for many of the factors used to estimate forest carbon stocks. The average ranges for the parameters are shown in Table 30. Based on the values shown, default multipliers of 0.5 and 1.75 were selected to convert FICAT mid-range estimates to minimum and maximum range estimates, respectively.

Table 30. Uncertainty Factors Based on IPCC 2006 Guidelines (IPCC 2006a)

Parameter	Average multiplier to convert from the average to the minimum value	Average multiplier to convert from the average to the maximum value
Forests: above ground biomass	0.52	1.65
Forests: Root to shoot ratio	0.85	1.79
Forests: Litter	0.46	1.85
Mineral soil reference carbon stocks	No factor	No factor
Mineral soil factors to convert from reference carbon stocks to actual soil carbon stocks	0.64	1.36
Emission factors for drained organic soils	0.19	2.35
Cropland: biomass	0.79	2.10
Grassland: biomass	0.25	1.75
Factor selected as default in FICAT	0.5	1.75

14.2 Carbon in Products

The IPCC 2006 Guidelines for National Greenhouse Gas Inventories indicate that Tier 1 estimates for carbon storage in products, using the national inventory methods, could have uncertainties of +/-50% or more (IPCC, 2006a). The estimates for carbon storage in products generated by FICAT are likely no more uncertain those developed using Tier 1 national inventory methods. Potential increases in uncertainty associated with the assumptions about the fate of the products (especially for exported products) would likely be offset by the decreased uncertainty in the activity data (e.g. the production rates of specific products). Accordingly, FICAT assumes that the uncertainty in estimates of carbon storage in products is +/-50%.

14.3 Emissions from Manufacturing Facilities

This element addresses only GHG emissions from fossil fuel combustion. These emissions are primarily comprised of CO_2 with smaller contributions from CH_4 and N_2O. (Methane emissions from landfills receiving mill wastes are included in the end-of-life element.) IPCC's 2006 National inventory Guidelines present data suggesting that the uncertainty in fossil fuel emission factors for CO_2 are generally felt to have 95% confidence intervals of +/-5% (IPCC, 2006b). The uncertainty in emission factors for CH_4 and N_2O are much larger (perhaps +/- a factor of 2), but this uncertainty has relatively little effect on the overall calculation since, even on a CO_2 equivalents basis, CH_4 and N_2O typically contribute less than 1% of the emissions from fossil fuel combustion (see the emissions factors in Table 15).

IPCC also notes that countries with good tracking systems can estimate fuel consumption to within +/-2-3%. It is reasonable to assume that individual facilities would be able to do as well for fuel they consume. In some cases, however, estimates will include facilities not owned or controlled by the entity using the model. In these cases, the uncertainty in the estimates is considerably higher.

For FICAT, it is assumed that the user will have to use default values for parts of the value chain which are not under his/her control. Therefore, a combined uncertainty in manufacturing emissions of +/-15% is used.

14.4 Emissions Associated with Producing Wood

The factors in FICAT are known to be subject to considerable uncertainty. For most purposes the results of the uncertainty will be insignificant because these emissions are a relatively small part of value chain emissions. The uncertainty in these factors is due to many factors including (a) the uncertainty in the generation of CH_4 and N_2O in burning, (b) uncertainty in the emissions associated with fertilization, and (c) variability in the specific practices involving the of use of burning and fertilization. Given that the uncertainty in the emission factors for CH_4 and N_2O for fossil fuels is +/- a factor of 2 (see above) it is not unreasonable to assume that the factors in the model for virgin fiber production have an uncertainty of +/- a factor of 4. The uncertainty in the factors for producing recovered fiber are insignificant (not including transport). Where the user enters site-specific information on the use of fuel, fire, and chemicals, the uncertainty in these emissions will be much smaller than the default uncertainty values.

14.5 Emissions Associated with Producing Non-Fiber Inputs

The uncertainties associated with estimates of non-fiber inputs are highly variable. If a company has performed a detailed life cycle inventory based largely on primary data or has entered a list of chemicals into FICAT to develop a product/mill-specific factor, the estimates may be within +/-20% (based on NCASI's professional judgment). If the user relies on the defaults in FICAT, the uncertainties are far larger, probably at least +/- a factor of 2 (again based on NCASI's professional judgment).

14.6 Emissions Associated with Purchased Electricity, Steam, Etc.

The factors that influence the uncertainty in emissions associated with purchased electricity and steam are similar to those associated with estimating manufacturing emissions, except that the uncertainty in the emission factors for purchased electricity and steam are considerably larger than those associated with fossil fuel combustion. Accordingly, for purposes of FICAT, an uncertainty range of +/-25% is used.

14.7 Transport-Related Greenhouse Gas Emissions

National-level estimates for transport-related GHG emissions are generally associated with uncertainties of +/-10% or less. (See, for instance, EPA, 2020b, table 3-17). The estimates derived in FICAT are likely more uncertain than those derived in national inventories, however. There are several reasons for this. First, FICAT emission factors are based on travel distance and freight weight rather than fuel consumption. In addition, the travel distances for parts of the value chain will usually be estimated based on best judgment rather than data. For these reasons, the estimates of transport-related emissions in FICAT are assumed to have an uncertainty of +/-50% unless the user has data on the actual transport distances for raw materials, intermediate products, and final products.

