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THE GREENHOUSE GAS AND CARBON PROFILE OF THE GLOBAL FOREST PRODUCTS INDUSTRY

SPECIAL REPORT NO. 07-02
FEBRUARY 2007

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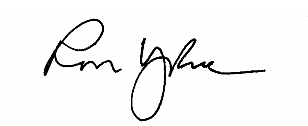
PRESIDENT'S NOTE

The connections between the climate change issue and the forest products industry are 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 in the forest ecosystem and ultimately in forest products. Most of the industry's manufacturing facilities require fossil fuels and these fuels generate greenhouse gases when burned. The industry obtains much of its energy, however, from carbon neutral biomass fuels. The forest products industry is one of the leaders in using co-generation, also known as combined heat and power (CHP), which is far more efficient than conventional electricity generation, meaning that smaller amounts of fuel are required and fewer greenhouse gases emitted. 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.

In this report, accepted international carbon and greenhouse gas accounting protocols have been used to characterize these and other elements of the carbon and greenhouse gas profile of the global forest products industry. Although there are significant uncertainties associated with some of the estimates, the analysis indicates that the greenhouse gas emissions that occur throughout the forest products industry's value chain are largely offset by sequestration. Avoided emissions associated with the use of biomass fuels, CHP, and recycling further enhance the industry's global greenhouse gas and carbon profile. An examination of the forces at work suggests that the industry's global carbon and greenhouse gas profile will continue to improve over time.



Ronald A. Yeske

February 2007

MOT DU PRÉSIDENT

Les liens entre les enjeux associés aux changements climatiques et l'industrie des produits forestiers sont plus complexes que ceux des autres industries. Les forêts qui fournissent la matière première pour l'industrie retire le dioxyde de carbone de l'atmosphère et emmagasine le carbone dans l'écosystème forestier et ultimement, dans les produits forestiers. La plupart des installations manufacturières de l'industrie utilisent des combustibles fossiles et ces derniers génèrent des gaz à effet de serre lorsqu'ils sont brûlés. Toutefois, l'industrie obtient la majeure partie de son énergie de la biomasse, soit un combustible neutre en carbone. L'industrie des produits forestiers est un des chefs de file en matière de cogénération, aussi connue sous le vocable « production combinée de chaleur et d'énergie » (PCCE), la cogénération étant de loin plus efficace que la production conventionnelle d'électricité. Ceci signifie que des plus petites quantités de combustibles sont nécessaires et par conséquent, moins de gaz à effet de serre sont émis. Les options de gestion en fin de vie des produits forestiers, allant du recyclage à l'enfouissement et la combustion pour récupérer l'énergie, génèrent des répercussions importantes mais complexes sur les gaz à effet de serre et le carbone.

Dans ce rapport, nous avons utilisé les protocoles internationaux reconnus pour comptabiliser le carbone et les gaz à effet de serre afin de les caractériser et de caractériser d'autres éléments du profil de carbone et de gaz à effet de serre de l'ensemble de l'industrie des produits forestiers. Bien qu'il y ait d'importantes incertitudes associées à quelques uns des estimés, l'analyse indique que les émissions de gaz à effet de serre qui surviennent dans la chaîne de valeur de l'industrie des produits forestiers sont largement compensées par la séquestration. L'utilisation des combustibles à base de biomasse, la PCCE et le recyclage avancé permet d'éviter des émissions, ce qui rehausse le profil global de l'industrie pour ce qui est des gaz à effet de serre et du carbone. L'examen des efforts déployés à ce jour nous incite à croire que ce profil continuera à s'améliorer avec le temps.

Ronald A. Yeske

Février 2007

THE GREENHOUSE GAS AND CARBON PROFILE OF THE GLOBAL FOREST PRODUCTS INDUSTRY

SPECIAL REPORT NO. 07-02
FEBRUARY 2007

ABSTRACT

The global forest products industry's carbon and greenhouse gas profile is composed of emissions, sequestration, and avoided emissions. Emissions from the forest products value chain are comprised of direct emissions from manufacturing (~260 million tonnes CO_2 per year), as well as a number of different types of indirect emissions including those associated with electricity purchases (~190 million tonnes CO_2 per year), transport (~70 million tonnes CO_2 per year) and methane from discarded forest products in landfills (~250 million tonnes CO_2 equivalents per year). Carbon is sequestered in forests used to supply fiber to the industry (net sequestration of at least 60 million tonnes CO_2 per year) and in forest products (~540 million tonnes CO_2 per year). Avoided emissions, which further enhance the industry's global profile, are associated with the industry's use of biomass fuels (~175 million tonnes CO_2 avoided per year), combined heat and power (~95 million tonnes CO_2 avoided per year), recycling (~150 million tonnes CO_2 equivalents avoided per year) and product substitution effects (not possible to estimate on global basis)[*]. Although the estimates are subject to considerable uncertainty, they clearly indicate that the greenhouse gas emissions that occur along the forest products industry value chain are largely offset by sequestration.

Net emissions from the global forest products industry value chain are expected to decline for several important reasons. First, the industry is expected to continue to reduce the carbon intensity of manufacturing. Second, landfill methane releases are expected to continue to decline because of efforts to control what is placed in landfills and the growth in the use of landfills designed and operated to minimize methane releases. Third, carbon sequestration in products will become an even larger piece of the industry's profile as the demand for forest products increases in response to population growth and increasing standards of living.

Continued progress in improving the industry's greenhouse gas and carbon profile will depend on industry maintaining its efforts to reduce emissions intensity. Private investment and public policies will also be needed to ensure adequate supplies of biomass for raw material and fuel. Also critical will be policies that keep forest products out of landfills and control methane releases from landfills.

KEYWORDS

carbon, climate change, global industry profile, greenhouse gases, life cycle, sequestration

RELATED NCASI PUBLICATIONS

Special Report No. 04-03 (August 2004). *An analysis of the methods used to address the carbon cycle in wood and paper product LCA studies*.

Carbon sequestration in forest products along the value chain. (December 2003).

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[*] Avoided emissions are included here to illustrate several important connections between the industry and the global carbon cycle. The question of how avoided emissions should be included in a greenhouse gas balance sheet is a policy issue beyond the scope of this report. [Footnote added April 11, 2007.]

LE PROFIL DES GAZ À EFFET DE SERRE ET DU CARBONE DE L'ENSEMBLE DE L'INDUSTRIE DES PRODUITS FORESTIERS

RAPPORT SPÉCIAL NO. 07-02
FÉVRIER 2007

RÉSUMÉ

Le profil des gaz à effet de serre et du carbone de l'ensemble de l'industrie des produits forestiers est composé d'émissions, de séquestration et d'émissions évitées. Les émissions associées à la chaîne de valeur des produits forestiers comprennent des émissions directes provenant des activités de fabrication (~260 millions de tonnes de CO_2 par année) de même qu'un nombre d'émissions indirectes de différents types, incluant celles associées aux achats d'électricité (~190 millions de tonnes de CO_2 par année), au transport (~70 millions de tonnes de CO_2 par année) et au méthane émis par les produits forestiers éliminés dans les sites d'enfouissement (~250 millions de tonnes d'équivalent CO_2 par année). Le carbone est séquestré par les forêts destinées à alimenter en fibres l'industrie (séquestration nette d'au moins 60 millions de tonnes de CO_2 par année) et dans les produits forestiers (~540 millions de tonnes de CO_2 par année). Les émissions évitées, qui rehaussent le profil global de l'industrie, proviennent de l'utilisation de combustibles à base de biomasse par l'industrie (~175 millions de tonnes de CO_2 évitées par année), de la production combinée de chaleur et d'énergie (~95 millions de tonnes de CO_2 évitées par année), du recyclage (~150 millions de tonnes d'équivalent CO_2 évitées par année) et des effets associés à la substitution de produits (impossibles à estimer sur à l'échelle globale)*. Bien qu'une incertitude considérable entoure les estimés, ils indiquent clairement que les émissions de gaz à effet de serre qui surviennent tout au long de la chaîne de valeur de l'industrie des produits forestiers sont largement compensées par la séquestration.

Un déclin des émissions nettes de la chaîne de valeur de l'ensemble de l'industrie des produits forestiers est prévu et ce, pour plusieurs raisons importantes. D'abord, l'industrie continuera à réduire l'intensité de carbone associé à la fabrication. Deuxièmement, les rejets de méthane des sites d'enfouissement continueront de baisser suite aux efforts de contrôle des matériaux éliminés dans les sites d'enfouissement et l'augmentation de l'utilisation de sites conçus et opérés pour minimiser les rejets de méthane. Enfin, la séquestration du carbone dans les produits deviendra un élément encore plus important du profil de l'industrie puisque la demande en produits forestiers augmente en réponse l'accroissement de la population et des standards de vie.

Les progrès visant à améliorer le profil des gaz à effet de serre et du carbone de l'industrie dépendront de la capacité de l'industrie à maintenir ses efforts pour réduire l'intensité des émissions. Les investissements privés et les politiques publiques seront également requis afin d'assurer l'alimentation adéquate en biomasse comme matière première et combustible. De plus, les politiques visant à éviter l'élimination des produits forestiers dans les sites d'enfouissement et à contrôler les rejets de méthane de ces sites joueront un rôle décisif.

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* *Les émissions évitées figurent dans le présent rapport afin de faire ressortir plusieurs liens importants entre l'industrie et le cycle mondial du carbone. Comment inclure les émissions évitées dans un bilan sur les gaz à effet de serre? Comme cette question est de nature stratégique, elle dépasse le cadre du présent rapport. [Note de bas de page ajoutée le 11 avril 2007.]*

MOTS CLÉS

carbone, changements climatiques, profil global de l'industrie, gaz à effet de serre, cycle de vie, séquestration

AUTRES PUBLICATIONS DE NCASI DANS CE DOMAINE

Rapport spécial no. 04-03 (août 2004). *An analysis of the methods used to address the carbon cycle in wood and paper product LCA studies*.

Carbon sequestration in forest products along the value chain. (décembre 2003).

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TABLES

THE GREENHOUSE GAS AND CARBON PROFILE OF THE GLOBAL FOREST PRODUCTS INDUSTRY

1.0 INTRODUCTION

Conceptually, the forest products industry's carbon and greenhouse gas profile can be divided into three distinct parts: emissions, sequestration, and avoided emissions. Emissions consist of transfers of greenhouse gases to the atmosphere from forest products industry facilities or from elsewhere in the forest products industry value chain. These emissions consist primarily of carbon dioxide from fossil fuel combustion and methane from decomposition of discarded products in landfills. The sequestration component of the industry's profile consists of carbon contained in, and transferred between, forests, forest products, and landfills. The avoided emissions component of the forest products industry's profile consists of the emissions that would have occurred were it not for certain industry activities. Key among these are a) the emissions from combustion of fossil fuels that would have occurred if the industry did not rely so heavily on biomass fuels, and b) the emissions of methane from landfills that would have occurred if paper was not recycled.

