Characterizing Carbon Sequestration in Forest Products Along the Value Chain

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EXECUTIVE SUMMARY

In recent years, much attention has been focused on carbon accounting for harvested wood products in the context of national greenhouse gas inventories. The methods being considered for national accounting, however, are not particularly appropriate for value chain accounting.[1] This is partly due to the practical difficulties that companies face in assembling the historical production data and other information required by the methods. A more important limitation, however, is the tendency of national accounting methods to yield results that are heavily influenced by historical data and past practices. As a result, these methods provide little insight into the significance of current practices and opportunities for improvement. This is a serious drawback because value chain assessments are often performed with the specific objective of revealing opportunities for improvement.

In this report, several approaches are reviewed for estimating the amounts of carbon sequestered in forest products in the post-manufacturing portions of the forest product value chain. Because forest product value chain studies often involve end-of-life issues, the report also examines methods for estimating carbon sequestration in landfills and landfill methane emissions from forest products.

Several methods have been examined for estimating carbon sequestration in products-in-use. Some of these are based on the methods being considered by IPCC for national-level accounting for harvested wood products. These do not appear to be appropriate for value chain accounting, however, for the reasons outlined above. This report recommends, instead, a method for estimating carbon sequestration in products-in-use that is based on the assumption that any carbon that is expected to remain in use for at least 100 years can be considered to be permanently sequestered.

Several different types of mathematical equations (i.e. decay curves) have been identified in the literature for estimating the amounts of carbon remaining in use for 100 years. Policy concerns will undoubtedly play a role in selecting from among them. Among those examined in this study, only the Row and Phelps decay curve allows a small amount of long term sequestration for items with relatively short half-lives (e.g. newspapers). In its draft guidance for national accounting (still under review) IPCC is considering a different mathematical function - the First Order

[1] In this paper, "value chain" means a series of operations and entities, starting with the forest and extending through end-of-life management. The operations and entities supply or add value to raw materials and intermediate products to produce final products for the marketplace or are involved in the use and end-of-life management of these products.

Decay curve. The Row and Phelps decay curve has been used for the calculations in this report. A comparison of several of the decay curves can be seen in Figure 2 of this report.

The decay curves are used to develop time-in-use distributions from half-life data, so the half-life information used in the analysis is important. A number of different publications have suggested half-lives for a variety of forest products. The draft good practice guidance for Land Use, Land Use Change, and Forestry, now being reviewed under the auspices of IPCC summarizes some of the available half-life information and IPCC's summary has been included in this report as Table 1. As would be expected, wood product half-lives are generally much longer than those for paper and paperboard products. Depending on the product involved and the decay curve selected, over a 100-year period the fraction of carbon sequestered in wood products during use ranges from 5 to 25% or more of the carbon in the original product. For paper and paperboard products, the amounts of carbon sequestered during use ranges from near zero to about 7% of the carbon in the original product.

After use, a fraction of forest products are disposed in landfills where the carbon is sequestered or converted to gas. To estimate carbon sequestration in landfills, this report recommends ignoring decomposition rates and focusing instead on the carbon expected to remain in landfills indefinitely. A literature review was conducted to obtain the most appropriate and credible estimates of the non-degradable carbon content of forest products in landfills. Based on this review, it appears that the most appropriate data come from studies conducted for USEPA in the 1980s and from some very recent work by the State Forests of New South Wales in Australia. The data are shown in Table 2 of this report. These sources of information suggest that much (80 to 93%) of the carbon in wood products, coated paper and paperboard, and mechanical pulp fibers remains in landfills indefinitely. Uncoated grades of paper made of chemical pulps degrade more completely.

The carbon that is not permanently sequestered in the landfill is assumed to be converted to a mixture of methane (a relatively potent greenhouse gas) and climate-neutral carbon dioxide. To estimate the releases of these gases, a calculation method is used that is essentially the same IPCC's default method for landfill methane.

For purposes of describing, at a very coarse scale, the sequestration potential of the industry's products, it is possible to divide these products into three general categtories;

- wood products,
- slowly degrading paper and paperboard products (i.e. those that are either coated or are comprised mostly of mechanical fibers), and
- highly degradable paper and paperboard products (i.e. those that are uncoated and comprised primarily of chemical pulp fibers).

Although significant variations are expected from one country to the next, it appears that for every ton of wood products manufactured by the forest products industry, approximately 0.2 tons of carbon equivalents are removed from the atmosphere by sequestration (considering products in-use and products in landfills after adjusting for methane emissions). For every ton of slowly degrading paper and paperboard that is manufactured, approximately 0.03 to 0.1 tons of carbon equivalents are removed from the atmosphere (again considering product use and disposal). Depending on national circumstances and the particular product in question, the carbon impacts associated with highly degradable products probably range from a small net sequestration of carbon to a net emission of 0.2 tons or more of carbon equivalents per ton of production. Carbon sequestration increases as (a) times-in-use become longer, (b) recovery rates increase, (c) less organic waste is sent to landfills, and (d) more landfills are equipped with gas control systems.

There are several elements of the post-manufacturing portion of the forest industry value chain that are important to the industry's climate profile but not addressed by this report. These include the value of biomass energy derived from non-recyclable forest products, the energy efficiency and carbon advantages associated with many wood fiber-based materials compared to alternatives, and the importance of forest products as a source of economic incentive to keep land in forest. The carbon sequestration aspects of the industry's climate profile need to be considered within the framework of the overall environmental profile of the value chain, and with due recognition of the important substitution effects that can accompany shifts in consumption between forest products and competing materials.

INTRODUCTION

The forest industry value chain begins in the forest and ends with the reuse or disposal of forest products. Forests are both sources and sinks for greenhouse gases (GHGs) and GHGs are emitted in harvesting and transporting wood as well in manufacturing products from wood fiber. Greenhouse gases are emitted during the use of certain forest products as well in their recovery, reuse, and disposal. Greenhouse gas studies of the forest industry value chain have commonly addressed most or all of these emissions. Commonly lacking, however, is an appreciation of the greenhouse gas benefits associated with carbon sequestration along the value chain.

Wanting to better understand the importance of carbon sequestration to the GHG profile of the forest industry value chain, the Climate Change Working Group of the International Council of Forest and Paper Associations (ICFPA) is examining methods for characterizing carbon sequestration in forest products. The eventual goal is to develop global consensus in the forest-based industry on a method for characterizing carbon sequestration in forest products. This follows a similar successful effort to develop a consensus method for estimating the GHG emissions from pulp and paper mills (ICFPA 2003).

