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THE GREENHOUSE GAS AND CARBON PROFILE OF THE U.S. FOREST PRODUCTS SECTOR

SPECIAL REPORT NO. 08-05

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PRESIDENT'S NOTE

In 2007, NCASI collaborated with Dr. John Perez-Garcia at the University of Washington to develop a comprehensive end-to-end assessment of the connections between the global forest products industry and the global carbon cycle (described in NCASI Special Report No. 07-02). This global greenhouse gas and carbon profile gained significant attention and resulted in additional work at NCASI involving development of profiles for national industry sectors (NCASI Special Report No. 07-09 describes the Canadian industry's profile), as well as profile tools for individual companies and specific products. One such project has been a collaboration between NCASI and the USDA Forest Service to develop a greenhouse gas and carbon profile of the U.S. forest products sector. Its results are described in this report.

This study differs somewhat from earlier profile studies published by NCASI in that it is organized around a carbon footprint framework developed, with assistance from NCASI, by the Confederation of European Paper Industries (CEPI). The results, however, are generally similar to those of earlier profile studies. In particular, the largest emissions along the value chain are found to be attributable to manufacturing operations (both direct emissions from fossil fuel combustion and emissions attributable to electricity purchases by the industry). Methane emissions attributable to decomposing forest products in municipal solid waste landfills are also important. Other sources (e.g., transport and upstream emissions associated with manufacturing inputs) are less important. Total emissions from the U.S. forest products industry value chain in 2005 were estimated to be 212 Tg CO_2 eq., about half of which were attributable to energy consumption at the industry's manufacturing facilities. While there are varying degrees of uncertainty associated with each of our estimates, we believe they give a correct view of the overall magnitudes and relative magnitudes of emissions and additions to carbon sinks.

As a result of the extensive adherence to sustainable forest management principles, the industry's activities in the forests do not appear to be causing significant increases or decreases in forest ecosystem carbon stocks. In 2005, however, the amounts of forest carbon stored in products (in use and in landfills) were increasing at a rate equivalent to removing 108.5 Tg of CO_2 per year from the atmosphere. This net sequestration was adequate to offset about half of the U.S. forest product industry's value chain emissions and all of the emissions associated with energy consumption at U.S. manufacturing facilities. The results in this report further document the unique role of the forest products industry in the global carbon cycle and the importance of carbon sequestration to the industry's greenhouse gas and carbon profile.

Ronald A. Yeske

September 2008

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MOT DU PRÉSIDENT

En 2007, NCASI a collaboré avec le docteur John Perez-Garcia de l'université de Washington afin de développer une évaluation exhaustive des liens entre l'industrie globale des produits forestiers et le cycle global du carbone (cette étude est décrite dans le Rapport spécial n° 07-02 de NCASI). Ce profil global des gaz à effet de serre et du cycle de carbone a attiré une attention croissante ce qui a généré des travaux additionnels chez NCASI portant sur le développement de profils pour des secteurs industriels nationaux (le Rapport spécial n° 07-09 de NCASI décrit le profil de l'industrie au Canada) et d'outils servant à établir le profil de compagnies individuelles et de produits spécifiques. Un de ces projets, issu d'une collaboration entre NCASI et le Service des forêts du département de l'agriculture des États-Unis visait le développement d'un profil de gaz à effet de serre et de cycle de carbone pour le secteur des produits forestiers des États-Unis. Les résultats de ce projet sont décrits dans ce rapport.

La présente étude diffère sensiblement des études précédentes réalisées par NCASI qui traitent du développement de profils puisqu'elle a été organisée selon un cadre de bilan de carbone développé par la Confederation of European Paper Industries (CEPI), avec l'assistance de NCASI. Par contre, les résultats de cette étude sont similaires à ceux d'études de profils précédentes. Plus particulièrement, les auteurs ont observé que les émissions les plus importantes dans la chaîne de production forestière sont attribuables aux opérations de fabrication (émissions directes provenant de la combustion de combustibles fossiles et émissions attribuables aux achats d'électricité par l'industrie). Les émissions de méthane attribuables à la décomposition de produits forestiers dans les sites d'enfouissement de déchets municipaux sont, elles aussi, importantes. Les autres sources telles que le transport et les émissions en amont associées aux intrants requis pour la fabrication sont moins importantes. En 2005, les émissions totales de la chaîne de valeur des produits forestiers des États-Unis ont été estimées à 212 Tg d'éq. CO_2, dont environ la moitié était attribuable à la consommation d'énergie dans les installations de fabrication de l'industrie. Quoiqu'il y ait un certain niveau d'incertitude à chacune de nos estimations, nous croyons qu'elles procurent un portrait adéquat des amplitudes globales et des amplitudes relatives des émissions ainsi que des additions aux puits de carbone.