The methods for combining the different components into an overall picture of the industry's profile remain controversial. Nonetheless, there is little question that all of these can contribute to the industry's effect on atmospheric greenhouse gases.

Many of these aspects of the industry's greenhouse gas and carbon profile were examined by Subak and Craighill (1999). Since then, methods and data have evolved for estimating the different components of the profile. In addition, this earlier work did not address several aspects of carbon sequestration and avoided emissions. For these reasons, and because significant time has passed since that analysis was done, this paper revisits the issue of the characteristics of the different components of the forest product industry's global greenhouse gas and carbon profile.

Below we examine, in turn, the significance of emissions, sequestration, and avoided emissions. It must be emphasized that the relative importance of the different pieces of the industry's carbon and greenhouse gas (GHG) profile will vary in different regions. For example, methane emissions from decaying forest products in landfills are expected to be less significant in Europe and Japan than in North America due to differences in paper recovery rates and differences in policies to keep biodegradable materials out of landfills. On the other hand, the net sequestration in forest products is expected to be relatively more important in North America where more wood is used in long-lived products, housing in particular. In addition, different types of forest products will have different profiles with, for instance, paper products storing less carbon in use and contributing more to methane emissions from landfills than wood products.

2.0 GREENHOUSE GAS EMISSIONS FROM THE FOREST PRODUCTS INDUSTRY VALUE CHAIN

Life cycle studies have determined that most of the greenhouse gas emissions from the forest products value chain come from four sources:

1. fossil fuel combustion at industry facilities,
2. fossil fuel combustion by the producers of electricity that the industry purchases,
3. fossil fuel combustion associated with the transport of the industry's raw materials and products, and
4. methane emissions attributable to the anaerobic decomposition of forest products in municipal solid waste (MSW) landfills.

The first of these consists largely of "direct emissions," i.e., emissions that occur from sources owned or controlled by forest product industry companies. Emissions associated with purchased power are called "indirect emissions" because they originate from a source that is not owned or controlled by the industry but they occur as a result of the industry's activities. Transportation emissions can be direct, if the sources are owned by the industry, or indirect if the sources are owned by other entities. Emissions of methane from MSW landfills are indirect because, with few exceptions, MSW landfills are owned or controlled by companies or public entities outside of the industry.

2.1 Direct Emissions from the Forest Products Industry Manufacturing Facilities

Almost all of the greenhouse gas emissions from forest products industry manufacturing facilities are the result of fossil fuel combustion. The industry also burns large quantities of biomass fuels but the CO_2 released from biomass combustion is not included in greenhouse gas totals because it contains biogenic carbon that is part of a natural cycle. It is for this reason that biomass-derived CO_2 is called "carbon neutral." Small amounts of nitrous oxide and methane are also released during the combustion biomass fuels and fossil fuels.

Greenhouse gas emissions estimates are published by a number of national pulp and paper associations and government agencies. To develop global estimates, these data have been extrapolated to global totals using production data for paper and paperboard from the United Nations Food and Agriculture Organization (FAO) and for market pulp from *Pulp and Paper Magazine* (FAO 2006a; Pulp and Paper 2005).

Greenhouse gas emissions data representing the period of 2002 to 2004 were obtained for the U.S. (USDOE 2002), Canada (Environment Canada 2004), Europe (CEPI 2005, 2006), Japan (JPA 2006), and Australia (A3P 2005). It was determined that together, these regions represent 67% of global production of market pulp, paper, and paperboard. By extrapolating the emissions from these regions to the rest of the world, one can calculate that the global pulp and paper industry emits 198 million tonnes of CO_2 per year.

The International Energy Agency (IEA) 2004 data on sector fuel use in OECD countries can also be used to estimate greenhouse gas releases (IEA 2006). Using these data and generic emission factors for fuels, the emissions from the pulp and paper industry in OECD countries are estimated to be 136 million tonnes CO_2 per year. Using the same sources of production data as discussed above (FAO 2006a; Pulp and Paper 2005), this can be extrapolated to a global estimate of 191 million tonnes of CO_2 per year, a value that agrees closely with the estimate based on extrapolated association data.

Using a mid-point estimate between these two, the global pulp and paper industry direct emissions of greenhouse gases is estimated to be 195 million tonnes CO_2 per year associated with fossil fuel use.

Data on greenhouse gas emissions from wood products facilities (primarily lumber mills and panel plants) are very scarce. Therefore, estimates for this sector of the industry have been developed using only fuel consumption data from the International Energy Agency. Greenhouse gas emissions from OECD wood products facilities are estimated to be 16.4 million tonnes CO_2 in 2004. Based on FAO data, OECD countries are estimated to produce 64.6% of the world's sawnwood and wood-based panels, so that global emissions associated with fossil fuel use at wood products facilities can be estimated to be approximately 25 million tonnes of CO_2.

Total direct greenhouse gas emissions related to fossil fuel combustion at forest products industry facilities are therefore estimated to be 220 million tonnes CO_2 per year. This represents about 0.9% of global fossil fuel-related CO_2 emissions, estimated by IEA to be 23,683 million tonnes CO_2 in 2001 (IEA 2003).

The combustion of fossil fuels can result in the release of small amounts of methane and nitrous oxide. Biomass fuels, which supply about one-half of the industry's fuel (WBCSD 2005), can also be associated with these releases. The emission factors in Table 2.1 suggest that CH_4 and N_2O emissions amount to 5% or less of the CO_2 emissions from fossil fuel combustion. Therefore, to account for non-CO_2 emissions, the CO_2 emissions estimated above for the paper industry have been increased by 5% to yield an estimate of total combustion-related direct GHG emissions of approximately 230 million tonnes CO_2 equivalents (205 million for pulp and paper and 25 million for wood products).

Table 2.1 Greenhouse Gas Emission Factors for Fossil and Biomass Fuels

		Emissions (kg gas/TJ)	Emissions (kg CO_2 equivalents/TJ)
Fossil fuel			
	CO_2	55,000 to 125,000 kg CO_2/TJ	55,000 to 125,000
	CH_4 *	0.3 to 10 kg CH_4/TJ	6 to 210
	N_2O *	0.03 to 5 kg N_2O/TJ	9 to 1550
Biomass fuel			
	CO_2	0.0 kg CO_2/TJ	0.0
	CH_4 **	<1 to 41 kg CH_4/TJ	<21 to 861
	N_2O **	<1 to 8.8 kg N_2O/TJ	<310 to 2730

* Tier 1 emission factors from IPCC 2006
** NCASI 2005

Examination of a number of GHG inventories suggests that the only significant non-combustion-related emissions are methane emissions from landfills, and perhaps from anaerobic wastewater treatment plants. Analysis of unpublished information suggests that these methane emissions constitute less than (and probably much less than) 10% of direct GHG emissions from forest product industry operations. An estimate of approximately 20 million tonnes CO_2 equivalents per year appears reasonable.

In many cases, primary products are further processed to yield final products. In most cases, however, these operations emit low quantities of greenhouse gases compared to primary manufacturing. Data from the U.S. Department of Energy, for instance, indicate that the "printing and related support industries," which includes some facilities that print on non-paper surfaces, have direct emissions that are only 4% of those from the paper and paperboard industry (USDOE 2005). A life cycle study of magazines in North America found that greenhouse gas emissions attributable to printing were 3 to 7% of those from pulp and paper manufacturing (Gower et al. 2006). For some paper products, copy paper for instance, almost no additional greenhouse gases are generated in converting the primary product, e.g., converting rolls of paper into cut sheets. Life cycle studies of houses in Europe have found that the emissions resulting from house construction (not including worker transport) are less than 10% of the embodied greenhouse gas emissions in the building materials (Cole 1999). In total, the available information suggests that, for purposes of developing the forest products industry's greenhouse gas profile, it is reasonable to assume that secondary manufacturing operations are responsible for emissions equal to 10% of those from primary manufacturing. This amounts to approximately 25 million tonnes of CO_2 equivalents per year. These emissions consist of a combination of direct emissions and indirect emissions associated with purchased electricity, but the precise breakdown is not known. For purposes of this exercise it is assumed that the emissions are evenly divided between these two types, meaning that direct emissions from secondary manufacturing are estimated to be 12 million tonnes CO_2 per year. This brings the total manufacturing-related emissions to 262 million tonnes CO_2 equivalents per year.

In terms of the range of uncertainties encountered in developing a global carbon and GHG footprint for the forest products industry, the uncertainty associated with direct emissions estimates is considered relatively low. In the judgment of the authors, the uncertainty around the estimate is likely to be +/-20%. The industry's direct emissions are summarized in the Table 2.2.

Table 2.2 Direct Emissions from the Global Forest Products Value Chain

Direct emissions source	Emissions* (10^6 tonnes CO_2 equiv. per year)	Uncertainty, based on professional judgment
Fuel consumption at pulp and paper mills	205	+/- 15%
Fuel consumption at wood products facilities	25	+/- 25%
Management of mill wastes	20	+/- 25%
Secondary manufacturing operations (i.e., converting primary products into final products)	12	+/- 50%
Total	262	+/- 20%

* Considering biomass CO_2 to be carbon neutral, but including CH_4 and N_2O from all combustion processes.

2.2 Indirect Emissions Associated with Purchases of Electricity

For pulp and paper mills, emissions associated with purchased electricity can be derived from either a) indirect emissions estimates from national associations and national governments, or b) data on electricity purchases, and purchased electricity emission factors that are country-specific, or multi-national in the case of Europe (USDOE 2002; CEPI 2005, 2006; JPA 2006; A3P 2005; EC 2002). The data are extrapolated to the globe using the methods described above for direct emissions data. Using this approach and data on indirect emissions or power purchases by the pulp and paper industry in the U.S., Europe, Japan, and Australia, it is estimated the electricity purchased by the global pulp and paper industry is responsible for the indirect emissions of approximately 140 million tonnes of CO_2 per year. IEA (2006) reports only electricity consumption, which includes on-site production, a substantial component of consumption at pulp and paper mills, so the IEA data cannot be used to develop estimates of indirect emissions from purchased power.

Because wood products facilities seldom produce power on site, however, it is reasonable to assume that electricity consumption at wood products facilities equals electricity purchases. IEA (2006) reports that wood products facilities in OECD countries consumed (purchased) 54,184 GWh in 2004. Using an emission factor of 450 tonnes CO_2 per GWh, a factor that is about midway between regions heavily reliant on coal for electricity and those regions that are more reliant on hydropower and nuclear power, electricity purchases by OECD wood products facilities are estimated to account for 25 million tonnes per year of CO_2. Using the FAO data described above to extrapolate to the globe, it is estimated that indirect emissions associated with purchased electricity by wood product facilities are approximately 40 million tonnes CO_2 per year.