Under the auspices of the Intergovernmental Panel on Climate Change (IPCC), several different accounting approaches are currently being examined for addressing harvested wood products (HWP) in national GHG inventories (IPCC 2003a). The issues encountered in preparing national GHG emissions inventories, however, are very different from those that are important to understanding the "climate profile"[2] of the forest industry value chain. In national accounting, for instance, one of the most important issues is how to account for the carbon that crosses national boundaries in imports and exports. This is not an issue in value chain accounting because these flows of carbon are contained within the boundaries of the value chain. Similarly,

[2] The term "climate profile" is used in this report to describe the overall effect of the industry's value chain (including important substitution effects) on the levels of carbon dioxide and other greenhouse gases in the atmosphere.

in national accounting, essentially all forests within the nation's borders are included whereas, in value chain accounting, it is the forest that provides or could provide fiber to the forest-based industry that is of primary concern. In national accounting, a very broad definition of "products" is appropriate so the accounting is done on "harvested wood products" or HWP – a term that includes all wood removed from the forest, regardless of its use. In value chain accounting, a different definition of "product" is more appropriate because the focus is on the valued-added output of the forest-based industry. In addition, national accounting methods are often impractical for use at smaller scales and the results are heavily influenced by historical production rates, the time-in-use of former products, and past product disposal practices. For these and other reasons, the approaches used for carbon accounting in national inventories may not be appropriate for corporate, sector, or value chain accounting in the forest products industry.

Almost all of the sequestered carbon in the forest industry value chain is contained in three "pools" – the forest (including above-ground and below-ground biomass), products in-use, and products disposed in landfills. While there are aspects of carbon accounting that are common to all three segments, there are also important differences between the issues encountered in forest carbon accounting compared to product carbon accounting. This report addresses methods for characterizing carbon sequestration in products in-use and products disposed in landfills. Forest carbon sequestration is an important issue to the forest industry but it is not addressed in this report. The forest industry, however, is involved in a variety of corporate-, sector-, national-, and international-level projects that address forest carbon accounting.[3]

Carbon sequestration in forest products is only a piece of the overall climate profile of the forest industry value chain. To help put product carbon sequestration into perspective, this report also examines, in general terms, the other important aspects of the climate profile of the forest industry value chain.

AN OVERVIEW OF THE FOREST INDUSTRY VALUE CHAIN

This section of the report provides the reader with a general understanding of those elements of the forest industry value chain that are important to its climate profile.

Forests

The forest industry value chain begins in the forest. It is in the forest that carbon is removed from the atmosphere by photosynthesis and is added to stocks of forest carbon. Carbon is removed from forest carbon stocks through two primary vectors – emissions from the forest to the atmosphere and wood removed via harvesting. The balance between the inputs and outputs of carbon to the forest determine whether forest carbon stocks increase or decrease.

Enormous quantities of atmospheric carbon are stored in forests and forest soils - more than 1,100 gigatons (Gt) divided between forest vegetation (approximately 350 Gt) and forest soils (approximately 800 Gt). By comparison, the atmosphere contains about 800 Gt of carbon and the world's oceans contain almost 40,000 Gt (IPCC 2000).

[3] Several companies are, for instance, working with the Chicago Climate Exchange (www.chicagoclimatex.com) to develop methods for forest carbon accounting.

The balance between additions and losses of stocks of forest carbon varies at different places on the globe. Stocks of carbon in mid- and upper-latitude forests are growing. Stocks of carbon in tropical forests appear to be decreasing, primarily due to deforestation, but there is significant uncertainty in these estimates. Globally, the stocks of forest carbon are thought to be declining, but this will remain uncertain until the estimates for tropical forests are improved (IPCC 1996, 2000). Attempts to develop a global carbon budget suggest that terrestrial uptake of carbon, including forests, is in the range of –0.3 to +1.7 Gt/y. This can be compared to global emissions of carbon equal to 6.3 Gt/y (IPCC 1996, 2000).

Although forest carbon stocks are very important to the value chain climate profile, they cannot be viewed in isolation. Even if carbon stocks are remaining constant (i.e. additional carbon is not being sequestered in the forest), the carbon removed in harvested wood remains sequestered for varying amounts of time. The amounts of carbon remaining sequestered for long periods of time in forest products are important enough to have a significant impact on the value chain climate profile. Estimates of annual sequestration of carbon in forest products range from 26 to 139 x 10^6 tons per year (Winjum 1998, IPCC 2003b), an amount adequate to offset much or all of the GHG emissions from forest products manufacturing [4].

Tools for estimating forest carbon sequestration have been developed and continue to be improved. Methods for forest carbon accounting at the national level have been issued by IPCC (IPCC 1997a, b, c) and are being updated (IPCC 2003a). In addition, national governments have developed methods tailored to national circumstances and forest industry companies are adapting and improving forest inventory tools to address carbon sequestration.

Harvesting and transporting wood to manufacturing facilities

The amounts of GHGs emitted in harvesting and transporting wood to manufacturing operations are primarily determined by the distance traveled and the mode of transportation. The relative importance of these emissions is revealed by the results of three studies – one conducted in the US, a second focusing on the European situation, and a third dealing with circumstances in Canada. In the US study, energy consumption in wood harvesting and transport was estimated to be 1 to 2 GJ/ton paper (Paper Task Force 2002). If this is converted into GHGs (assuming that diesel fuel is used) it amounts to approximately 0.03 tons of carbon per ton of paper. The European-focused study found that total emissions from transport (including products) were approximately 0.02 tons of carbon per ton of paper (IIED 1996). While these two studies suggest emissions equaling only 10 to 20% of the average emissions from pulp and paper manufacturing, they are far more significant, relatively speaking, for wood products facilities because wood products manufacturing is usually less GHG intensive that pulp and paper manufacturing. This is reflected in the results of a Canadian study that estimated that wood transportation accounts for nearly 60% of the forest product sector's fossil fuel consumption – a figure reflecting both the Canadian industry's strong reliance on renewable energy for manufacturing and the dominant role of wood products in the Canadian industry [5] (Apps 1999).

[4] The industry's manufacturing emissions are estimated below.
[5] According to Forest Products Association of Canada (FPAC) statistics, Canadian wood products shipments are about twice pulp and paper shipments on a weight basis.

Tools are readily available for estimating the GHG emissions from transportation. Most national governments, for instance, have emission factors and calculation methods for transportation sources of GHG emissions. IPCC has issued international guidance (IPCC 1997a, b, c). The Calculation Tools for Estimating Greenhouse Gases from Pulp and Paper Mills contain methods for estimating emissions from harvesting and transportation sources (ICFPA 2003).