Étant donnée la vaste adoption des principes de gestion durable des forêts, il semble que les activités de l'industrie en forêt ne causent pas d'augmentations ni de diminutions des stocks de carbone de l'écosystème forestier. Par ailleurs, en 2005, les quantités de carbone forestier contenues dans les produits (en cours d'utilisation ou dans des sites d'enfouissement) augmentaient à un taux équivalent à l'enlèvement de 108,5 Tg de CO_2 par an de l'atmosphère. Cette séquestration nette était suffisante pour compenser environ la moitié des émissions de la chaîne de valeur de l'industrie américaine des produits forestiers et toutes les émissions associées à la consommation d'énergie des installations de fabrication des États-Unis. Les résultats présentés dans ce rapport documentent une fois de plus le rôle unique de l'industrie des produits forestiers dans le cycle global du carbone ainsi que l'importance de la séquestration du carbone dans le profil des gaz à effet de serre et du carbone de l'industrie.

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THE GREENHOUSE GAS AND CARBON PROFILE OF THE U.S. FOREST PRODUCTS SECTOR

SPECIAL REPORT NO. 08-05
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ABSTRACT

A greenhouse gas and carbon profile was developed by examining net fluxes of CO_2 and other greenhouse gases to the atmosphere from the U.S. forest products industry value chain. Where possible, estimates are included for 1990 and 2005 or the closest dates with available data. The value chain examined for this analysis consists of the forests supplying wood to the U.S. industry, the fate of that wood through manufacturing, use, and disposal, and emissions that occur in harvesting, transport, manufacturing, producing raw materials and fuels, and at products' end of life. The profile does not include carbon stored in imported wood or imported forest products.

An analysis of the carbon stocks on industry-owned timberlands, essentially all of which are managed under sustainable forest management principles, suggests that between 2000 and 2005 these lands may have been small net sources of CO_2, with carbon stocks declining by the equivalent of approximately 11 Tg CO_2 equivalents (eq.) per year, or about 0.1% per year on a land base of 2.5 Pg C, not including soil carbon. The industry obtains wood, however, from many sources besides its own land, and over this same period forest ecosystem carbon stocks on all private timberlands (including industry-owned timberlands) increased by 129 Tg CO_2 eq. Small increases and decreases in carbon stocks on industry-owned timberlands are expected as land owners adjust harvesting and restocking rates to account for market conditions, forest age class distributions, and other factors. It is reasonable to speculate that intensive management of industry-owned land for wood production reduces demand for wood on other timberland, with the indirect result of carbon accumulation on non-industry-owned timberland. It is also reasonable to assume that a portion of the accumulation of carbon on non-industrial private timberland is due to the industry's ongoing efforts to promote sustainable forest management practices among all of its suppliers of wood. Overall, while it is not possible to precisely calculate the net effects of the industry's activities, there is no reason to suspect that these activities are responsible for significant net losses or gains in forest ecosystem carbon. For purposes of this study, therefore, the net flux of CO_2 attributable to the industry's effects on forest ecosystem carbon is assumed to be zero.

Much of the carbon removed from forests is transferred to products. Stocks of carbon in products attributable to the U.S. forest products sector are growing, representing net removals of CO_2 from the atmosphere. In 2005, the growth in product carbon stocks was equivalent to the annual sequestration of 108.5 Tg CO_2 eq. Approximately 40% of this growth was in products in use, while 60% of the growth was in products in landfills.

Direct emissions from manufacturing, almost all of which are due to burning fossil fuels at primary manufacturing facilities, amounted to 64.6 Tg CO_2 eq. in 2004. Indirect emissions associated with purchased electricity were estimated to be 43.6 Tg CO_2 eq. in 2004. Emissions associated with production of raw materials were approximately 28 Tg CO_2 eq. per year.

Transport is required at several points in the forest products industry value chain. Emissions associated with transporting raw materials, finished products, and recovered fiber were estimated to total 19.6 Tg CO_2 eq. in 2005.