14.8 Emissions Associated with Product Use

The only emissions associated with product use in FICAT are CH_4 and N_2O emissions associated with burning biomass-derived energy products. The CH_4 and N_2O emission factors for fossil fuels have uncertainties of +/- a factor of 2 (see above). The data base for deriving CH_4 and N_2O emission factors for biomass-derived energy products is much smaller and the factors are more uncertain. FICAT assumes that the uncertainty is +/- a factor of 4.

14.9 Emissions Associated with Product End-of-Life

The there is great uncertainty in estimates of methane emissions from landfills associated with decomposing forest products. There are many factors which must be estimated or assumed in the calculations including; the amount of product discarded, the fraction of material landfilled, the type of landfill, the type and effectiveness of the landfill cover, and the fraction of carbon that degrades. The estimates begin with uncertainty in the product carbon calculations, which establish the discard rates and the fraction landfilled, and then add the uncertainty in the other parameters needed to estimate methane generation and release. As noted above it was suggested that estimates of carbon storage in products, based on default assumptions, might be accurate to within +/- 50%. FICAT uses an uncertainty range for methane emissions from landfills of +/- a factor of 3.

14.10 Avoided Emissions

There are many different types of avoided emissions and they can be calculated many different ways. It is not possible, therefore, to make a generic statement about the uncertainty in avoided emission estimates.

REFERENCES

American Petroleum Institute. 2009. *Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Gas Industry*. Z00109. Washington DC: API. https://www.api.org/~/media/files/ehs/climate-change/2009_ghg_compendium.pdf.

Fisher International. 2008. *Fisher International Database*. 50 Water Street, South Norwalk, CT 06854 USA.

Argonne National Laboratory. (2021). GREET: The Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model. [Version 2021]. [Computer software]. Lemont, IL: Argonne National Laboratory. Available from https://greet.es.anl.gov/

IPCC. 2006a. *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (eds.)]. Volume 4 Agriculture, Forestry and Other Land Use. Institute for Global Environmental Strategies. http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html (accessed 09 July 2009).

_____. 2006b. *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (eds.)]. Volume 2 Energy. Institute for Global Environmental Strategies. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_0_Cover.pdf (accessed 09 July 2009)

_____. 2006c. 2006 IPCC Guidelines for National Greenhouse Gas Inventories (eds.)]. Volume 5 Waste. Institute for Global Environmental Strategies. https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html (accessed 06 March 2022)

_____. 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press

_____. 2019. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5, Waste. https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/.

_____. 2021. *AR6 Climate Change 2021: The Physical Science Basis.* Cambridge University Press. In Press. Retrieved from https://www.ipcc.ch/report/ar6/wg1/

Kulay, L.A. and al, e. 2006. *Contribution to the Brazilian Database: Offset paper LCA*. Washington, D.C.:

Markewitz, D. 2006. Fossil fuel carbon emissions from silviculture: Impacts on net carbon sequestration in forests. *Forest Ecology and Management* 236(2):153-161.

Milota, M. and Puettmann, M.E. 2017. Life-Cycle Assessment for the Cradle-to-Gate Production of Softwood Lumber in the Pacific Northwest and Southeast Regions. *Forest Products Journal* 67(5/6):331-342.

National Council for Air and Stream Improvement, Inc. (NCASI). 2004. *Critical Review of Forest Products Decomposition in Municipal Solid Waste Landfills*. Raleight, NC: National Council for Air and Steam Improvement, Inc.

National Renewable Energy Laboratory (NREL). 2008. *U.S. Life Cycle Inventory Database*. https://www.nrel.gov/lci/ .

_____. 2021. *U.S. Life Cycle Inventory Database, FY20.Q4.01*. https://www.lcacommons.gov/nrel/search.

Oneil, E. and Puettmann, M.E. 2017. A Life Cycle Assessment of Forest Resources of the Pacific Northwest, USA. *Forest Products Journal* 67(5/6):316-330.

Sonne, E. 2006. Greenhouse Gas Emissions from Forestry Operations: A Life Cycle Assessment. *Journal of Environmental Quality* 351439-1450.

Swiss Center for Life Cycle Inventories. 2010. *ecoinvent Database v.2.2*.

United States Environmental Protection Agency. 2009. Part 98 - Mandatory Greenhouse Gas Reporting. Tables C-1 and C-2. *Federal Register* 74(209):56409-56411. October 30.

United States Environmental Protection Agency (U.S. EPA). 2020a. *Documentation for Greenhouse Gas Emission and Energy Factors Used in the Waste Reduction Model (WARM) - Containers, Packaging, and Non-Durable Good Materials Chapters*. Washington, DC: Prepared by ICF For the U.S. Environmental Protection Agency.

https://www.epa.gov/sites/production/files/2020-12/documents/warm_containers_packaging_and_non-durable_goods_materials_v15_10-29-2020.pdf.

_____. 2020b. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018*. EPA 430-R-20-002. Washington, DC: U.S. EPA. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2018.

_____. 2020c. Annexes to the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018. EPA 430-R-20-002. Washington, DC: U.S. EPA. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2018.

World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD). 2004. *A Corporate Accounting and Reporting Standard - Revised Edition*. Conches-Geneva and Washington DC: GHG Protocol.

_____. 2011. *Corporate Value Chain (Scope 3) Accounting and Reporting Standard*. GHG Protocol.