Manufacturing forest products

The forest products industry relies heavily on carbon-neutral biomass fuels [6]. According to OECD statistics, the forest products industry derives more of its energy from biomass than any other industry (OECD/IEA 1999 and 2003). The forest products industry also uses fossil fuels that generate GHGs when burned.

Based on information from industry associations and government agencies, it can be estimated that the direct GHG emissions[7] from the pulp and paper industry in Australia, Canada, the EU plus Norway and Switzerland, Japan, and the United States total approximately 41 million tons of carbon (APIC 2003, FPAC 2002, CEPI 2002, JPA 2003, EIA 2001). FAO statistics indicate that these regions produce approximately 63% of the paper and paperboard in the world (FAO 2003). This suggests that the GHG emissions from the global pulp, paper and paperboard industry are approximately 65 million metric tons of carbon.

GHG Emissions from wood products manufacturing in OECD countries are approximately 5 million tons of carbon per year [8]. FAO statistics indicate that the OECD produces about 70% of the sawn wood and wood panels, suggesting that global GHG emissions from wood products plants are approximately 7 million tons of carbon per year (OECD/IEA 1999 and 2003, FAO 2003).

In total, therefore, the direct emissions from the forest-based industries can be estimated to be approximately 72 million tons of carbon per year or approximately one percent of global GHG emissions (IPCC 2001).

Many forest products manufacturing facilities also purchase electricity. There are no easily accessible data, however, that would allow the indirect emissions associated with these purchases to be estimated for the global forest products industry. For the pulp and paper industry in Europe, emissions associated with purchased power are approximately 30% less than the industry's direct emissions (from data in CEPI 2002 and PWC 2002). In the United States, they are about 40% less than direct emissions (EIA 2001). In the wood products sector, these indirect emissions may exceed the direct emissions from manufacturing facilities, although they are still less than the

[6] The carbon in biomass was removed from the atmosphere at the beginning of the value chain so burning biomass only returns carbon to the atmosphere, resulting in no net increase in atmospheric CO_2 levels.
[7] Direct emissions are from sources owned or controlled by the forest products industry. They do not include emissions associated with purchased electricity.
[8] Wood product manufacturing emissions have been estimated from OECD/IEA statistics, which exclude fuels used to produce electricity. Unlike pulp, paper, and paperboard mills, however, few wood products facilities produce electrical power from fossil fuels.

emissions attributable to electricity purchases by pulp and paper mills (for instance, see EIA 1994).

The ICFPA has completed a project that resulted in globally-accepted and peer-reviewed tools for estimating greenhouse gas emissions from pulp and paper mills (ICFPA 2003). They can also be used to estimate fossil fuel-related emissions from wood products plants.

Transporting final products to users

The emissions associated with this segment of the value chain are affected by the same factors that influence emissions in transporting raw materials – i.e. transport distance and mode of transport. The discussion above regarding emissions from wood harvesting and transport summarized several studies. The information contained in those references does not allow a separate estimate of product transport-related emissions. Those references suggested that total transportation-related emissions could range from 0.02 to over 0.03 tons of carbon per ton of product depending on local circumstances.

Products in use

This portion of the value chain is critical to the GHG profile for several reasons. First, emissions are associated with using some forest products. Fossil fuel-derived energy is used, for instance, to heat wood-framed and -sided homes. The differences in energy efficiency between wood-based and other types of homes (i.e. substitution effects) can be important to the value chain climate profile. These substitution effects have been the subject of numerous life cycle studies, especially for wood-based building systems. A number of studies have found the life cycle energy and GHG profiles of wood-based building materials to be superior to steel, brick, and concrete alternatives. These studies have addressed a range of geographical and cultural settings including Australia (Glover 2002), Canada (Trusty 1999), Europe (Scharai-Rad 2002), and the United States (CORRIM 2002). The relative life cycle advantages of wood-based materials are affected by the use of forest residuals and end-of-life management practices (Borjesson 2000).

In addition to substitution effects, this part of the value chain is important because while products are being used, they continue to sequester carbon. This sequestration is an important element of the climate profile of the forest industry value chain. It has been estimated that 40 x 10^6 tons of carbon are sequestered annually in products-in-use (IPCC 2003b). Carbon sequestration in products is a major focus of this report and is dealt with in great detail later.

End-of-life management

After use, most forest products are reused, burned for energy, or landfilled. This part of the value chain has several effects on the climate profile of the forest-based industry.

First, used forest products must be collected, a process that requires fossil fuel for transport. The discussions above regarding transportation are relevant here. Again the controlling factors are transportation distance and mode of transport. Because these factors vary from one location to another, it is not surprising that different studies come to varying conclusions about the relative importance of used paper transportation. One US-focused study, cited earlier, suggests that GHG emissions from used paper transportation are less than those from harvesting and transporting virgin wood fiber (Paper Task Force 2002) while another study of European conditions indicates that "[t]he overall effect [of collecting more paper for recycling] would be an increase in emissions of CO_2…from transport…" (IIED 1996).

Second, when forest products are recycled the recycling activity has multiple and complicated effects on GHG emissions and sequestration along the value chain. Increased recycling may reduce forest harvests and allow longer rotation times, but the benefits to carbon sequestration in the forest are likely to be obscured by the effects of market forces on decisions regarding harvesting and land use. Recycling prevents methane emissions by keeping used paper out of municipal solid waste landfills where, over time, it would have degraded into CO_2, which is carbon neutral, and methane, which is a potent greenhouse gas. At the same time, recycling reduces the amount of carbon sequestered in landfills. In some markets, recycled and virgin fibers compete, so that the substitution effects within the value chain become important. Studying these substitution effects, however, requires life cycle studies that attempt to examine not only the differences between virgin and recycled product manufacturing, but also the carbon implications of recycling along the complete value chain. This is a difficult task, especially in cases where market forces related to changing demands for fiber may affect forest harvesting, land use, and used paper recovery.

Third, when forest products are burned for energy, they can displace fossil fuels. This is important to the climate profile of the forest products value chain because biomass-based fuels are carbon-neutral and do not contribute to increases in atmospheric CO_2 levels when burned whereas fossil fuels add new CO_2 to the atmosphere, resulting in increases.

Fourth, as noted above, forest products that are deposited in landfills will degrade over time and release both CO_2, which is climate neutral, and methane, which is not. Indeed, methane has 21 times the greenhouse gas potency of an equal mass of CO_2 [9]. In some cases, however, this methane is captured and burned as a biomass fuel, offsetting fossil fuels.

Fifth, the carbon in forest products that decays slowly in landfills can remain there for very long periods of time, continuing to sequester carbon from the atmosphere.

The significance of carbon sequestration in landfills and the offsetting effects of methane emissions from landfills are among the primary subjects of this report and are, therefore, discussed in detail later in this report.