At end-of-life a certain fraction of used products are disposed in landfills. In landfills a fraction of the carbon is degraded to methane, a greenhouse gas that has a warming potential many times that of CO_2. Amounts of methane released to the atmosphere depend not only on the specific types and amounts of used forest products placed in landfills, but also on the designs and operation of the landfills. Given current waste management and landfill design practices in the U.S., it is estimated that these emissions were 56 Tg CO_2 eq. in 2005.

Total emissions through the value chain in 2004 to 2005 were estimated to be 212 Tg CO_2 eq/yr. The largest source was manufacturing: 51% of the total if only direct emissions and indirect emissions associated with purchased electricity are considered and 64% of the total if upstream emissions associated with production of all raw materials are also included. Methane emissions attributable to decomposing forest products in landfills made up 26% of value chain emissions, while transport accounted for the rest (9% of the total).

Carbon sequestration along the value chain amounted to an estimated 108.5 Tg CO_2 eq. in 2005, an amount adequate to offset all direct emissions plus all indirect emissions associated with purchased electricity (over half of total value chain emissions).

Between 1990 and 2004/5, a period over which the industry's production increased by about 15%, total value chain emissions (not considering sequestration) decreased by about 6%. Some elements of the profile improved over that period and others did not. Overall carbon sequestration decreased by 18%, primarily reflecting an increased reliance on imported products and decreased amounts of used paper sent to landfills. Direct emissions from manufacturing were reduced by 15% and those attributable to purchased electricity increased by 3%, representing a combined reduction of 9%. Emissions of methane attributable to decaying forest products were reduced by 8% and transport-related emissions increased by about 15%, a direct result of increases in industry production. Net transfers to the atmosphere from the U.S. forest products industry value chain, considering both value chain emissions and net sequestration of biomass carbon, increased from 91.8 Tg CO_2 eq. in 1990 to 103.5 Tg CO_2 eq. in 2005, with the increase being attributable to reduced storage of carbon in products in 2005. While there are varying degrees of uncertainty associated with the estimates herein, we believe they give a correct view of the overall magnitudes and relative magnitudes of emissions and additions to carbon sinks.

KEYWORDS

carbon, climate change, GHG, greenhouse gas, profile

RELATED NCASI PUBLICATIONS

Special Report No. 07-09 (October 2007). *The greenhouse gas and carbon profile of the Canadian forest products industry*.

Special Report No. 07-02 (February 2007). *The greenhouse gas and carbon profile of the global forest products industry*.

Technical Bulletin No. 925 (November 2006). *Energy and greenhouse gas impacts of substituting wood products for non-wood alternatives in residential construction in the United States*.

LE PROFIL DU CARBONE ET DES GAZ À EFFET DE SERRE DU SECTEUR DES PRODUITS FORESTIERS DES ÉTATS-UNIS

RAPPORT SPÉCIAL N^{O} 08-05
SEPTEMBRE 2008

RÉSUMÉ

Un profil de carbone et des gaz à effet de serre a été développé en examinant les flux nets de CO_2 et des autres gaz à effet de serre dans l'atmosphère provenant de la chaîne de valeur de l'industrie des produits forestiers américaine. Lorsque cela était possible, des estimés sont présentés pour les années 1990 et 2005 ou les dates les plus rapprochées pour lesquelles des données sont disponibles. La chaîne de valeur examinée pour cette analyse comprenait les éléments suivants : les forêts fournissant le bois à l'industrie américaine, le devenir de ce bois lors de la fabrication, l'utilisation et l'élimination, et les émissions survenant lors de la récolte, du transport, de la fabrication, de la production de matières premières et de combustibles et à la fin de la vie utile du produit. Le profil n'inclut pas le carbone emmagasiné dans le bois importé ou les produits forestiers importés.