The wood products facility estimates can be checked against estimates generated using data from the CORRIM (Consortium for Research on Renewable Industrial Materials) studies (described in Lippke et al. 2004, Perez-Garcia et al. 2005, and Puettmann and Wilson 2005). Using CORRIM emissions data and FAO production data, the global wood products industry is estimated to release 59 million tonnes CO_2, combined direct emissions and indirect emissions associated with purchased power. This compares reasonably with the 65 million tonnes of CO_2 derived by adding the direct (25) and indirect (40) emissions estimates developed above, even considering that the CORRIM-based estimates are derived only from U.S. emissions data and include logging operations whereas the estimates derived from the other sources cited above do not.

Unlike pulp and paper mills, the wood product sector's indirect emissions associated with purchased electricity are larger than its direct emissions. This reflects the fact that wood products facilities rely heavily on biomass fuels for on-site steam generation, reducing direct emissions, but seldom produce power on site, requiring them to purchase electricity. Given the proper incentives, however, more of these facilities could produce biomass-based electricity.

As noted above, emissions associated with purchased power at secondary manufacturing facilities are estimated to be 13 million tonnes CO_2 per year.

Adding indirect emissions from pulp and paper mills to those from wood products facilities and secondary manufacturing yields an estimated 193 million tonnes CO_2 per year of indirect emissions associated with purchased electricity. This represents about 0.7 percent of global emissions of CO_2 from fossil fuel combustion (IEA 2003).

There are several sources of uncertainty associated with these estimates. First, the information on electricity purchases collected by national associations may be developed using a range of methods. Examples of situations where methodological differences may be important include situations where mills both buy and sell power and cases where mills have outsourced "power islands" (i.e., boilers and power generation facilities that are intimately connected to a mill but owned by a separate company). The potential significance of these differences in data collection methods is uncertain, but is likely small compared to other sources of uncertainty in characterizing the industry's global GHG and carbon footprint.

There is also uncertainty in the emission factors used for purchased power. It is likely that in some cases these include minor GHGs while in other cases they do not. In addition, indirect emissions are inherently less precise than estimates of direct emissions because of uncertainties about the fuels used by power producers at specific times and places.

In terms of the range of uncertainties encountered in developing a global carbon and GHG footprint for the forest products industry, the uncertainty associated with estimates of indirect emissions associated with purchased power is considered to be medium. The data are inadequate for developing a quantitative estimate of uncertainty, but in the judgment of the authors, it is reasonable to assume that the estimates are accurate to within +/- 30%. The industry's indirect emissions from purchases of electrical power are summarized in Table 2.3.

Table 2.3 Indirect Emissions Attributable to Purchases of Electrical Power by the Global Forest Products Industry

Indirect emissions source	Emissions (10^6 tonnes CO_2 equiv. per year)	Uncertainty, based on professional judgment
Electricity purchases by pulp and paper mills	140	+/- 25%
Electricity purchases by wood products facilities	40	+/- 50%
Secondary manufacturing operations (i.e., converting primary products into final products)	13	+/- 50%
Total	193	+/- 30%

2.3 Emissions Associated with Procuring and Transporting Raw Materials and Products

Because fossil fuels are used to procure and transport the industry's raw materials and products, these elements of the industry's value chain are associated with the release of greenhouse gas emissions. These emissions are usually a combination of direct and indirect emissions, but for purposes of this footprint they are all shown as indirect because most of these emissions are associated with transportation, a function often provided by outside firms. The amounts of greenhouse gases emitted vary greatly depending on the distances involved and the mode of transport. As a result, estimates for this part of the industry's profile are very uncertain. Of the various raw materials used in the forest products industry, wood fiber is used in much greater quantities than any other raw material. Therefore, the analysis herein focuses on wood fiber procurement and transport, and the subsequent transport of products.

2.3.1 *The Paper and Paperboard Sector*

A study of conditions in the North American pulp and paper industry found that tree harvesting and transport resulted in greenhouse gas emissions that were generally about 10% of virgin manufacturing emissions (direct plus indirect) (PTF 2002). Emissions from collecting recovered paper were about 5% of recycled paper manufacturing emissions (direct plus indirect). Transport of products to markets, unlike transport of raw materials, was found to contribute very little to life cycle greenhouse gas emissions, a finding that does not agree with a number of other studies. Using an estimate of 10% of total (direct and indirect emissions for paper and paperboard manufacture) suggests transport-related emissions approach 40 million tonnes CO_2 per year for the paper and paperboard sector.

A more recent study of the value chain of paper for several North American magazines found that transportation represented 10 to 18% of direct emissions from the mill, or 9% to 14% of combined direct emissions and indirect emissions from purchased power (Gower et. al. 2006)[*]. Using 12% of total emissions from paper and paperboard production (approaching 400 million tonnes CO_2 per year) suggests transport-related emissions of nearly 48 million tonnes CO_2 per year for the paper and paperboard sector.

IIED estimated that paper distribution in Europe results in the emission of 69.3 kg CO_2 per tonne of paper and paperboard (IIED 1996). Applied to annual global production of 350 million tonnes of

[*] The study also includes analysis of a lumber value chain but because unresolved questions remain regarding the study's estimates of transport-related emissions for lumber, the estimates are not used here.

paper and paperboard (FAO 2006a), this suggests transport-related emissions of about 24 million tonnes CO_2 per year for the paper and paperboard sector.

Based on these three estimates, it appears reasonable to suggest that transport accounts for 40 million tonnes CO_2 per year for the paper and paperboard sector.

2.3.2 *The Wood Products Sector*

Fewer studies are available to support estimates of transportation-related emissions associated with wood products. Data developed in the CORRIM research program, and summarized in Puettmann and Wilson 2005, can be used to characterize these emissions, although the resulting estimate is highly uncertain. For purposes of developing the industry's greenhouse gas profile, it is assumed that wood products are transported 2500 km by rail and 60 km by road (with empty backhaul) and that diesel fuel is used. Using this assumption, combined with information in Puettmann and Wilson 2005, and extrapolating to global production of lumber and wood panels, one finds that transportation emissions for the wood products sector are approximately 26 million tonnes CO_2 per year.

Other studies can be used to develop separate estimates of emissions related to raw material procurement (including transport) and product transport. A study of the front half of the transport system found that in Europe, CO_2 emissions from harvesting and transporting (by truck) roundwood to the forest products industry range from 6.3 to 21.7 kg CO_2 equivalents per cubic meter of roundwood depending on the country (Schwaiger and Zimmer 2002). This range is consistent with the results of studies by Berg and Karjalainen (2003) for Sweden and Finland. If a value of 15 kg CO_2 equivalents per cubic meter is applied to global industrial roundwood production of 1.7 billion cubic meters (FAO 2006a), it yields an estimate of global transport-related emissions of 25 million tonnes CO_2 per year. Assuming that one-half of this used in wood products, it suggests that harvest and wood transport is responsible for 13 million tonnes CO_2 per year for the wood products sector. If an adjustment were made to account for the fraction of roundwood that is transported globally by rail or ship, this estimate would be lower. Preharvest activities, particularly burning and fertilization, can be associated with the release of greenhouse gases, but the contribution of these appears to be small relative to wood transport emissions (Sonne 2006) and therefore, they are not considered in this analysis.

Emissions from the back half of the distribution system, i.e., wood products to consumers, can be estimated using the results of a study published by Petersen and Solberg where it was found that transport of oak flooring to the building site was responsible for the emission of approximately 20 kg CO_2 per cubic meter of flooring (Petersen and Solberg 2003). If this is applied to the total global production of sawnwood and wood panel products [660 million cubic meters according to FAO (2006a)] it amounts to about 13 million tonnes of CO_2 per year.

Adding the pre-manufacturing transport emissions (estimate 13 million tonnes CO_2 per year) to the wood product transport emissions (another 13 million tonnes CO_2 per year) yields a total of approximately 26 million tonnes CO_2 per year for transport in the wood products sector, which is identical to that developed above using the CORRIM data.

FAO data indicate that the global production of wood products (lumber and wood panels) is about equal to the amount of pulp and paper on a mass basis, suggesting that transport-related emissions for the wood products sector might be comparable to those for the pulp and paper sector—approximately 40 million tonnes CO_2 per year (FAO 2006a). Given these various estimates, it is reasonable to conclude that transportation-related emissions are approximately 30 million tonnes CO_2 per year for the wood products sector.

Adding the transport-related emissions for pulp and paper to those estimated for wood products yields an estimate of 70 million tonnes of CO_2 per year for the global forest products industry. The uncertainty in this estimate is considered large. In the judgment of the authors, the true value could be different from the estimate by +/- 50%. The industry's indirect emissions associated with procurement and transport of wood fiber and products are summarized in Table 2.4.

Table 2.4 Indirect Emissions Associated with Procuring Wood Fiber and Transport of Wood Fiber and Products

Harvest and Transport-related emissions	Emissions (10^6 tonnes CO_2 equiv. per year)	Uncertainty, based on professional judgment
Pulp and paper sector	40	+/- 50%
Wood products sector	30	+/- 50%
Total	70	+/- 50%

2.4 Methane Emissions Attributable to Forest Products in Landfills

When exposed to anaerobic conditions, as exist in many municipal solid waste (MSW) landfills, forest products can degrade, resulting in the formation of methane and carbon dioxide. Because the carbon dioxide is biogenic in origin, it is not considered in greenhouse gas totals (IPCC 2006), but the methane is considered in greenhouse gas totals because its global warming potential (GWP) is over twenty times that of carbon dioxide. (In current reporting, a GWP of 21 is used for methane, but due to updated information, the GWP is likely to be changed to 23 at some point in the future.)

The methane released from MSW landfills is the result of the decomposition of a range of materials, only a fraction of which are forest products. As a result, estimates of total methane releases from MSW landfills are not appropriate for characterizing the forest products industry's greenhouse gas profile. Instead, it is necessary to estimate the amounts of methane that are released as the result of the decomposition of forest products only.

The amount of methane released to the atmosphere from the decomposition of used forest products in landfills is dependent on a number of factors including

a) the amounts of used products that are discarded;
b) the amounts of discarded products that are landfilled rather than being recycled, burned or used for other purposes;
c) the amounts of landfilled products that are placed in anaerobic landfills (anaerobic conditions are required for methane production);
d) the amounts of carbon in the products that can be decomposed under anaerobic conditions [a significant fraction of the carbon in many forest products is essentially non-degradable under anaerobic conditions (IPCC 2006)];
e) the rate at which the degradable carbon in the product decomposes; and
f) the efficiency of the landfill's design and operating features that result in the destruction of some of the methane into carbon-neutral CO_2 before it can escape to the atmosphere.