OPTIONS FOR CHARACTERIZING CARBON SEQUESTRATION IN PRODUCTS-IN-USE

The products manufactured by the forest products industry contain large amounts of sequestered atmospheric carbon. World wide, the industry's annual production (considered equal to total production of paper, paperboard, wood panels and sawn wood) contains approximately 290 x 10^6 tons of carbon (IPCC 2003b). This new production represents additions to existing stocks of carbon in products-in-use. These additions are offset by losses of carbon from the existing stocks

[9] In its Third Assessment Report, IPCC changed the 100-year Global Warming Potential for methane to 23. Because the GWP of 21 will be used through the first commitment period, however, it is also used throughout this report.

as products are removed from service. It is the change in the total stocks of carbon that is important. If the total stocks of carbon in products-in-use increase, it represents the removal of an equal amount of carbon from the atmosphere. Conversely, if the total stocks of carbon in products-in-use decrease, it represents an emission to the atmosphere from the products-in-use carbon pool.

Over the last forty years, the net additions to stocks of carbon in products-in-use have varied between 30 and 60 x 10^6 tons of carbon per year. In 2000, carbon was being added at a rate of approximately 40 x 10^6 tons of carbon per year (IPCC 2003b). Due to the long useful lifetimes for many of the industry's products and increased consumption caused by increasing standards of living, stocks of carbon in products-in-use are growing and are expected to continuing growing for the foreseeable future (IPCC 2000, 2003b).

Because it is the net change in carbon stocks that is important to the climate profile of the value chain, a method is needed for estimating changes in the amounts of carbon sequestered in products-in-use. There are two basic options. One follows the approach being considered by IPCC for national GHG inventories. The second is a variation on the national accounting approach that may be better suited to corporate, sector, and value chain accounting.

For national GHG inventories, IPCC is proposing that changes in stocks of carbon in products-in-use be estimated by netting annual additions to stocks against annual losses (IPCC 2003a). Using this approach, additions to stocks of carbon in products-in-use are netted against losses from the existing stocks that occur in the same year. The result is the actual year-to-year change in current stocks of carbon in products-in-use. In this report, this method is referred to as the "national inventory method."

With the alternative method, current year additions are not netted against losses from the currently existing stock, but instead are netted against future losses from current year additions. The result, therefore, is the amount of carbon in the current year's production that is expected to remain in-use. If a long enough time period is used, the carbon remaining sequestered in products-in-use can be considered, for all practical purposes, permanently sequestered and therefore represents a permanent removal of carbon from the atmosphere.

In several other applications, IPCC has used 100-years to define similar long-term or "permanent" effects. National inventories submitted under the UNFCCC are prepared using global warming potentials that are derived by "integrating the total radiative forcing of an emissions pulse over a 100-year time horizon…." (IPCC 2000). It has been suggested that a similar approach, involving a 100-year time horizon, could be used to characterize removals via sequestration. The IPCC Special Report on Land Use, Land Use Change, and Forestry suggests the following application of a 100-year time horizon in the "ton-year" approach.

> "If the ton-year approach is adopted, incremental credit can be awarded for each year that carbon stocks remain sequestered. The cumulative award of credit would equal the credit from a "permanent" emission reduction of the same magnitude if the stocks remained intact for 100 years. If the stocks were

> released at any time prior to the 100-year time horizon, only the appropriate amount of partial credit would have been awarded." (IPCC 2000, page 88).

Using an analogous approach, a 100-year time horizon can be used to estimate the amount of carbon in current production that is expected to be permanently sequestered. In this report, we call this approach "the 100-year method." This method was first suggested by Dr. Sergio Galeano of Georgia-Pacific Corporation and the first known application of the method in a corporate GHG inventory was by Georgia Pacific Corporation (Georgia Pacific 2002). The method is also highlighted in an ISO Technical Report (ISO 2003).

<u>The "national inventory method" compared to the "100-year method"</u>

The national inventory method has two primary advantages. First, it is most consistent with the way carbon accounting is done in national inventories. As a result, it might be more readily accepted by stakeholders who are familiar with national carbon accounting. Second, the emissions or removals calculated using the national inventory method are more easily compared to current year emissions occurring from other parts of the value chain because they represent changes in carbon stocks in the current year.

There are several problems, however, with applying the national inventory method in assessments of the climate profile of the forest products value chain. The first is a practical problem. The national inventory method requires an estimate of losses from current carbon stocks. At the national level, this is done in one of two ways. One approach is to estimate current year losses from all past years' production. The other approach is to assume that current year losses are equal to a specified percentage of the total carbon sequestered in products-in-use. This requires that the total carbon in products-in-current-use either be measured or estimated. Both of these approaches require reconstructing past production records and making assumptions about the fates of carbon in past years' production. While this might be possible at the national level, it introduces significant complexity for corporate, sector, and even value chain assessments. This not only makes the estimates difficult to derive, it also leads to the results being less consistent and less easily understood by industry stakeholders.

Another reason why the national inventory method is not particularly appropriate for characterizing the climate profile of the forest industry value chain is that the results are heavily influenced by past practices over which the current producer may have little or no control. This is because the losses from current stocks are strongly related to (a) the quantities of past production, (b) the durability of past products, (c) past construction practices, and a variety of other factors and past activities that may be completely unrelated to the current situation. In many cases, value chain assessments are intended to provide stakeholders with an understanding of the current circumstances and the opportunities to improve current performance. Because of the strong influence of historical conditions, this is difficult, if not impossible, to accomplish with the national inventory method.

The 100-year method is conceptually and mathematically simpler, so it is easier to perform and more likely to be applied consistently from one assessment to the next. This will help in gaining acceptance of the results by industry stakeholders. The 100-year method also yields results that reflect conditions and opportunities that are most likely to be influenced by current manufacturers – i.e. those conditions and opportunities that are, or can be, applied to current production.

Perhaps the largest disadvantage of the 100-year method is that some industry stakeholders may be uncomfortable with assuming that a 100-year horizon is adequate for defining permanent sequestration. Other time horizons could be used but at present it appears that the 100-year horizon is the only one with precedent in the areas of carbon accounting and climate change.

Both the national inventory method and the 100-year method are conceptually consistent with stock accounting concepts, which are the basis of IPCC's current default accounting methodology for Land Use, Land Use Change, and Forestry. This is because they both estimate stock changes. The national inventory method estimates actual year-to-year stock changes while the 100-year method estimates future stock changes.

Because of the questionable applicability of the national inventory method for value chain assessments, details on methodology are presented only for the 100-year method.

USING THE 100-YEAR METHOD FOR CHARACTERIZING CARBON SEQUESTERED IN PRODUCTS-IN-USE

The 100-year method involves four steps.