Une analyse des stocks de carbone contenu dans les forêts que possède l'industrie et dont la majeure partie est gérée selon les principes de foresterie durable, suggère qu'entre 2000 et 2005, ces terres ont pu être de faibles sources nettes de CO_2 puisque les stocks de carbone ont décliné approximativement de 11 Tg d'équivalents (éq.) CO_2 par année, ou environ 0,1% par année sur une surface de terre de 2,5 Pg C, excluant le carbone contenu dans le sol. Par contre, outre le bois de ses propres terres, l'industrie obtient du bois de plusieurs autres sources et pour cette même période de temps, les stocks de carbone de l'écosystème forestier de toutes les terres à bois privées (incluant les terres à bois dont l'industrie est propriétaire) ont augmenté de 129 Tg d'éq. CO2. On s'attend à de faibles augmentations et diminutions de stocks de carbone des terres à bois dont l'industrie est propriétaire, puisque les propriétaires ajustent leurs taux de récolte et de reboisement en fonction des conditions du marché, de la distribution de l'âge des forêts et d'autres facteurs. Il est raisonnable de faire l'hypothèse que la gestion intensive des terres dont l'industrie est propriétaire et dont elle tire son approvisionnement de bois réduit la demande en bois d'autres terres à bois, ceci ayant pour effet indirect de favoriser l'accumulation de carbone dans les terres à bois dont l'industrie n'est pas propriétaire. Il est aussi raisonnable de faire l'hypothèse qu'une portion de l'accumulation de carbone dans les terres privées non industrielles est le résultat des efforts continus de l'industrie pour promouvoir une gestion durable des forêts parmi tous ses fournisseurs de bois. Globalement, même s'il n'est pas possible de calculer de manière précise les effets nets des activités de l'industrie, il n'y a pas de raison de croire que ces activités soient responsables d'augmentations ou de diminutions significatives du carbone de l'écosystème forestier. Ainsi, pour les fins de cette étude, on supposera que le flux net de CO_2 attribuable aux effets de l'industrie sur le carbone de l'écosystème forestier est nul.

La majorité du carbone retiré des forêts est transféré dans les produits fabriqués. Les stocks de carbone contenus dans les produits attribuables au secteur de l'industrie des produits forestiers des États-Unis sont en augmentation, ce qui représente des soustractions nettes de CO_2 de l'atmosphère. En 2005, l'accroissement des stocks de carbone dans les produits était équivalent à la séquestration annuelle de 108,5 Tg d'éq. CO_2. Approximativement 40% de cette croissance était attribuable aux produits en cours d'utilisation tandis que 60% de la croissance était attribuable aux produits dans les sites d'enfouissement.

Les émissions directes générées lors de la fabrication de produits, provenant pour la grande majorité de l'utilisation de combustibles fossiles dans les installations de fabrication primaires, totalisaient 64,6 Tg d'éq. CO_2 en 2004. Les émissions indirectes associées à l'achat d'électricité ont été estimées à 43,6 Tg d'éq. CO_2 en 2004. Les émissions associées à la production de matières premières étaient de l'ordre de 28 Tg d'éq. CO_2 par année, approximativement.

Le transport est nécessaire à plusieurs étapes de la chaîne de valeur de l'industrie des produits forestiers. Les émissions associées au transport des matières premières, des produits finis et des fibres récupérées ont été estimées à un total de 19,6 Tg d'éq. CO_2 en 2005.

À la fin de leur vie utile, une certaine fraction des produits utilisés sont éliminés dans des sites d'enfouissement. Dans les sites d'enfouissement, une portion du carbone se dégrade sous forme de méthane, un gaz à effet de serre dont le potentiel de réchauffement est beaucoup plus élevé que celui du CO_2. Les quantités de méthane rejetées à l'atmosphère dépendent non seulement des types et quantités spécifiques de produits forestiers usés qui sont éliminés dans les sites d'enfouissement, mais aussi de la conception et de l'opération des sites d'enfouissement. Étant donné les pratiques actuelles de gestion des déchets et de conception des sites d'enfouissement aux États-Unis, ces émissions furent estimées à 56 Tg d'éq. CO_2 en 2005.

Les émissions totales dans la chaîne de valeur ont été estimées à 212 Tg d'éq. CO_2 en 2004 et 2005. La source principale était la fabrication : 51% du total si seules les émissions directes et les émissions indirectes associées à l'achat d'électricité sont comptabilisées et 64% du total si les émissions en amont et associées à la production de l'ensemble des matières premières sont aussi incluses. Les émissions de méthane attribuables à la décomposition des produits forestiers dans les sites d'enfouissement contribuaient à 26% des émissions de la chaîne de valeur, tandis que le transport contribuait à la balance (soit 9% du total).

En 2005, la séquestration du carbone dans la chaîne de valeur s'élevait à une valeur estimée de 108,5 Tg d'éq. CO_2, une quantité suffisante pour compenser la totalité des émissions directes et des émissions indirectes associées à l'achat d'électricité (qui représentent plus de la moitié de la quantité totale des émissions de la chaîne de valeur).