These factors are accounted for in the methods published by the Intergovernmental Panel on Climate Change (IPCC) for use in national accounting of carbon in forest products (IPCC 2003, 2006). Therefore the IPCC methods have been used to characterize this part of the forest products industry's greenhouse gas profile. The amounts of products discarded every year are estimated by developing a time series of carbon stocks in products in use. This time series of carbon in products in use reflects each year's new production and the eventual removal from use of previously manufactured products. The time in use is determined using a first order decay curve and the half-life values shown in Table 2.5 (IPCC 2003).

Table 2.5 Representative Half-Lives for Forest Products (IPCC 2003)

	Half-life (years)
Paper products	2
Sawn wood	35
Structural panels	30
Non-structural panels	20

To the extent that the carbon stocks in products in use increase more slowly than the carbon added in new production, the difference represents a discard of carbon in forest products. The discards are managed in a number of ways, with a fraction being discarded in landfills. Assumptions regarding the fraction discarded in landfills are taken from IPCC 2006 and shown in Table 2.6. It must be noted that for this study, it is assumed that the fractions shown below represent the fractions of non-recovered paper going to MSW landfills. An examination of the IPCC values suggests, however, that some of the factors are based on MSW before used paper is recovered for recycling or otherwise removed from the waste stream. In these cases, using these numbers will yield high estimates of paper going to landfill.

Table 2.6 Fraction of Discards Sent to Landfills (IPCC 2006)

Eastern Asia	0.55
South-Central Asia	0.74
South-East Asia	0.59
Africa	0.69
Eastern Europe	0.90
Northern Europe	0.47
Southern Europe	0.85
Western Europe	0.47
Caribbean	0.83
Central America	0.50
South America	0.54
North America	0.58
Oceania	0.85

Using this approach with time in use values for forest products suggested by IPCC (IPCC 2003) and production data from FAO, a time series was developed from 1900 through 2005 (with the last two years being based on estimated production data). Most of the parameters used in the estimates were IPCC default values or were based on them (IPCC 2003, 2006). Where available in IPCC references, regional values for various parameters were used. It was assumed that most of the forest products that are landfilled remain under anaerobic conditions, and as a result, methane generation would be 80% of what would be expected if all of the waste was disposed in anaerobic landfills (i.e. a weighted average methane correction factor of 0.8). The degradation rates used in the calculations were 0.0575 yr^{-1} for paper and 0.03 yr^{-1} for wood products. These are the averages of the rates for wet tropical and dry temperate climates in IPCC 2006. It was also assumed that 50% of the organic carbon was degradable under anaerobic conditions, IPCC's current default assumption (IPCC 2006). Data generated by Barlaz (2004) indicate that many wood products, as well as paper products that are coated or high in lignin, are expected to degrade to a much smaller extent than suggested by IPCC defaults. This would cause the estimates for methane generation derived from the IPCC defaults to be high.

Another very important factor affecting methane emissions estimates is the fraction of MSW landfills globally that are equipped with methane collection systems. Bogner and Matthews developed estimates of global methane releases from MSW landfills assuming that 6.6 to 18.2 percent of the potential methane releases were captured and burned, but noted that these estimates were probably low by 50 to 100% due to underreporting of landfills that burn gas without recovering energy (Bogner and Matthews 2003). As a result, for this analysis, it was assumed 20% of potential releases were collected and burned.

These assumptions yield an estimate of average methane emissions for the period 2000 to 2005 of approximately 250 million tonnes of CO_2 equivalents per year attributable to the decomposition of forest products in landfills. Using IPCC defaults for the fraction of carbon that can be degraded under anaerobic conditions (50%), it can be estimated that about two-thirds of this is attributable to paper products and one-third to wood products. If, for wood products, it is assumed that only 25% of the carbon can be degraded under anaerobic conditions (a value comparable to findings for coated papers and newsprint in Barlaz 2004), the total releases are reduced to about 200 million tonnes, about three-quarters of which are due to paper products rather than wood products.

A report by IIED suggests a best estimate of 12 million tonnes of methane per year from paper in landfills, equaling about 250 million tonnes of CO_2 equivalents per year. (IIED 1996; Subak and Craighill 1999) Although the estimate reported by IIED appears to agree with the estimate derived above, it is important to note that the IIED estimate is based only on paper and paperboard whereas the estimated derived above includes wood products as well. An estimate more comparable to the IIED estimate was obtained in this study setting the landfill degradation rate to zero for wood products. This yielded an estimate of 150 million tonnes of CO2 equivalents attributable to paper and paperboard in landfills. In comparing the IIED estimate with the ones derived herein, it is important to consider that the two estimates were developed using very different approaches.

The results from this study can also be compared to estimates of global landfill methane emissions. These estimates are reported to vary from 9 to 70 million tonnes of methane, or 189 to 1470 tonnes of CO_2 equivalents per year (Bogner and Matthews 2003). The size of this range highlights the uncertainties associated with the estimates attempted above. Bogner and Matthews suggest that within this range, it is most likely that global methane releases from landfills are 16 to 20 million tonnes methane (336 to 420 million tonnes CO_2 equivalents) per year (Bogner and Matthews 2003).

Methane emissions from MSW landfills in the United States, the EU-15, and Japan combined amount to approximately 210 million tonnes of CO_2 equivalents (EC 2005; USEPA 2006a; and MOE 2006). According to World Bank statistics, these three regions represent approximately 40% to 60% of global gross domestic product, suggesting that an estimate of global MSW methane releases of 336 to 420 million tonnes CO_2 equivalents is not unreasonable.

Of course, landfill methane is generated from waste materials besides discarded forest products so it would be expected that the estimates for total landfill methane releases would be larger than those attributable only to forest products. If global methane releases from landfills are 336 to 420 million tonnes CO_2 equivalents per year, and forest products are responsible for 250 million tonnes of CO_2 equivalents per year, one can estimate that decomposing forest products are responsible for as much as two-thirds of global landfill methane emissions.

This can be checked against information collected in the United States. U.S. emissions of methane from MSW landfills have been reported to be 141 million metric tonnes CO_2 equivalents in 2004 (USEPA 2006a). If it is assumed that two-thirds of this is due to paper and wood products, it can be estimated that about 95 million tonnes of CO_2 equivalents of methane are attributable to forest products in landfills. The U.S. accounts for approximately 30% of global consumption of pulp, paper and wood products (FAO 2005), and probably a larger than 30% share of landfilled forest products globally because relatively more paper and wood are landfilled in the United States than in many other developed countries. An estimate of 250 million tonnes of CO_2 equivalents of emissions attributable to decomposition of forest products globally, therefore, does not appear unreasonable.

In calculations described above, IPCC default values were used to estimate that 150 million tonnes, or about 60%, of global methane emissions attributable to forest products in landfills originate in paper and paperboard. Other data suggest that the relative contribution of certain types of paper may be particularly significant. Data generated by Barlaz (2004) suggest that much of the methane released from decaying forest products is attributable to paper and paperboard products that are low in lignin content and are uncoated (Barlaz 2004). Keeping such materials out of landfills would be expected to have a disproportionately large impact on methane production.

It is important to note that since the early 1990s landfill methane emissions have been declining in many countries as a result of efforts to divert organic material from landfills (by increasing the recovery of used forest products, for instance), and requirements for landfills to capture and burn methane (EC 2005; USEPA 2006a; and MOE 2006). For instance, emissions of methane from MSW landfills have decreased by about 35% in Europe and Japan since 1990 and by 18% in the United States. It is to be expected, therefore, that the significance of this element of the industry's greenhouse gas profile will diminish with time.

Due to the many assumptions in this estimate and the uncertainties in much of the underlying data, the uncertainty in the estimate must be characterized as very high. In the judgment of the authors, the estimate could be in error by a factor of two (i.e., -50% to +100%). See Table 2.7 This large uncertainty appears warranted given the range in estimates of total landfill methane emissions globally reported by Bogner and Matthews (2003).

Table 2.7 Indirect Emissions of Methane from Municipal Solid Waste Landfills Attributable to Decomposing Forest Products

Methane emissions from forest products decomposition in anaerobic municipal solid waste landfills	Emissions (10^6 tonnes CO_2 equiv. per year)	Uncertainty, based on professional judgment
Attributable to paper products	156	
Attributable to wood products	94	
Total	250	-50% to +100%

3.0 CARBON SEQUESTRATION IN THE FOREST PRODUCTS INDUSTRY VALUE CHAIN

3.1 Accounting for Forest Carbon

Carbon dioxide is removed from the atmosphere by trees and stored for a period before being returned to the atmosphere. The sequestered carbon is stored not only in trees. It is also stored in forest products for periods ranging from days to centuries. If the amounts of carbon removed from the atmosphere by forests are exactly balanced by the amounts of forest-derived carbon returning to the atmosphere (as a result of biomass combustion and the decay of organic matter in forests and wood products) the net effect on the atmosphere is zero – i.e., atmospheric levels of CO_2 do not change.

But in any given year, the amounts of carbon removed from the atmosphere by forests may not match the amounts returned to the atmosphere so methods are required to estimate the effects of forest carbon movement on atmospheric levels of CO_2. There are two basic approaches to tracking forest carbon through the forest products value chain. The first looks at the transfers (or flows) of carbon to and from the atmosphere occurring along the value chain. This is called the atmospheric flow approach. The second method looks at the stocks of sequestered carbon along the value chain and estimates the transfers of carbon to or from the atmosphere based on the changes in these stocks. Therefore, it is called the stock change approach (IPCC 2006).

At the global level, the two approaches should yield identical estimates of effects on atmospheric CO_2. The methods are different, however, in how they calculate the net transfer of carbon to (or from) the atmosphere. In the atmospheric flow approach, the net transfer of carbon to (or from) the atmosphere is calculated by summing all of the transfers that occur along the value chain. Specifically, the carbon removed from the atmosphere in the forest is netted against all of the transfers back to the atmosphere along the value chain. Under the stock change approach, the net transfer of carbon to (or from) the atmosphere is calculated by summing all of the changes in the stocks of carbon in forests, products in use, and products in landfills. Because the stock change calculations include all major pools of forest-derived carbon, the net change in carbon stocks across all pools is mathematically equal to the mass of carbon transferred to or from the atmosphere.

In this analysis, we have chosen to use stock change accounting because it is more aligned with the available data (which mostly consist of stock change estimates) and it more readily allows examination of the role of carbon sequestered in different pools along the forest products value chain. Atmospheric flow accounting would give the same overall result but would distribute the transfers differently along the value chain and would not illuminate the role of carbon sequestered in forest products.