1. Identify the types of products-in-use that are made from current production
2. Determine the carbon contained in those products attributable to current production
3. For each type of product-in-use, obtain a decay curve or other information that describes the amounts of carbon expected to be in use in the future.
4. Use the decay curves to estimate the amount of carbon remaining in-use for at least 100 years. This amount represents a permanent removal of carbon from the atmosphere.

The four steps are applied as follows.

Forest products have a variety of uses and a wide range of expected times-in-use. Tissue products are unlikely to remain in use for a year while a significant fraction of the sawn wood used in single family home construction will still be in use in 100-years. Even within a single product type, however, times-in-use can vary substantially. Sawn wood used in shipping containers, for instance, remains in use for a far shorter time than sawn wood used in home construction. It is important, therefore, to understand how products are used, not only because product lifetimes vary, but also because time-in-use information is typically associated with specific end uses. The first step in the process, therefore, is to divide current production into the categories of products for which time-in-use data are available.

The current production is obtained from production records or statistics and the carbon content is estimated by multiplying the production by its carbon content. A common default assumption for paper, paperboard and wood products is that they are 50% carbon by weight (dry) (IPCC 2003a). In general, this is more accurate for wood products than for paper products, which sometimes contain a considerable amount of inorganic material (i.e. filler and coating). None-the-less, for purposes of estimating stocks of carbon in-use, an assumed carbon content of 50% is probably adequate because only a very small fraction of paper remains in use for 100-years.

Information on product time-in-use often comes in the form of half-life values and decay curves. The half-life of a product is the time over which one-half of the original material leaves the pool of carbon stocks-in-use. IPCC uses a simple first order relationship to convert the half-life into a decay curve that allows one to calculate the fraction remaining as a function of time. The first order decay time-in-use curve is represented by the following equation.

Equation 1: First Order Decay Curve

$$FR = \left(\frac{1}{1 + (0.69315 / HL)} \right)^{Y}$$

Where: *FR = Fraction of carbon remaining in use in year Y*
HL = half-life (years)
Y = elapsed time (years)

Other relationships have been used, however, to convert half-life information into decay curves for time-in-use. The European Forest Institute (EFI) has used the equation shown in Equation 2 (EFI 2002) [10].

Equation 2: EFI Decay Curve

$$FR = 1.2 - \left(\frac{1.2}{1 + (5 * e^{-(Y / HL)})} \right)$$

Where: *FR = Fraction of carbon remaining in use in year Y*
HL = half-life (years)
Y = elapsed time (years)

A third option for converting half-life values into decay curves has been used by Row and Phelps and is shown in Equations 3a, 3b, and 3c (Row and Phelps 1996) [11]. The Row and Phelps approach divides the decay curve into three pieces. The Row and Phelps decay curves have been used by the US in preparing its national inventory for UNFCCC.

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[10] The equation is slightly different than the version shown in EFI 2002 so that the result can be shown as a fraction instead of a percentage.
[11] The original Row and Phelps 1996 publication contained typographical errors in the equations. The equations shown here have been corrected.

Equation 3: Row and Phelps Decay Curve

Equation 3a: *If:* $Y < HL/2$

$$FR = 1 - \left(0.4191 * \frac{Y}{HL}\right)$$

Equation 3b: *If:* $Y > HL/2$ *and* $Y < HL$

$$FR = 1 - \left(\frac{0.5}{1 + \left(2 * \ln(HL / Y)\right)}\right)$$

Equation 3c: *If:* $Y > HL$

$$FR = \left(\frac{0.5}{1 + \left(2 * \ln(Y / HL)\right)}\right)$$

Where: *FR = Fraction of carbon remaining in use in year Y*
HL = half-life (years)
Y = elapsed time (years)

The effects of selecting different decay curves are illustrated in Figure 1. The primary differences occur at times longer than the half-life of the product. This is important because the 100-year method uses only the estimated fraction remaining at 100 years.

Figure 2 shows the results of using the three different decay curves to predict the fraction of the carbon remaining in use at 100 years as a function of product half-life. For products with half-lives of 40 years or less, the Row and Phelps decay curve predicts the largest amount of carbon remaining in use. For products with half-lives between 40 and 100 years, the first order decay curve predicts the largest amount of carbon remaining in use. The EFI model predicts the smallest amount of carbon remaining in use until product half-lives are 80 years or greater, at which point its estimates are close to the Row and Phelps estimates.

Although this discussion has highlighted three decay curves, others are also available (e.g. Apps 1999, Pingoud 2001). It is difficult to know which decay curves are most appropriate. Indeed, it is possible that different decay curves may be appropriate under different circumstances. Several considerations can influence the decision, however.

First, of the decay curves identified by NCASI, only the Row and Phelps decay curve reflects the "archive effect" – i.e. a certain fraction of product is predicted to be stored for 100 years in places such as archives and libraries even though the half-lives are short. With the first order and EFI decay curves and others known to NCASI, only products with half-lives of greater that 10 to 30 years are predicted to store any carbon at all for 100 years.