Entre 1990 et 2004/5, une période durant laquelle la production de l'industrie s'est accrue d'environ 15%, les émissions totales de la chaîne de valeur (en ne considérant pas la séquestration) ont diminué d'environ 6%. Certains éléments du profil se sont améliorés durant cette période tandis que d'autres non. La séquestration globale du carbone a diminué de 18%, ce qui reflète bien le recours grandissant aux produits importés et aux quantités moindres de papiers usés envoyés aux sites d'enfouissement. Les émissions directes liées à la fabrication ont été réduites de 15% et celles attribuables aux achats d'électricité ont augmenté de 3% pour une réduction combinée de 9%. Les émissions de méthane attribuables à la décomposition de produits forestiers ont été réduites de 8% et les émissions reliées au transport ont augmenté d'environ 15%, en lien direct avec la production accrue de l'industrie. Les transferts nets à l'atmosphère venant de la chaîne de valeur de l'industrie des produits forestiers, en tenant compte des émissions de la chaîne de valeur ainsi que de la séquestration nette du carbone de la biomasse, se sont accrues de 91,8 Tg d'éq. CO_2 en 1990 à 103,5 Tg d'éq. CO_2 en 2005; cet accroissement étant attribuable à la réduction du stockage de carbone dans les produits pour l'année 2005. Quoique qu'il existe un certain niveau d'incertitude associée aux estimés présentés dans ce rapport, nous croyons que ces derniers procurent un portrait adéquat des amplitudes globales et des amplitudes relatives des émissions ainsi que des additions aux puits de carbone.

MOTS CLÉS

carbone, changements climatiques, GES, gaz à effet de serre, profil

AUTRES PUBLICATIONS DE NCASI DANS CE DOMAINE

Rapport spécial n^{o} 07-09 (Octobre 2007). *The greenhouse gas and carbon profile of the Canadian forest products industry*.

Rapport spécial n^{o} 07-02 (Février 2007). *The greenhouse gas and carbon profile of the global forest products industry*.

Bulletin technique n^{o} 925 (Novembre 2006). *Energy and greenhouse gas impacts of substituting wood products for non-wood alternatives in residential construction in the United States*.

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FIGURES

THE GREENHOUSE GAS AND CARBON PROFILE OF THE U.S. FOREST PRODUCTS SECTOR

1.0 INTRODUCTION

As efforts intensify to control the increase in atmospheric concentrations of greenhouse gases (GHGs), emissions from the industrial sector are coming under increasing scrutiny, in part because of their magnitude. According to the Intergovernmental Panel on Climate Change (IPCC), direct GHG emissions from the global industrial sector were 7200 Tg CO_2 eq. (a teragram, or Tg, is 10^{12} grams, equivalent to a million metric tonnes) in 2004, while total emissions, including indirect emissions associated with electricity used by the sector, were about 12,000 Tg CO_2 eq. (Bernstein 2007). These direct and total emissions represented approximately 15% and 24%, respectively, of the 49,000 Tg CO_2 eq. of GHG emissions globally (IPCC 2007). In the United States the industrial sector's 2006 direct emissions were 1370 Tg CO_2 eq., while total emissions, including those associated with electricity used by the sector, were 2030 Tg CO_2 eq. Total U.S. GHG emissions were 7200 Tg CO_2 eq., so direct and total emissions from the industrial sector represented 19 and 28%, respectively, of U.S. emissions (USEPA 2008).

While such figures are helpful for understanding the role of industry as a source of emissions, they fail to reveal the full effects of industry's activities. This is especially true of the forest products industry, where carbon sequestration and storage and end-of-life emissions can be as important as direct emissions. The overall GHG and carbon profile of the forest products industry was recently examined at the global level (Miner and Perez-Garcia 2007). That study revealed features of the forest products value chain that are not always appreciated by stakeholders: that a) end-of-life emissions from products in landfills appear to be as important as manufacturing-related emissions; and b) emissions along the value chain, including those from end-of-life, are largely offset by carbon sequestration and storage, mostly in forest products.[1]

The authors of that study noted that different results might be obtained at the national level than at the global level. They also indicated that national studies would be able to reduce uncertainties in the estimates because many countries and national industries collect data that are missing at the global level. In this report, information is assembled and analyzed to document the GHG and carbon profile of the U.S. forest products industry sector.

This study addresses emissions, sequestration, and avoided emissions. Emissions consist of transfers of GHGs from forest products industry facilities or from elsewhere in the forest products industry value chain to the atmosphere. The emissions consist primarily of carbon dioxide (CO_2) from fossil fuel combustion and methane (CH_4) from decomposition of discarded products in landfills. Sequestration consists of carbon contained in and transferred between the atmosphere, forests, forest products, and landfills. Avoided emissions consist of emissions that would have occurred were it not for certain industry activities.