3.2 Carbon Sequestration in Forests

Sustainably managed forests not only provide the industry's raw material, they also provide a range of economic and environmental benefits, including the storage and cycling of vast amounts of carbon. It has been estimated that biomass in the world's forests contains 283 billion tonnes of carbon. The global forest ecosystem as a whole, including deadwood, soils, and litter, contains 638 billion tonnes of carbon (FAO 2006b). This is approximately equal to the amount of carbon in the atmosphere (IPCC 2001). The amounts of carbon cycling between global forests and the atmosphere (gross primary productivity) has been estimated to be approximately 85 billion tonnes per year (WBCSD 2005). About 30 billion tonnes of the carbon removed from the atmosphere by forests per year are converted into biomass (net primary productivity), representing about one-half of the biomass production in the terrestrial environment (Sabine et. al. 2004). By comparison, the amounts of carbon removed from forests by the forest products industry are small, amounting to approximately 0.30 to 0.35 billion tonnes per year (WBCSD 2005). The amounts of biomass and carbon in forests are stable or increasing in essentially all developed countries (Kauppi et. al. 2006).

The effects of the forest products industry on forest carbon stocks are difficult to estimate because the industry uses wood from a combination of industrial, non-industrial private, and public forests. In addition, forest ownership patterns vary enormously between countries. In the U.S., for instance, most of the wood used by the forest products industry comes from industrial and non-industrial private forests, while just over the border in Canada, most of the wood comes from government-owned forests. Even for industrial forests, there are few data to support estimates of forest carbon stocks over time, especially at the global scale. Thus, although there are data on national forest carbon stocks, it is very difficult to estimate the stock changes on land that is managed primarily to produce wood for the forest products industry.

3.2.1 *Managed Forests*

Given the requirements of sustainable forestry management programs to employ practices that ensure a continued supply of wood, it is reasonable to assume that carbon stocks in industrial forests managed under sustainable forestry principles are, at worst, stable over time.[*] In fact, it appears likely that an assumption of constant forest carbon stocks understates the carbon benefits of sustainably managed industrial forests. In the U.S. alone, carbon stocks on private timberland[†] are increasing by

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[*] The ability of sustainable forest management practices to maintain carbon stocks has recently been recognized in the U.S. government's program for voluntary reporting of greenhouse gas emission reductions (DOE 2006).
[†] Private timberland meets minimum levels of productivity and is available for timber harvest.

more than 240 million tonnes of CO_2 equivalents per year (Bickel et al. 2004). It appears that about one-quarter of private timberland is managed to produce wood for the forest products industry, suggesting that 60 million tonnes of forest carbon sequestration can be directly attributed to the U.S. forest products industry.* Significant increases in forest carbon stocks have also been reported for Europe and throughout the developed world (FAO 2005; Kauppi et. al. 2006) but the data are inadequate to support an estimate of how much of this occurred on land used for wood production. Significant amounts of carbon are contained in portions of industry-owned forests that are set aside for water quality production, habitat preservation, and other environmental and conservation purposes, and these carbon stocks may be increasing. In addition, carbon is accumulating in significant areas of forest that are not managed primarily for wood production, but which provide wood to the industry nonetheless. In many cases, these forests would be cleared (and the carbon benefits lost) were it not for the income from sales to the forest products industry.

Since forest carbon stocks are increasing in the countries that produce most of the world's forest products (Kauppi et. al. 2006), it is reasonable to suggest that globally, land managed for wood production is currently accumulating carbon at a rate at least equal to the accumulation in land managed to produce wood for the U.S. forest products industry. This amounts to 60 million tonnes CO_2 per year. At a time when global emissions are increasing, this could provide important short- to intermediate-term benefits. Nonetheless, averaged over long times, managed forests probably do not accumulate significant amounts of carbon. The uncertainty in this is estimate is high although the estimate is probably too low. The authors suggest a range of uncertainty of -50% to +100% or more.

3.2.2 *Establishing New Managed Forests*

The global forest products industry can also affect global forest carbon stocks by planting new forests. Where new forests are planted on non-forestlands (i.e., afforestation) the new forest adds to stocks of carbon sequestered in global forests. Where planted forests are established by first clearing natural forests, there can be a net decline in the carbon stored on the affected land area because planted forests managed for wood production often store less carbon than natural forests.

Conversion to planted forests represents a small fraction of annual losses of natural forests. In the tropics, for instance, 90% or more of the natural forests that were lost in the 1990s involved conversion of the land to non-forest uses. Nonetheless, it has been estimated that in this same period about 50% of new plantations established globally were established via conversion of natural forests with the remaining 50% involving establishment of forests on previously unforested land (FAO 2001).

At least one study has suggested that the net effect of establishing new managed forests has been to increase global stocks of sequestered carbon. Subak and Craighill (1999) examined the carbon gained through establishing new plantations as well as the carbon lost due to conversion of natural forests to plantations. They estimated the balance to be net sequestration of 158 million tonnes CO_2 per year although it was noted that the estimate was subject to considerable uncertainty.

There is great variability in forest carbon stocks, even within a single region. Nonetheless, general default values for different types of natural and planted forests are published by IPCC. (IPCC 2003). Representative information for the Americas is shown in Table 3.1. It is clear from the data in the table that forests contain far more aboveground carbon than non-forests.

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* Private timberland covers about 360 million acres in the U.S. (Smith et. al. 2004). The Sustainable Forestry Initiative includes about 130 million acres of certified forests (AF&PA 2006), about 50 million of which are in Canada (Abusow 2004). This leaves 80 million in the United States, which would represent one-quarter of all private timberland.

Table 3.1 Representative Aboveground Biomass in the Americas (IPCC 2003)

Tropical and subtropical regions	Tonnes dry matter per hectare
Natural forests (except for dry areas)	200 to 350
Planted pine or eucalyptus forests (except for dry areas)	110 to 300
Grassland	2.3 to 6.2
Temperate regions	
Natural forests, greater than 20 years old	120 to 140
Planted pine and broadleaf forests	90 to 175
Grassland	1.6 to 2.7

The soil disturbance associated with converting non-forestland or natural forest to managed forest usually results in short-term losses of soil carbon, with levels recovering over time. The level to which soil carbon recovers depends on a number of factors, including the pre-conversion land use. In non-forestland, belowground carbon levels can be much greater than the aboveground levels (IPCC 2003), but the aboveground carbon stocks in forests are so much greater than those in non-forestland that, with few exceptions, total carbon stocks are increased significantly when non-forest is converted to managed forest. The ranges for soil carbon levels in natural and managed forests, however, are large and overlapping (IPCC 2003), meaning that converting natural forest to managed forest will sometimes lower total carbon stocks and in other cases will increase carbon stocks. Due to the complexities of assessing the global effects on soil carbon when natural forest is converted to managed forest, soil carbon is not included in this analysis. It is clear, however, that significant gains in soil carbon are expected from the establishment of planted forests on non-forestland, which represent about one-half of the new-planted forests in the 1990s.

Examining the values in the table above, as well as corresponding values for Asia, one finds that the stock increases associated with converting grassland to planted forests can be as large as or larger than the losses associated with converting natural forests to planted forests. As noted above, FAO has estimated that the amount of land converted from non-forest to planted forest in the 1990s was about the same as the amount converted from natural forest to planted forest. Therefore, on balance, it appears reasonable to conclude that, at worst, during the 1990s, the loss of carbon on natural forestland converted to plantations was approximately offset by the increase in carbon stocks on non-forest land that was converted to plantations. This finding, however, is subject to considerable uncertainty. The authors would not be surprised if the true value for net sequestration due to establishing new planted forests was several hundred million tonnes of CO_2 equivalents above or below this “net zero” finding.

3.2.3 *Loss of Forest to Non-Forest Uses*

Carbon stocks are not stable or increasing everywhere. While carbon stocks in European and North American forests are stable or increasing, those in Africa, Asia, and South America are declining (FAO 2006b), mostly due to deforestation. The causes of deforestation are complex and vary from one location to another, but at the global scale, deforestation is “mainly due to conversion of forests to agricultural land…” (FAO 2006b). The difference between countries accumulating forest biomass and countries losing forest biomass is not related to the size of the harvest (Kauppi et. al. 2006). Instead, the most significant factors contributing to deforestation are high population density and low income per capita (Uusivuori, Lehto, and Palo 2002; Kauppi et. al. 2006). The non-sustainable and illegal harvesting of wood has been uniformly denounced by the global forest products industry who, acting through the International Council of Forest and Paper Associations, has "committed to a global expansion of third-party certification of sustainable forest management practices – where companies commit to externally developed standards and their performance is audited against these standards" (ICFPA 2005).

3.3 Sequestration in Forest Products in Use

After manufacturing, forests products remain in use for periods varying from days to centuries. During this period, the carbon remains sequestered, delaying its return to the atmosphere. If carbon in products is being added to the in-use pool faster than it is being removed by the retirement of previously manufactured products, the stocks of carbon in the products in use pool will grow.

As discussed earlier, the significance of carbon in products in use can be estimated using a number of IPCC methods, all of which provide the same estimates at the global level (although not at the national level) (IPCC 2006). The IPCC methods involve the development of a time series of carbon stocks using the methods described earlier in this paper.

Stocks of carbon in products in use were estimated using FAO data and IPCC methods and, in most cases, default parameters recommended by IPCC. The expected times in use for various types of forest products were described using IPCC's first order equation method (IPCC 2006) and IPCC half-lives that vary by product type, shown above in the discussion of methane releases. Stocks of carbon in products in use were estimated for the period 1900 to 2005. The annual growth in the stocks of carbon in products in use averaged 55.4 million tonnes of carbon (approximately 200 million tons of carbon dioxide equivalents) per year between 2000 and 2005.

Pingoud et al. estimated that in the late 1990s, global stocks of carbon in products in use were growing at approximately 35 million tons of carbon per year, a value 35% lower than the estimate developed in this analysis (UNFCCC 2003; Pingoud et. al. 2003). It appears that the estimate developed herein is larger than the Pingoud et al. estimate primarily due to the use of lower product half-lives in the Pingoud et al. study (approximately a 20-year half-life for all wood products and a 0.7-year half-life for paper products) although some of the difference may be due to increased production in the post-2000 period.

The global estimate derived herein can also be compared to the estimates in the U.S. inventory of greenhouse gas emissions. EPA reports that the pool of carbon in products in use in the U.S., attributable to U.S. production, is growing at a rate of 61 million tonnes CO_2 equivalents per year, an amount equal to one-quarter to one-third of the amount estimated herein for the globe (USEPA 2006a). The U.S. produces about one-quarter of global output of sawnwood, paper and paperboard products (FAO 2005), suggesting that the global estimate derived above is reasonable.

The estimate derived in this study and those in the literature have been developed using a common approach that models the accumulation of carbon in products. The uncertainties in this model have not been well characterized. In addition, for this study, the model has been used with default factors. Therefore, the authors characterize the uncertainty in the estimates as high, suggesting that they could be in error by +/-50%. Nonetheless, they clearly illustrate the importance of carbon sequestered in products to the industry's global carbon and greenhouse gas footprint.