Figure 1. Decay curves for a 50-year half-life product

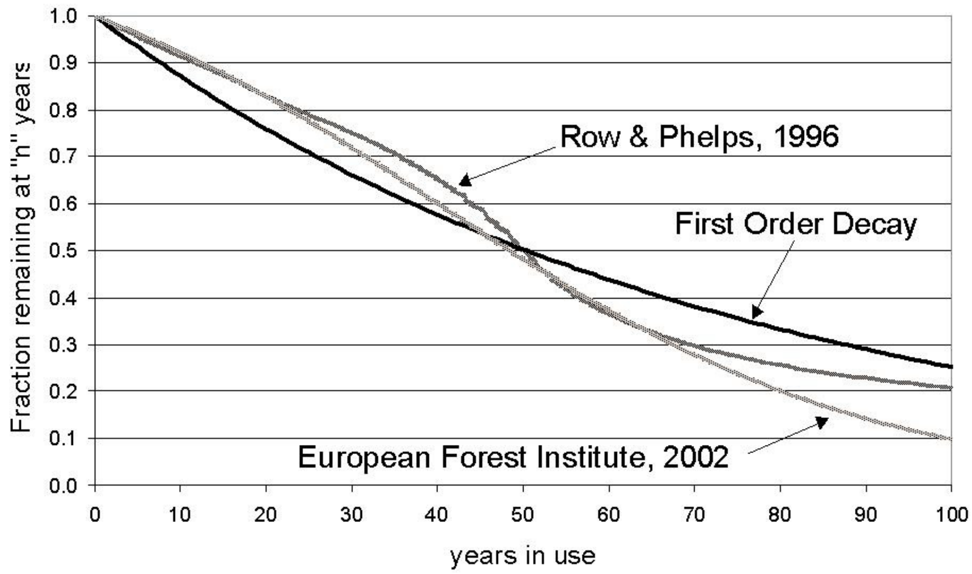
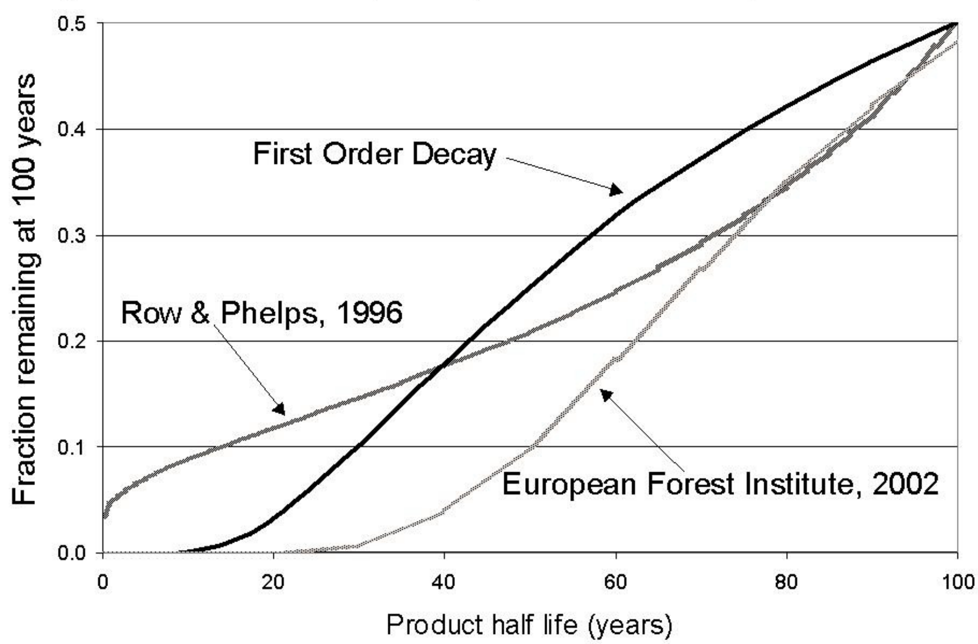


Figure 2. Fraction remaining at 100-years as a function of product half-life



On the other hand, the first order decay curve is probably the simplest approach and is most comparable to the method currently being considered by IPCC in its draft good practices guidance for national inventories (IPCC 2003a). Currently, however, beyond these two considerations, there seems to be little technical basis for choosing between the decay curves found in the literature.

Half-life estimates also vary. It is reasonable to expect some variability between countries due to different building practices, for instance. Some of the differences, however, are probably due to different approaches to estimating product half-life. Table 1, which was copied from IPCC's draft good practice guidance for LULUCF, contains a summary of much of the available information on times-in-use for various forest products (IPCC 2003a).

Table 1. Half-life values from Draft Good Practice Guidance for LULUCF (IPCC 2003a)

Appendix Table 3.2.19. Half life of solidwood and paper products in use			
Country/ region	Reference	HWP category	Half life in use (years)
Defaults		**Solidwood**	
		Sawnwood	**35**
		Veneer, plywood and structural panels	**30**
		Non structural panels	**20**
		Paper	**2**
Finland	Pingoud et al. 2001	Sawnwood and plywood (based on change in inventory of products)	30
Finland	Karjalainen et al. 1994	Sawnwood and plywood average	50
		Paper from mechanical pulp average	7
		Paper from chemical pulp average	5.3
Finland	Pingoud et al. 1996	Average for paper	1.8
		Newsprint, household, sanitary paper	.5
		Linerboard fluting and folding boxboard	1
		80 % of printing and writing paper	1
		20% of printing and writing paper	10
Netherlands	Nabuurs and Sikkema 2001	Paper	2
		Packing wood	3
		Particleboard	20
		Sawnwood average	35
		Sawnwood – spruce & poplar	18
		Sawnwood – oak & beech	45
United States	Skog and Nicholson 1998	Sawnwood	40
		Structural panels	45
		Non structural panels	23
		Paper (free sheet)	6
		Other paper	1

The following examples illustrate how the 100-year method can be applied.

Example 1:

A company produces 5 million tons of plywood in 2000. It is assumed to contain 50% carbon by weight, or 2.5 million tons of carbon. The plywood goes into uses with an expected half-life of 30 years. The company decides to use the Row and Phelps decay curves and calculates from Equation 3 (or observes from Figure 2) that about 15% of the carbon is expected to remain in use for 100-years. Multiplying 2.5 million tons of carbon by 15% shows that 375,000 tons of carbon are sequestered for at least 100 years, representing a permanent removal of carbon from the atmosphere.

Example 2:

A company produces 5 million tons of uncoated freesheet in 2000. It is assumed to contain 45% carbon by weight, or 2.25 million tons of carbon. The freesheet goes into uses with an expected half-life of 2 years. The company decides to use the Row and Phelps decay curves and calculates from Equation 3 (or observes from Figure 2) that about 5% of the carbon is expected to remain in use for 100-years. Multiplying 2.25 million tons of carbon by 5% shows that 112,500 tons of carbon are sequestered for at least 100 years, representing a permanent removal of carbon from the atmosphere.

OPTIONS FOR CHARACTERIZING THE FATE OF CARBON IN LANDFILLS

Carbon deposited in landfills can remain sequestered from the atmosphere for very long periods of time. Because of the importance of this segment of the forest product value chain, as part of this project, Dr. Morton Barlaz of North Carolina State University reviewed the literature to identify data that might be used to predict the fate of carbon in forest products in landfills. A separate copy of his report is being supplied to the ICFPA Climate Change Working Group (Barlaz 2003). The following material is drawn largely from Dr. Barlaz's report.

There are a number of factors that are known to influence the rate at which forest products decompose in municipal solid waste (MSW) landfills, but moisture content, pH, and the inherent degradability of the substrate have consistently been shown to be the most important (Barlaz 2003). Although a number of studies have been conducted on the decomposition of mixed municipal solid waste, very few data have been developed on the rates at which forest products can be expected to decay in landfills. This is largely due to the difficulty of separately characterizing forest products carbon from other organic carbon in landfills (e.g. food waste, clothing, etc.). It also reflects the difficulty of conducting laboratory experiments that accurately mimic the conditions that affect the rate of decomposition in a landfill (Barlaz 2003).