An effort has been made to estimate these elements of the profile in both 1990 and 2004/2005 to reveal the changes that have occurred over that period.

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[1] The reader is cautioned against direct comparisons of this study to earlier studies involving some of these same authors (e.g., Miner and Perez-Garcia 2007; NCASI 2007) because calculation methods and parameter values are not identical among them.

2.0 GREENHOUSE GAS EMISSIONS FROM THE FOREST PRODUCTS INDUSTRY VALUE CHAIN

In this study, emissions, sequestration, and avoided emissions were examined within the ten-element framework developed in Europe for characterizing the GHG and carbon footprints of paper and paperboard products (CEPI 2007):

1. Carbon sequestration in forests
2. Carbon stored in forest products
3. GHG emissions from forest products manufacturing facilities
4. GHG emissions associated with producing fiber
5. GHG emissions associated with producing non-fiber inputs and fuels
6. Indirect emissions associated with purchases of electricity
7. Transport-related GHG emissions
8. Emissions associated with product use
9. Emissions associated with product end-of-life
10. Avoided emissions

2.1 Carbon Sequestration in Forests

Approximately 33% (303 million hectares) of the U.S. land area is forested. Most of this forest (251 million hectares) is in the 48 conterminous states. Approximately 203 million of these 251 million hectares are classified as timberland, meaning they meet minimum levels of productivity and are available for timber harvest. The remaining forest is either reserved forest land (withdrawn by law from management for production of wood products) or lower productivity forest land (USEPA 2008; Smith 2004).

From the early 1960s to the late 1980s forest land declined by approximately 10 million hectares. Since then it has increased by about 7 million hectares, representing an annual rate of change of only 0.1%. Given the low rate of change in U.S. forest land area, the major influences on the current net carbon flux from forest land are management activities and the ongoing impacts of previous land use changes. Improved forest management practices, regeneration of previously cleared forest areas, and timber harvesting and use have resulted in net uptake (i.e., net sequestration) of carbon each year from 1990 through 2006 (USEPA 2008). Annual fluxes of CO_2 into the forests of the U.S. are shown in Table 2.1. The data clearly document an accumulation of carbon in U.S. forests over this period.

These data, however, do not reveal the effects on forest carbon specifically attributable to the activities of the forest products sector. Such an analysis is complicated by several factors. Most important is the variety of sources supplying the industry's wood. Wood used by the U.S. forest products sector comes from public (national- and state-owned) forests, industry-owned forests, and non-industrial private forests. Industry-owned forests are managed to produce a continuing output of wood while protecting or enhancing a range of environmental and wildlife attributes of the land. Public forests may provide wood to the industry, but wood production is usually only one of a number of management objectives. A large number of private non-industrial landowners supply wood to the industry; some have serious interest in wood production and others have only casual interest. The industry has the potential to affect carbon stocks in all of these types of forests.

Table 2.1 Net Fluxes of Carbon Dioxide into Managed U.S. Forests
(Tg CO_2 eq./yr; negative numbers indicate net uptake)

Carbon Pool	1990	1995	2000	2001	2002	2003	2004	2005	2006
Aboveground biomass	-287.6	-318.4	-335.4	-367.7	-384.4	-406.5	-406.5	-406.5	-406.5
Belowground biomass	-54.2	-62.4	-67.2	-73.7	-76.9	-80.9	-80.9	-80.9	-80.9
Dead wood	-40.1	-57.5	-44.9	-50	-53	-56.9	-56.9	-56.9	-56.9
Litter	-63.3	-34.9	-17.3	-36.3	-47.7	-56.2	-56.2	-56.2	-56.2
Soil organic carbon	-43.9	-67.5	28	-1.3	-36	-34.5	-34.5	-34.5	-34.5
TOTAL	-489.1	-540.5	-436.8	-529	-598	-635.1	-635.1	-635.1	-635.1

[SOURCE: USEPA 2008]

Given the complexity of wood procurement situations, it is not possible to precisely estimate the effects of the industry's activities on national forest carbon stocks. Insights can be gained, however, by analyzing forest carbon stocks according to ownership. In this study, the FORCARB2 model was used to examine carbon stock changes in different types of forests used by the industry for fiber, with a focus on private timberland, especially industry-owned timberland. The FORCARB2 base scenario run from the 2005 Resources Planning Act (RPA) assessment was used to perform this analysis (Haynes et al. 2007). The model runs at five-year increments for the South and ten-year increments for other regions. Data were interpolated between the ten-year increments in the other regions to report by five-year increments for the whole U.S. Results are shown in terms of carbon and forested area in Tables 2.2 and 2.3. Results in Table2.1 and FORCARB2 are based on USDA Forest Service Forest Inventory and Analysis data. However, these data are used directly in the year measured for Table 2.1, while the FORCARB2 model compiles data unadjusted to an averaged year to initialize projections for long-term trends.