Errors in estimating the carbon stored in products in use will tend to be offset by inverse errors in estimating carbon stored in products in landfills. In other words, underestimating the discards from products in use will result in a high bias in the estimates of carbon stored in products in use and a low bias in estimates of carbon stored in products in landfills. Thus the total sequestration estimates are less sensitive to assumptions about time in use than are the estimates of the two components of total sequestration.

3.4 Sequestration in Forest Products in Landfills

After use, products are recycled or discarded. The end-of-life management of waste materials varies greatly among countries and even within countries. In most countries, however, a fraction of the discards are placed in landfills. In many cases, these landfills are anaerobic, which provides an environment wherein many forest products decay only slowly, if at all. As a result, the amounts of carbon in MSW landfills are increasing with time.

The IPCC-endorsed methods used to estimate the accumulation of carbon in MSW landfills are described in the section of this paper dealing with methane emissions from MSW landfills. Essentially, the methods involve developing a landfill mass balance for carbon. The carbon in new discards to landfills is netted against carbon lost in gas, both in methane and carbon dioxide. If the losses of carbon in gas are smaller than the carbon in new discards, the stocks of carbon in the landfills are growing. Using the methods described above, it is estimated that from 2000 to 2005, the stocks of carbon in forest products in landfills were increasing by an average of 92 million tonnes of carbon (337 tonnes of carbon dioxide equivalents) per year.

While there is significant uncertainty in this estimate, the uncertainties are less than those associated with estimates of methane emissions because of a number of highly uncertain factors affecting landfill methane emissions that do not affect estimates of carbon in landfills, e.g., the fraction of methane collected and destroyed. The authors suggest that the uncertainty around this estimate is +/- 50%.

3.5 The Net Contribution of Forest Products in Landfills

In this assessment, methane emissions attributable to paper and wood products are approximately offset by net sequestration attributable to those same products. This finding is similar to that found in a study of forest products and waste management in Finland (Pingoud, Savolainen, and Seppälä 1996).

It is also possible to compare this result to the situation in the United States. U.S. emissions of methane from MSW landfills have been reported to be 141 million metric tonnes CO_2 equivalents in 2004 (USEPA 2006). If it is assumed that two-thirds of this is due to paper and wood products (see the discussion in the section above regarding methane generation), it can be estimated that about 95 million tonnes of CO_2 equivalents of methane are attributable to forest products in landfills.

The net sequestration attributable to paper and wood products in U.S. landfills is reported to be 156 million tonnes CO_2 equivalents in 2004 (USEPA 2006a). Thus, sequestration is 1.6 times the methane emissions attributable to decomposing paper and wood products in the United States. This is somewhat different from the global situation where the estimates herein indicate that sequestration is about equal to methane emissions (carbon equivalent basis). The finding that sequestration offsets more methane in the U.S. than globally might be explained by several factors, but probably the most important factor is the more extensive use of methane capture and burning systems in the U.S. compared to the globe (almost 50% of U.S. landfills compared to an assumed 20% globally).

In considering the effect of forests products on landfill emissions and sequestration, it is important to recognize the differences between different types of forest products. Products high in lignin (e.g., lumber and newsprint) and those containing materials that tend to protect cellulose and hemi-cellulose from bacterial attack (e.g., coated papers) have been found to decay more slowly and less completely than those without such characteristics (USEPA 2002; Barlaz 2004). Thus, for solid wood products, landfills are likely a large net sink, even after considering methane emissions, while some paper products may result in methane emissions that are larger than the net additions to sequestration.

Keeping readily degradable paper products out of landfills is, therefore, more important to improving the industry's global carbon and greenhouse gas footprint than keeping solid wood products out of landfills.

Table 3.2 provides a summary of carbon sequestration for forest products in the value chain.

Table 3.2 Carbon Sequestration along the Global Forest Products Industry Value Chain

	Emissions (10^6 tonnes CO_2 equiv. per year)	Uncertainty, based on professional judgment
Carbon accumulation in managed forests	60	- 50% +100% or more
Carbon sequestration resulting from establishment of new managed forests	0	+/- several hundred million tonnes per year
Carbon sequestration in products in use	200	+/- 50%
Carbon sequestration in products in landfills	340	+/- 50%
Total	600	-50% to +100%

4.0 AVOIDED EMISSIONS ASSOCIATED WITH THE FOREST PRODUCTS INDUSTRY VALUE CHAIN*

Avoided emissions are those that would have occurred in the absence of an activity. Avoided emissions are fundamentally different from the other components of the industry's profile (described above). Direct emissions, indirect emissions, and movements of forest carbon into and out of the atmosphere are measurable phenomena. They do not require assumptions about alternative activities or speculation about what might have happened if things had been done differently. Avoided emissions, on the other hand, represent what might have happened if things had been done differently.

Estimates of avoided emissions are inherently uncertain because they require assumptions about events that would have occurred were it not for activities that are in place or assumed to occur under business as usual conditions. Nonetheless, avoided emissions estimates can provide insights into important attributes of the forest products industry's carbon and greenhouse gas profile and the public policies that influence it.

4.1 Avoided Emissions Associated with the Use of Biomass Fuels

Sixty-three percent of the fuel used by the wood products industry and 49% of the fuel used by the pulp and paper industry is biomass-derived (WBCSD 2005). This is far more than any other major industry. When these fuels are burned, they return carbon to the atmosphere that was only recently removed from the atmosphere, so these fuels are carbon-neutral. Fossil fuels put carbon into the atmosphere that has not resided there for millions of years, causing increases in atmospheric CO_2 levels. If the forest products industry used fossil fuels to satisfy the energy needs now satisfied by

* Avoided emissions are included here to illustrate several important connections between the industry and the global carbon cycle. The question of how avoided emissions should be included in a greenhouse gas balance sheet is a policy issue beyond the scope of this report. [Footnote added April 11, 2007.]

biomass fuels, its emissions would be significantly larger. The approximate magnitude of these avoided emissions can be estimated as follows.

On an energy in fuel basis, about one-half of the fuel used by the forest products industry is biomass-derived. If the energy derived from biomass was obtained instead from fossil fuel, less total fuel (in terms of energy content) would be required because fossil fuels generally burn more efficiently than biomass fuels. Assuming that one MJ of fossil fuel produces as much usable energy as 1.25 MJ of biomass fuel, one can calculate that the industry's fossil fuel requirements would increase by 80% if fossil fuel was used to displace the biomass fuel now used by the industry. It is reasonable to assume that this 80% increase in fossil fuel use would result in an 80% increase in the industry's direct emissions. Therefore, the avoided emissions associated with the industry's use of biomass fuels is approximately 175 million tonnes of CO_2 per year.

4.2 Avoided Emissions Associated with Combined Heat and Power (CHP) Systems

Combined heat and power or CHP systems involve the sequential use of steam to produce electricity and then heat, usually in steam that is used in pulping and paper making processes. CHP systems extract far more usable energy from fuels compared to systems that produce steam and electricity separately. USEPA indicates that CHP systems typically increase overall efficiencies by perhaps 50% and reduce fuel requirements by 35% (USEPA 2006b). CEPI has estimated the CHP systems in the European pulp and paper industry allow energy savings of 30 to 35% (CEPI 2005).

To estimate avoided emissions associated with the industry's use of CHP, one must assume a scenario representing the industry's activities in the absence of CHP systems. For purposes of estimating avoided emissions, it is assumed that if the industry did not use CHP systems, it would use the current fuel mix to generate process steam but would not generate electricity. In other words, the industry would continue to use biomass to supply about 50% of its fuel but the industry would cease producing electricity and instead would purchase all electricity needed by the industry. Characterized this way, the most significant effect of CHP on the industry's greenhouse gas profile is related to indirect emissions associated with purchased electricity.

The European paper industry produces about 46% of its net electricity consumption. Since approximately 93% of this is produced in CHP systems, about 43% of net consumption is produced in CHP systems (CEPI 2005; 2006). In the U.S., approximately 89% of the electricity generated by pulp and paper mills is generated in CHP systems, representing 40% of net electricity consumption (USDOE 2002). Using the lower of the two values (40%), one can estimate that electricity purchases and the associated indirect emissions from pulp and paper mills would increase by 67% (=40/60) if CHP systems were not used. This increase would amount to 94 million tonnes CO_2 per year in indirect emissions associated with purchased power. A reasonable estimate of the avoided emissions associated with the CHP systems in the pulp and paper industry, therefore, is 94 million tonnes of CO_2 per year. Wood products facilities seldom use CHP systems so the total avoided indirect emissions for the forest products industry associated with the use of CHP systems is also estimated to be about 95 million tonnes of CO_2 per year.

It must be understood that this estimate, like all estimates of avoided emissions, contains a number of assumptions and should therefore be used with caution. It remains useful, however, in gauging the relative importance of this feature of the industry's greenhouse gas profile.

4.3 Avoided Emissions Associated with Recycling Recovered Paper

The effects of paper recycling on carbon and greenhouse gases are complex. Paper recycling can keep discarded paper out of MSW landfills where it would decay, resulting in the release of methane. On the other hand, if the alternative to recycling is burning for energy, recycling can eliminate the opportunity to displace fossil fuel with a biomass energy source. In either case, keeping carbon out of landfills also eliminates carbon sequestration in landfills. The interactions between avoided methane emissions, displaced fossil fuel emissions from burning used paper (or landfill methane), and foregone landfill carbon sequestration are highly grade- and site-dependent.

Recycling mills sometimes release more greenhouse gases than virgin mills because recycling mills have less access to biomass fuels and are less likely to have equipment that is readily suited to burning them for energy. The differences in these direct emissions, however, are extremely dependent on the grades of paper being considered.

Recycling also reduces the need for virgin pulpwood fiber, potentially allowing additional carbon sequestration in the forest. The effects of recycling on forest carbon, however, are not as straightforward as sometimes thought. Activities that reduce the demand for virgin fiber can increase the chances that land will be converted from forests to other uses, resulting in the loss of large amounts of carbon. Or a loss in demand for pulpwood may result in a decision to delay harvesting only until the trees become large enough to be used as saw timber, at which point the harvesting eliminates some of the sequestration in the forest but adds to sequestration in long-lived building products. These various sources of “leakage” are very complex and difficult to quantify but can be important.

The authors are aware of only one study that attempts to deal with most of these factors. The study, which is based on conditions in the U.S., suggests that even considering these various sources of leakage, recycling can have carbon and greenhouse gas benefits (USEPA 2002). The impacts are highly grade-specific, however. In addition, the results would be very different in a setting where waste management practices are different from those in the U.S. Nonetheless, based on current studies, it appears that in many cases and at current recycling rates, paper recycling helps avoid life cycle emissions of greenhouse gases (although there are exceptions).