The published decay rates for both mixed municipal solid waste and forest products in MSW landfills vary over a large range (Barlaz 2003). This makes it difficult to use a method like the 100-year method to estimate permanent storage in landfills.

The published research, however, clearly indicates that a certain fraction of carbon in forest products is unlikely to degrade in landfills for very long periods of time due to inherent physical and chemical properties. This has been determined both in field studies and, importantly, in laboratory studies where conditions have been optimized for decomposition and where it has been possible to study specific types of materials separately. The resulting body of research indicates that (a) lignin is essentially non-degradable under anaerobic conditions, and (b) physical characteristics, such as inorganic coatings and lignin, isolate cellulose and hemicellulose, making much of the carbon in these materials inaccessible to the organisms that would otherwise decompose them (Barlaz 2003). The information generated in these studies can be used to estimate the amounts of forest product carbon sequestered in landfills. This research also provides a basis for estimating the quantities and fates of greenhouse gases that are released from landfills when forest products decompose.

In the following discussions, methods are presented for estimating carbon sequestration in landfilled forest products and methane emissions from forest products in landfills. It is important to remember that these phenomena are important only for that fraction of waste that is landfilled. Accordingly, to address landfill issues, the value chain assessment must include an estimate of the fraction of discarded forest products that end up in landfills and an estimate of what fraction of landfills are equipped with systems to capture and burn methane. These parameters vary significantly among nations.

Carbon sequestration in landfills

For national accounting of carbon in landfills, IPCC is considering an approach analogous to its proposed approach for carbon in products-in-use. In both cases, additions to the carbon stocks are assumed to decay at specified rates. The key difference is that in the case of landfills, carbon is divided into degradable and non-degradable fractions and only the degradable fraction decays. The annual additions to landfills are netted against losses from landfills (i.e. landfill gas) that occur in that same year, using an approach similar to the national inventory method for products-in-use. This requires the same reconstruction of past conditions that is needed to do national accounting for products-in-use. The discussion above pointed out that this is unworkable and inappropriate for value chain accounting. In the case of landfills, an added problem is the large uncertainty in decay rates.

For these reasons, a method is proposed for estimating carbon sequestration in landfills that does not consider degradation rates. The proposed method assumes that none of the degradable carbon is sequestered in landfills, even though it is known that much of the degradable carbon remains in landfills for very long periods of time. Only the non-degradable carbon is assumed to be sequestered in the landfill environment. The non-degradable carbon is expressed as a fraction of the total carbon using a carbon storage factor. Using the proposed approach, the permanently sequestered carbon is calculated by simply multiplying the amount of carbon placed in an anaerobic landfill by the appropriate carbon storage factor. IPCC uses essentially the same approach in its default method for estimating greenhouse gases from landfills (IPCC 1997).

Although a number of studies have characterized the decomposition of mixed municipal solid waste, at present, the best data for deriving carbon storage factors for paper and paperboard products are the laboratory data developed for USEPA by Dr. Barlaz and reported in USEPA 2002. Using the assumptions noted in the following table, NCASI has used the USEPA data to derive carbon storage factors shown in the table.

Table 2. Carbon Storage Factors for Forest Products in Landfills

Material		USEPA Carbon Storage Factor (USEPA 2002) - carbon to dry weight basis -	Assumed Carbon Content	Converted Carbon Storage Factor - carbon to carbon basis -
USEPA Description	Suggested Description	(tons of C sequestered per ton of dry material)	(tons of C per ton of dry material)	(tons of C sequestered per ton of C in material)
Corrugated Cardboard	Corrugated Containers, Containerboard, Paperboard and other uncoated materials comprised primarily of unbleached chemical pulp fibers	0.26	0.45	0.58
Magazines and Third class mail	Coated papers	0.34	0.40	0.85
Newspapers	Newpapers and other uncoated papers comprised primarily of mechanical pulp	0.42	0.45	0.93
Office Papers	Uncoated papers comprised primarily of bleached chemical pulp fibers	0.05	0.45	0.11
Branches – EPA also uses this value for wood and wood products		0.38		
Wood and wood products	Wood and wood products			0.85*
* Based on NCASI analysis of data published by Gardner 2002				

The table shows two sets of values for wood and wood products. The USEPA publication includes only data for tree branches and USEPA has used the tree branch-derived data to represent wood and wood products. There are some obvious shortcomings with this approach – e.g. tree branches contain volatile organic compounds not present in forest products and the moisture content of branches is much higher than most wood products. Recently, researchers at the State Forests of New South Wales have examined the fate of wood products in landfills. They determined that in one case, 4.1% of the carbon was lost in 19 years while in a second case, 2.5% of the carbon was lost in 29 years (Gardner 2002). If these data are fit to a first order decay model, they suggest that the 100-year carbon storage factors (gram carbon sequestered per gram of carbon in the original material) would be 0.80 and 0.91, respectively. Based on these data, NCASI is recommending that a carbon storage factor of 0.85 be used for wood products in landfills.

Greenhouse gases associated with forest product decomposition in landfills

As forest products slowly decay in landfills, they are eventually converted into carbon dioxide (CO_2) and methane (CH_4). The carbon dioxide, because it is derived from biomass, is climate-neutral. The methane, however, is returned to the atmosphere in a different and more potent form than was removed from the atmosphere. Methane, therefore, is counted as a greenhouse gas emission - currently considered to be 21 times more potent than an equal weight of CO_2.

In national accounting, methane releases from landfills are currently done independently of estimates of carbon sequestration in landfills. Methane emissions from landfills are reported in the IPCC Sectoral Tables for Wastes, which include landfill methane from all sources, not just forest products. Carbon sequestration in landfills is reported in the Land Use, Land Use Change, and Forestry Sectoral Tables (IPCC 1997a). In national accounting, there is no attempt, nor is it possible, to connect the two estimates to determine the net position of harvested wood products in landfills.

In value chain assessments, however, it may be important to understand not only the carbon sequestration benefits of forest products in landfills, but also the implications of the methane releases from those products. The intended use of the assessment will determine whether it is necessary to include an analysis of landfill gases.

The methane generated from decomposing forest products can be estimated from the carbon storage factors and other parameters using Equation 4. The equation was developed by combining multiple equations describing the mass balance of carbon through the following steps:

- starting at the mill
- partitioning between permanent sequestration during use and not sequestered during use
- partitioning carbon discards into fractions recycled and disposed,
- partitioning the disposed fraction into landfill disposal and all other disposal
- partitioning carbon in the landfill between sequestered and degradable carbon,
- converting degradable carbon into CO_2 and CH_4,
- converting some of the of CH_4 into CO_2 in gas recovery and landfill cover systems, and
- converting all of the emissions and removals into units of carbon equivalents.