Table 2.2 Forest Ecosystem Carbon Stocks (2000) and Stock Changes: 2000 to 2005
(all pools except soil average annual, carbon stock changes; negative numbers indicate sequestration)

Forest Type	Stocks (Pg C)	Stock Changes (Tg C/yr)	Stock Changes (Tg CO_2 eq./yr)
All U.S. forests	25.7	-121.2	-444
All timberland	21.6	-96.6	-354
All private timberland	14.0	-35.3	-129
All industry-owned timberland	2.5	3.0	11

Table 2.3 Land Area in Forest
(millions of hectares)

Forest Type	1995	2005	2010
All U.S. forests	248.2	248.9	248.8
All timberland	202.5	203.2	203.0
All private timberland	146.7	147.4	147.2
All industry-owned timberland	27.2	27.1	27.0

There are some important insights to be gained from these tables. First, the amount of timberland in all ownership categories has been relatively stable. Second, because wood production is a more important management objective on industrial timberland than on most other types of private timberland, carbon stocks are not accruing on industrial timberland in the same way they are accruing on private timberland generally. Timberlands in total gained carbon between 2000 and 2005 (354 Tg CO_2 eq./yr or about 0.7%/yr on a land base of 14.0 Pg C, not including soil carbon), while industry-owned lands lost a small amount (11 Tg CO_2 eq./yr or about 0.1%/yr on a land base of 2.5 Pg C, not including soil carbon).

It is reasonable to speculate that intensive management of industry-owned land for wood production reduces demand for wood on other timberlands, indirectly contributing to the accumulation of carbon on non-industry-owned timberland. Indeed, results from FORCARB2 indicate that from 2000 to 2005 removals from forest industry lands averaged 7.7 Mg CO_2 eq. /ha, while removals from private timberlands overall averaged 4.9 Mg CO_2 eq./ha. It is also reasonable to assume that a portion of the accumulation of carbon on non-industrial private timberland is due to the industry's ongoing efforts to educate non-industrial private forest owners on sustainable forest management practices.

A complete assessment of the effects of the industry's activities on forest ecosystem carbon, therefore, should encompass not only carbon stocks on industry-owned land, but also the indirect effects on carbon stocks on other land. Unfortunately, it is not possible to identify and precisely quantify these indirect effects. Nonetheless, given the large increases in carbon stocks on non-industrial private timberland, it appears reasonable to assume that over the period included in this analysis the industry's activities did not cause decreases in forest ecosystem carbon stocks or increases in atmospheric CO_2. For purposes of this study, therefore, it was assumed that net emissions attributable to the forest products industry's activities in the forest were zero for the period covered by the analysis.

Some of the wood removed from the forest is used for energy, providing more than half of the fuel used by the industry. The carbon in the biomass used as fuel is returned to the atmosphere within a short time after harvest, completing a cycle. The fact that this biomass energy is produced without causing net reductions in forest carbon stocks indicates that the carbon released when biomass is burned is matched by uptake in the forest, resulting in a net zero effect on atmospheric CO_2.

It is not unexpected that industrial timberland carbon stocks increase and decrease over short time periods, reflecting market conditions, forest age-class distributions, and other factors, but it is difficult to predict how these factors will influence management decisions and carbon stocks on industrial land in the future. If industrial land owners expect the market for wood to remain strong, they will have reason to keep land in forest, use sustainable forest management practices, and improve forest productivity, which will help maintain or increase carbon stocks on other timberlands. If the demand for wood is expected to weaken, however, pressures to convert industrial forestland to other uses will become greater and incentives to invest in productivity enhancements will diminish.

2.2 Carbon Stored in Forest Products

Carbon removed from forests is transferred into products, and some of these products are discarded into landfills at the end of their useful lives. This section examines the significance of carbon stored in products both in use and in landfills. (Small amounts of carbon are also stored in landfills receiving wastes from forest products manufacturing facilities, as discussed in Section 2.3.2, but the amounts of carbon are small enough to be ignored in overall carbon storage calculations.)