By using the methods for estimating landfill methane emissions described above, and setting the assumed degradation rate for wood products to zero, it has been determined that paper and paperboard products are responsible for 150 million of the 250 million tonnes CO_2 equivalents of methane emissions attributable to forest products in landfills. Of the 352 million tonnes of paper and paperboard produced globally in 2005, 162 million tonnes, or 46%, was recovered rather than being disposed (FAO 2006a). Accordingly, the methane emissions attributable to paper and paperboard in landfills would approximately double if the paper currently recovered was disposed instead. The resulting estimate of avoided emissions attributable to paper recycling is thus 150 million tonnes CO_2 equivalents per year. This estimate does not attempt to account for the complex issues of manufacturing emissions intensity and forest carbon sequestration outlined above, and as a result, it is even more uncertain than estimates of other types of avoided emissions. The authors suggest that the true value could be different from the estimate by more than a factor of +/- 2.

4.4 Avoided Emissions Associated with Product Substitution Effects

Forest products compete in the market place with alternative products that often have very different greenhouse gas and carbon profiles. As a result, when forest products either displace, or are displaced by, other products, there can be effects on greenhouse gas emissions. These “substitution effects” are very product-specific. Even for a single type of product, substitution effects will vary according to local conditions.

In the case of building products, a number of studies have found that for residential structures with comparable heating and cooling requirements, wood-based structures usually have lower life cycle greenhouse gas emissions than many alternative structures. See, for instance, NCASI 2006, Borjesson and Gustavsson 2000; Athena 2004; Scharai-Rad and Welling 2002; Peirquet, Bowyer, and Huelamn 1998; Lenzen and Treloar 2002; Gustavsson and Sathre 2006; Richter and Sell 1993; Gustavsson, Pingoud, and Sathre 2006, and the CORRIM studies described in Lippke et al. 2004; Perez-Garcia et al. 2005; and Puettmann and Wilson 2005. The size of the impact, however, can vary greatly depending on a number of factors including assumptions about end-of-life management (Borjesson and Gustavsson 2000), and about forest carbon impacts (Gustavsson, Pingoud, and Sathre 2006, NCASI 2006). Local climate will also affect the potential advantages of wood-based building materials.

The results for other types of products, however, can be very different. In general, studies that have been performed in this area suggest that the substitution effects for forest products are affected by a number of conditions. The energy required to assemble wood is obtained from the sun so that the manufacturing of wood-based materials often requires far less energy and results in fewer greenhouse gas releases than materials that require energy to assemble the basic material. Another key determinant of substitution effects is often the amount of mass required to perform the needed function since many environmental loads, including greenhouse gas emissions, are related to the mass of the product. End-of-life management is also a key consideration. End-of-life impacts may work to the disadvantage of degradable materials, like most forest products, in regions where large fractions of discards are disposed in landfills. On the other hand, end-of-life impacts may work to the benefit of biomass-based materials in regions where most discards are recycled or burned for energy.

The number of potential substitution effects and the number of local conditions that affect them are too numerous to contemplate. It is not possible, therefore, to generate a meaningful estimate of global avoided emissions due to substitution effects for this study. It is important to remember, however, that these effects can be considerable for specific products and circumstances.

4.5 Other Avoided Emissions

A large number of other avoided emissions can be identified in the forest products value chain. Some of these are listed here without any attempt to estimate their significance.

- the use of non-recyclable paper as biomass fuel, displacing fossil fuel
- the use of landfill-derived methane as biomass fuel, displacing fossil fuel
- the forest clearing that is avoided because the industry provides a market for wood

5.0 DISCUSSION OF THE CARBON AND GREENHOUSE GAS PROFILE OF THE FOREST PRODUCTS INDUSTRY

The size of the individual components of the industry's greenhouse gas and carbon profile, and the relative uncertainties associated with the estimates, are summarized in Table 5.1. The table clearly illustrates the many complex and important connections of the forest products industry to the climate change issue.

Table 5.1 Summary of the Greenhouse Gas and Carbon Profile of the Global Forest Products Industry

		Million tonnes CO_2 equivalents per year *	Degree of uncertainty (authors' judgment)
Direct Emissions	Fuel consumption at pulp and paper mills	205	+/- 15%
	Fuel consumption at wood products facilities	25	+/- 25%
	Management of mill wastes	20	+/- 25%
	Secondary manufacturing operations (i.e. converting primary products into final products)	12	+/- 50%
	Total direct emissions	262	+/- 20%
Indirect Emissions	Electricity purchases by pulp and paper mills	140	+/- 25%
	Electricity purchases by wood products facilities	40	+/- 50%
	Electricity purchases by secondary manufacturing operations (i.e. converting primary products into final products)	13	+/- 50%
	Harvest and transport emissions from the pulp and paper value chain	40	+/- 50%
	Harvest and transport emissions from the wood products value chain	30	+/- 50%
	Methane emissions from forest products decomposition in anaerobic municipal solid waste landfills	250	-50% to +100%
	Total indirect emissions	513	+/- 50%
Sequestration	Sequestration in sustainably managed forests	- 60	+/- a factor of 2 or more
	Sequestration resulting from establishment of new managed forests	0	+/- several hundred million tonnes sequestration per year
	Sequestration in products in use	- 200	+/- 50%
	Sequestration in products in landfills	- 340	+/- 50%
	Total sequestration	- 600	-50% to + several hundred million tonnes sequestration per year
Avoided Emissions**	Avoided emissions associated with the use of biomass fuels	- 175	+/- a factor of 2
	Avoided emissions related to the use of combined heat and power systems	- 95	+/- a factor of 2
	Avoided emissions associated with recycling paper	-150	More than +/- a factor of 2
	Avoided emissions associated with product substitution effects	?	?
	Total avoided emissions	- 270	-50% to + several hundred million tonnes avoided emissions per year

* Negative emissions indicates net sequestration

** Avoided emissions are included here to illustrate several important connections between the industry and the global carbon cycle. The question of how avoided emissions should be included in a greenhouse gas balance sheet is a policy issue beyond the scope of this report. [Footnote added April 11, 2007.]

Direct emissions are an important part of the industry's global profile, estimated to be 262 million metric tonnes per year of CO_2 equivalents per year. These emissions would be as much as 175 million metric tonnes of CO_2 per year greater were it not for the industry's use of biomass fuels. The industry in a number of regions has identified opportunities for further improvement in this area. The European paper industry, for instance, has a target of increasing average use of biomass from 49% to 56% of on-site total primary energy consumption by 2010 (CEPI 2003).

In most parts of the world, the forest products industry's direct emissions intensity (i.e., direct emissions per ton of production) has improved over the years. This has been accomplished by improving energy efficiency and substituting biomass fuels for fossil fuels. In some regions, Europe for instance, absolute emissions have increased even though emissions intensity has improved (CEPI 2005). In other regions, such as Canada, emissions intensity since 1990 has improved faster than production has grown, providing reductions in both emissions intensity and absolute emissions (FPAC 2006). Absent major technological breakthroughs, it is reasonable to assume that the industry's emissions intensity will continue to improve at about the same rate as production grows, allowing the industry's direct emissions to remain constant.

A number of factors will affect the industry's ability to continue to improve direct emissions intensity. First, fossil fuel prices have increased dramatically in recent years, providing an incentive for conserving energy and using biomass fuels (although the availability of relatively cheap coal may complicate attempts to forecast emission trends). The industry's ability to increase use of biomass as a raw material and fuel will depend on the continued availability of adequate supplies of affordable wood fiber. In some regions of the world, the supplies of forest biomass appear to be adequate to support the forest products industry and allow significant growth in the use of forest biomass-based fuels. In other regions, however, concerns have already developed over competition for wood fiber caused by generous incentives to produce biomass-based electricity, illustrating the need for balanced public policies that do not distort the market for forest biomass.

Indirect emissions associated with purchased electricity are a significant component of the industry's greenhouse gas profile, amounting to an estimated 190 million metric tonnes CO_2 per year. The industry's demonstrated ability to use CHP to avoid, at present, 95 million metric tonnes of CO_2 per year from purchased power suggests the value of policies to encourage expanded use of CHP in the industry. In addition, as electricity prices increase, mills may have additional incentives to produce, rather than purchase, electricity. It is also important, however, to consider the effects of energy conservation on electricity production. The primary effect of improving energy efficiency in a pulp and paper mill is usually to reduce the demand for process steam. Since less steam is needed, less is available for producing electricity via CHP.

Indirect emissions are also affected by the practices of companies selling electricity to the forest products industry. Power producers may have incentives in the future to reduce the emissions intensity of the power they produce, although this is not guaranteed since some experts are predicting increased use of coal for power production in many parts of the world. Without a change in the carbon intensity of purchased power, it seems unlikely that the indirect emissions associated with electricity purchased by the forest products industry will decline.

At the global level, transportation-related emissions, estimated to be 70 million metric tonnes CO_2 per year, are not a dominant feature of the forest product industry's greenhouse gas and carbon profile. For specific products or companies, however, these emissions can be significant, so they cannot be ignored. In addition, the continued globalization of the industry and the trend to move production from consuming countries to low-cost regions that are distant from major markets suggest that transportation-related emissions will become more important to the industry's greenhouse gas and carbon profile in the future.

In spite of the uncertainties in the estimates, it is clear that at the global level methane emissions from MSW landfills are a significant feature of the industry's greenhouse gas and carbon profile, although their significance will vary greatly among regions depending on paper recovery and waste management practices. In this study, it is estimated that 250 million tonnes CO_2 equivalents per year are released from landfills as the result of the decomposition of forest products. The industry's paper recycling activities are estimated to avoid releases of methane equal to 150 million tonnes of CO_2 equivalents per year. Methane emissions are large primarily because of a) economic forces and public policies that result in many used forest products being disposed in MSW landfills, and b) the still modest extent of use of systems to capture and burn landfill methane. Both of these factors are outside of the industry's control. Current trends in waste management, however, give reason to hope that landfill methane emissions attributable to discarded forest products will decrease over time. In 2003, MSW methane emissions in the EU-15 had been reduced by 36% compared to 1990 (EC 2005). In the U.S., landfill methane emissions decreased by 18% between 1990 and 2004 while in Japan the reduction was 34% (USEPA 2006a; MOE 2006). It is reasonable to project, therefore, that over time, methane from MSW landfills will become a less important feature of the forest product industry's greenhouse gas and carbon profile.

On balance, the methane emissions from landfills attributable to forest products approximately balance the net sequestration of carbon in forest products deposited in landfills. This overall balance, however, obscures the different effects of different types of forest products. The available information suggests that most of the methane is likely attributable to products that are low in lignin, are uncoated, or are otherwise unprotected against microbial attack. On the other hand, most of the sequestration in landfills is likely due to materials that are high in lignin (e.g., wood and newsprint) or are in a physical form that discourages microbial attack (e.g., pieces of solid lumber or coated papers).