Equation 4:

$$CH_4R = 3.818 * FrC * (1\text{-}SQ) * (1\text{-}RR) * FrFill * (1\text{-}CSF) * (0.9 - (0.675 * FrCov))$$

Where:

CH_4R = methane releases, ton carbon equivalents per ton of original production
FrC = fraction of carbon in original production
SQ = fraction of product remaining permanently sequestered in-use (see Table 1)
RR = fraction of discarded material recovered for reuse/recycle
FrFill = fraction of non-recovered material that is landfilled
CSF = fraction of carbon in landfilled material that is permanently sequestered (see Table 2)
FrCov = fraction of landfills that are covered with effective gas recovery systems

Note: Equation 4, like IPCC's method, assumes as a default, that gas collection systems are 75% efficient and 10% of methane migrating through landfill covers is oxidized to CO_2.

Applying the carbon sequestration and landfill gas equations to develop the carbon profile of the forest products in landfills is straightforward, as illustrated in the following examples.

Example 3:

The company in Example 1 estimated that its 5 million tons of annual production of plywood contained 2.5 million tons of carbon, 375,000 tons of which (15%) was going to be sequestered in-use. The company assumes that the recovery and reuse rates for products made from plywood are low enough that they can bee assumed to be zero. The company knows that in its markets, about 65% of organic waste is burned for energy, 10% is composted, and 25% is landfilled. Also, the company knows that about 20% of the landfills have modern gas collection systems. The company uses the recommended carbon storage factor for wood products, CSF=0.85. The carbon sequestered in the landfill and the offsetting methane emissions are then calculated as follows.

Carbon sequestered in landfill = 0.85 * 531,250 = 451,563

Methane (C equivalents) per ton of production calculated from equation 4.

= 3.8182*0.5*(1 - 0.15)*(1 - 0)*0.25*(1 - 0.85)*(0.9 – (0.675*0.2))
= 0.04655 tons C equiv./ton production

Methane emissions, tons C equivalents = 0.04655 * 5,000,000 = 232,760 CH_4 in tons C equiv.

Example 4

The company in Example 2 estimated that its 5 million tons of annual production of uncoated free sheet contained 45% carbon by weight (2.25 million tons of carbon), 112,500 tons of which was going to be sequestered in-use. In the company's markets, the recovery rate for products made from free sheet is 60%. The company knows that about 65% of organic waste is burned for energy, 10% is composted, and 25% is landfilled. Also, the company knows that about 20% of the landfills have modern gas collection systems. The company uses the recommended carbon storage factor for wood products, CSF=0.11. The carbon sequestered in the landfill and the offsetting methane emissions are then calculated as follows.

Carbon sequestered in landfill = 0.11 * 213,750 = 23,513 t C

Methane emissions (C equivalents) per ton of production from equation 4.

= 3.8182 * 0.45 * (1-.05) * (1-0.6) * 0.25 * (1-0.11) *) * (0.9 – (0.675*0.2))
= 0.1111 tons C equiv/ton production

Methane emissions = 0.1111 * 5,000,000 = 555,669 tons carbon equivalents

GENERAL OBSERVATIONS REGARDING CARBON SEQUESTRATION IN FOREST PRODUCTS IN USE AND IN LANDFILLS

For purposes of describing the sequestration potential of the industry's products, it is possible to divide these products into three general categtories;

- wood products, which are characterized by relatively long times-in-use, and slow degradation in landfills,
- slowly degrading paper and paperboard products (i.e. those that are either coated or are comprised mostly of mechanical fibers), and
- highly degradable paper and paperboard products (i.e. those that are uncoated and comprised primarily of chemical pulp fibers).

Wood products sequester substantial quantities of carbon during use as well as in the landfill, even after correcting for landfill methane emissions Averaged across all wood products, it appears that 10 to 25% or more of the carbon in the industry's wood products production is permanently sequestered during use (i.e. will be sequestered for at least 100 years). It appears likely that another 20% or more is sequestered in landfills, even after correcting for methane emissions. Overall, therefore, approximately 40% of the carbon in wood products is removed from the atmosphere. This amounts to approximatley 0.20 tons of carbon equivalents for every ton of wood products production.

For paper and paperboard products, as much as 7% of the carbon in the production can be expected to remain in use for 100 years. For those grades that degrade only very slowly in landfills (i.e. newsprint, coated materials, and materials whose physical form prevents bacterial attack) recovery rates and disposal practices vary enough from one country to another to have a significant effect on net sequestration in landfills. In countries with lower recovery rates and extensive reliance on landfills, the net carbon sequestration in the landfill (corrected for methane emissions) is approximately 20% of the carbon in the original product. In areas with high recovery rates and few landfills net sequestration is approximately 5% of the original carbon in industry production (after correcting for methane emissions). For these products, net sequestration appears unlikely to become negative (i.e. net emissions appear unlikely) under a range of reasonable scenarios. Overall, slowly degrading paper and paperboard products sequester up to 7% of the carbon during use and another 5% to 20% of the original carbon in the landfill (after correcting for methane emissions). Together, this totals approximately 0.03 to 0.1 tons of carbon equivalents sequestered for every ton of these products manufactured by the industry.

Paper and paperboard products that degrade fairly completely in landfills (i.e. uncoated paper and paperboard made primarily from chemical pulp fiber) also sequester up to 7% of the carbon during use, but the landfill balance is very different from other forest products. The net sequestration accomplished by these materials in the landfill is likely to be negative, meaning that the methane emitted is expected to be greater, on a carbon equivalents basis, than the carbon sequestered. Again, the landfill sequestration profile for these products differs significantly among countries. In countries with lower recovery rates and extensive reliance on landfills, the net carbon sequestration in the landfill (corrected for methane emissions) is –20% or more of the carbon in the original product. (Negative sequestration represents an emission.) In areas with high recovery rates and few landfills, net sequestration is approximately –1% to –15% of the original carbon in industry production (after correcting for methane emissions). Overall, considering both products in use and in landfills, the net sequestration accomplished by rapidly degrading paper and paperboard products is zero to negative (i.e. represents emissions) under most scenarios. Depending on national circumstances and the particular product in question, the net sequestration accomplished by rapidly degrading products probably ranges from 0.02 tons sequestered to 0.2 tons or more of carbon equivalents emitted for every ton of these products manufactured by the industry.

The climate footprint of the post-manufacture value chain of the forest products industry, of course, consists of much more than the sequestration profile of forest products. Topics not addressed in this report include the value of biomass energy derived from non-recycled forest products, the energy efficiency and GHG advantages associated with many forest-based products compared to alternatives, and the importance of forest products as a source of economic incentive to keep land in forest.

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