In this study, total value chain emissions are estimated to be approximately 775 million metric tonnes of CO_2 equivalents per year, although there is considerable uncertainty in this estimate due to uncertainty in the amounts of methane attributable to the decomposition of forest products in landfills. These emissions are comprised of direct emissions (34%), indirect emissions associated with purchased power (25%), transportation-related emissions (9%), and methane from forest products in MSW landfills (32%). Adding up direct emissions and emissions related to purchased power, one finds that 59% of the value chain emissions are manufacturing-related.

The sequestration benefits of the forest products value chain are large. Over long periods of time and large areas, it is not expected that managed forestlands would be accumulating significant amounts of carbon, but data suggest that at the current time, net sequestration on managed forests is significant. In this study, an estimate for net sequestration in managed forests is used that includes only documented sequestration on a fraction of private timberland in the United States, amounting to 60 million tonnes of CO_2 equivalents per year. There are reasons to suspect, however, that on a global basis, net sequestration on managed land is several million tonnes higher than this.

The net sequestration in forest products, in use and in landfills, is estimated to be the equivalent of 540 million tonnes of CO_2 per year. The carbon stored in forest products is extremely important to the carbon profile of the forest products industry and this carbon will almost certainly become even more important over time as consumption of forest products increases due to growing global population and increasing standards of living.

Thus, total net annual carbon sequestration along the forest products value chain is estimated to be at least 600 million tonnes CO_2 equivalents per year. Considering the uncertainty in the estimates, this sequestration is in approximate balance with the emissions that occur along the forest products value chain (775 million metric tonnes CO_2 per year). It is expected that this balance will continue to improve in coming years due to a) continuing reductions in direct emissions intensity of manufacturing, b) likely reductions in the carbon intensity of purchased power, c) expanded efforts to keep degradable materials out of landfills and to capture and destroy landfill methane, and d) increasing carbon sequestration along the value chain, especially in forest products.

The carbon and greenhouse gas benefits of product substitution are highly variable and extremely difficult, if not impossible, to estimate at the global level. They should not be ignored, however, because, at the regional or local level, it may be possible to estimate the effects of product substitution, and these effects can be significant.

In 1999, Subak and Craighill examined the carbon and greenhouse gas profile of the global paper industry (Subak and Craighill 1999) and their estimates were used extensively by IIED in its report, *Towards a Sustainable Paper Cycle* (IIED 1996). Table 5.2 compares the estimates of Subak and Craighill, which cover only the paper industry, with those derived in this study, which include both the paper and wood products industries. Not shown are the Subak and Craighill estimates of the small incremental increases in direct CO_2 emissions associated with recycling (estimated to be 4 million tonnes CO_2 per year) or offsets due to use of used paper or landfill methane as fuel (estimated to be 3 million tonnes CO_2 per year).

Table 5.2 Comparison of Two Studies of the Greenhouse Gas and Carbon Profile of the Global Forest Products Industry

		Tonnes CO_2 equivalents per year*	
		This study	Subak and Craighill, 1999 (covers only the paper industry)
Direct Emissions	Fuel consumption at pulp and paper mills	205	172**
	Fuel consumption at wood products facilities	25	Not estimated
	Management of mill wastes	20	Not estimated
	Secondary manufacturing operations (i.e. converting primary products into final products)	12	Not estimated
	Total direct emissions	262	
Indirect Emissions	Electricity purchases by pulp and paper mills	140	118**
	Electricity purchases by wood products facilities	40	Not estimated
	Electricity purchases by secondary manufacturing operations (i.e. converting primary products into final products)	13	Not estimated
	Harvest and transport emissions from the pulp and paper value chain	40	29
	Harvest and transport emissions from the wood products value chain	30	Not estimated
	Methane emissions from forest products decomposition in anaerobic municipal solid waste landfills	250 (156 for paper only)	250 (only for paper)
	Total indirect emissions	513	

(Continued on next page. See notes at end of table.)

Table 5.2 Continued

		Tonnes CO_2 equivalents per year*	
		This study	Subak and Craighill, 1999 (covers only the paper industry)
Sequestration	Sequestration in sustainably managed forests	- 60	Not estimated
	Sequestration resulting from establishment of new managed forests	0	- 158 (net value, considering sustainably managed land, new plantation establishment and loss of natural forest)
	Sequestration in products in use	- 200	Not estimated
	Sequestration in products in landfills	- 340	Not estimated
	Total sequestration	- 600	
Avoided Emissions	Avoided emissions associated with the use of biomass fuels	- 175	Not estimated
	Avoided emissions related to the use of combined heat and power systems	- 95	Not estimated
	Avoided emissions associated with recycling paper	-150	Not estimated
	Avoided emissions associated with product substitution effects	?	Not estimated
	Total avoided emissions	- 270	

*Negative emissions indicates net sequestration

** The emissions estimate in Subak and Craighill (290 million tonnes per year) is assumed to include direct and indirect emissions associated with purchased power. The values calculated above assume that the ratio of direct to indirect emissions in the Subak and Craighill study is the same as found in this study

Because the current study covers the global forest products industry (paper and wood products) while the Subak and Craighill study covered only the paper industry, a direct comparison of the individual estimates from the two studies is not possible for most of the components of the profile. Nonetheless, it is reasonable to examine the extent to which the two studies agree on the relative size of the different features of the industry's global carbon and greenhouse gas profile.

Both studies highlight the importance of manufacturing-related emissions. The studies yield generally comparable estimates of manufacturing-related emissions for the global pulp and paper industry (290 million metric tonnes CO_2 per year estimated by Subak and Craighill in the late 1990s compared to 345 million metric tonnes CO_2 per year estimated in this study). Both studies highlight the importance of landfill emissions of methane to the global industry's carbon and greenhouse gas profile. Both studies also suggest that transportation-related emissions, while not trivial, are not a major feature of the profile.

Subak and Craighill (1999) examined the effects of sustainable forest management, new plantations, and conversion of natural forests, and concluded that the net effect was sequestration of 158 million metric tonnes of CO_2 per year. In the current study, we conclude that the forest industry's effect on global forests is net sequestration, but the data are inadequate to develop a robust global estimate. Currently, it appears that managed forests are accumulating significant amounts of carbon (more than 60 million tonnes CO_2 per year) while the industry's other effects on forest carbon appear to be small. Although carbon stocks in managed forests appear to be increasing now, it is likely that the annual growth in these stocks will eventually decline and, at some point, the stocks will become relatively stable.

Subak and Craighill (1999) did not attempt to characterize the potential significance of avoided emissions associated with biomass use, combined heat and power, and other industry activities. In this study, several of these elements of the industry's profile have been estimated, albeit with significant uncertainty, and have been shown to be important to understanding the industry's effect on greenhouse gases.

Perhaps the most important differences between the two studies are related to carbon in products. Subak and Craighill did not examine the effects of carbon in products, while in this study we used IPCC accounting methods to examine this feature of the industry's global profile. The results indicate that the equivalent of 540 million metric tonnes per year of CO_2 is sequestered in forest products in use and in landfills. Over very long periods, most of this carbon will return to the atmosphere, but for the foreseeable future, carbon will be added to the pool of carbon in products at a rate that greatly exceeds the rate at which it returns to the atmosphere. This is expected because global demand for products is increasing in response to improving standards of living and increasing global population.

The differences between the scopes of the two studies result in the studies coming to somewhat different conclusions. Subak and Craighill conclude that the global paper industry is a net emitter of greenhouse gases while this study suggests that, considering the uncertainty in the estimates, the global forest product industry's emissions are largely, and perhaps entirely, offset by carbon sequestration. Furthermore, this study suggests that it is likely that sequestration will become larger while value chain emissions will diminish. To appreciate the attributes of the industry's profile, this study also suggests that it is important to acknowledge avoided emissions related to biomass use, combined heat and power systems, paper recycling, and substitution effects.

6.0 CONCLUSIONS

The forest products industry has more complex connections to the climate change issue than any other industry. The industry's carbon and greenhouse gas profile is composed of emissions, sequestration, and avoided emissions. Emissions from the global forest products industry value chain are comprised of direct emissions (~260 million metric tonnes CO_2 per year), indirect emissions associated with electricity purchases (~190 million metric tonnes CO_2 per year), harvest- and transport-related emissions (~70 million metric tonnes CO_2 per year), and methane from discarded forest products in landfills (~250 million metric tonnes CO_2 equivalents per year). Carbon is sequestered in managed forests (net increases equivalent to at least 60 million tonnes CO_2 per year) and forest products (~540 million tonnes CO_2 equivalents per year). Avoided emissions, which further enhance the industry's global profile, are associated with the industry's use of biomass fuels (~175 million metric tonnes CO_2 avoided per year), combined heat and power (~95 million metric tonnes CO_2 avoided per year), recycling (~150 million tonnes CO_2 equivalents per year), and product substitution effects (not possible to estimate)*. The available data demonstrate that the greenhouse gas emissions along the forest products industry value chain are largely offset by the sequestration accomplished in forest products.

Due to data gaps and uncertainties in the estimates, especially with regard to carbon in forests and methane emissions from landfills, it is not clear whether sequestration is somewhat larger than or somewhat smaller than the emissions along the value chain. Additional work is needed to reduce the uncertainties in the estimates of emissions or sequestration at several points in the forest products industry value chain. The uncertainties are especially large for a) transportation-related emissions,

* Avoided emissions are included here to illustrate several important connections between the industry and the global carbon cycle. The question of how avoided emissions should be included in a greenhouse gas balance sheet is a policy issue beyond the scope of this report. [Footnote added April 11, 2007.]

b) carbon sequestration in land owned, controlled, or managed by the industry, and c) methane emissions attributable to decomposition of forest products in landfills.

The emissions from the global forest products industry value chain are expected to remain constant or slowly decline over time as increases in emissions related to production growth are offset by improvements in the emissions intensity of manufacturing and reductions in methane releases from landfills. Sequestration, especially in products, is expected to become an even more important of the industry's profile as demand for products increases because of population growth and increasing standards of living. Avoided emissions related to the use of biomass fuels, combined heat and power, and recycling are also expected to continue to grow.

Improvements in the industry's greenhouse gas and carbon profile will require a combination of industry activities and public policies. Industry can assist by reducing the use of fossil fuels and electricity through energy efficiency improvements and increased use of biomass. This will require industry investments and public policies that ensure the continued availability of adequate supplies of affordable biomass for use as raw material and fuel. Public policies directed at sectors outside of the forest products industry will play a large role in several critical areas. Policies that minimize the use of landfills for disposing of easily degradable forest products will continue to be important, as will policies that encourage the use of landfills designed and operated to minimize releases of methane. Also helpful will be policies that encourage additional use of CHP and provide new opportunities for exporting biomass-derived electricity to the grid. Finally, where substitution effects are found to be important, public policies that promote the use of the least greenhouse gas intensive products may be appropriate.

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