2.2.1 *Carbon Stored in Products in Use*

After manufacturing, forests products remain in end uses for periods varying from days to centuries. Carbon remains stored during this time, delaying its return to the atmosphere. If carbon in products is being added to the pool of products in use faster than it is being removed by the retirement of previously manufactured items, stocks of carbon in the products in use pool grow.

Estimates of annual changes in carbon held in products in use shown herein were made for EPA's annual sinks and emissions report using the Woodcarb II model. Woodcarb II uses methods recommended by IPCC (2006). The model estimates changes in harvested wood products held in end uses, discards from use, deposits in dumps (unmanaged disposal sites) and landfills (disposal sites managed for leachates, air emissions, etc.), and decay in dumps and landfills. It is used to prepare carbon change estimates for the annual national GHG emissions inventory prepared by EPA (USEPA 2007, 2008; Skog 2008). The production accounting approach was used to report carbon changes herein. Thus, carbon in products is tracked if the wood came from trees harvested in the U.S., including exported wood and paper products but excluding imported products (IPCC 2006).

Additions to products in use are based on production and trade data from the United States Department of Commerce (USDOC) Census, the United States Department of Agriculture (USDA) Forest Service, and the American Forest and Paper Association (AF&PA) from 1900 to 2006. Estimates were made of amounts of wood and paper in end uses from 1990 to 2006 and amounts of products discarded each year. Estimates of discards were used in landfill calculations described herein.

A key determinant of discard rates is the time various products remain in use. Discard rates were estimated to follow a first order decay function with half-lives for various uses (Table 2.4). Half-life estimates were developed so the Woodcarb II model produced estimates of carbon in housing in 2001 that match Census-based estimates, and produced estimates of wood and paper discards to landfills that match EPA estimates from 1990 to 2001. It was assumed that the small portion of exported wood and paper products had the same use life, discard disposition, and decay features in solid waste disposal sites in other countries as in the U.S. The general methods and data used to estimate carbon changes in wood and paper in use were explained by EPA (USEPA 2008) and in more detail by Skog (2008). Data used to estimate annual additions to product in use are from various sources (U.S. Census Bureau 1976; AF&PA 1999a, 1999b; Hair 1958; Hair and Ulrich 1963; Howard 2003, 2007; Steer 1948; Ulrich 1985, 1989). Half-lives for products in use are shown in Table 2.4.

Table 2.4 Estimated Solid Wood and Paper End Use Half-Life Parameters

Parameter	Estimated Value
Half-life of solid wood in single family housing – 1920 and before (years)	78.0
Half-life of solid wood in single family housing – 1921 to 1939 (years)	78.0
Increase in half-life for housing for each 20 yr period after 1921 to 1939 (years)	1.97
Ratio of half-life for solid wood in multifamily housing to half-life in single family housing	0.61
Ratio of half-life for solid wood in alterations and repair of housing to half-life for single family housing	0.30
Half-life for solid wood in all other end uses (years)	38.0
Half-life for paper in all end uses (years)	2.53

[SOURCES: USEPA 2008; Skog 2008]

Estimates of annual changes in carbon in products in use are shown in Table 2.5 and Figure 2.1. Additions are notably greater for wood products than for paper because of the shorter use life of paper. Annual net additions decreased from 65 Tg CO_2 eq. in 1990 to 45 Tg CO_2 eq. in 2006. As noted, these estimates are for carbon in products where the wood came from U.S. harvest, including exported products in use in other countries. One reason for the decline in annual additions is the decreasing proportion of U.S. consumption that comes from domestic harvest, with an increasing fraction from imported wood and paper.

Table 2.5 Annual Changes in Carbon in Wood and Paper Products in Use (Tg CO_2 eq.)

Year	Wood	Paper	Total
1990	52.7	12.1	64.8
1991	43.6	11.2	54.8
1992	46.3	13.6	59.9
1993	44.8	10.1	54.9
1994	44.4	14.0	58.4
1995	41.2	14.0	55.2
1996	42.0	9.6	51.7
1997	43.1	10.9	54.0
1998	41.7	7.3	49.0
1999	44.5	7.3	51.8
2000	43.5	3.5	47.0
2001	36.9	-5.0	31.9
2002	39.1	-4.0	35.1
2003	37.1	-1.6	35.4
2004	42.6	3.0	45.5
2005	43.4	3.9	47.3
2006	39.6	5.6	45.3

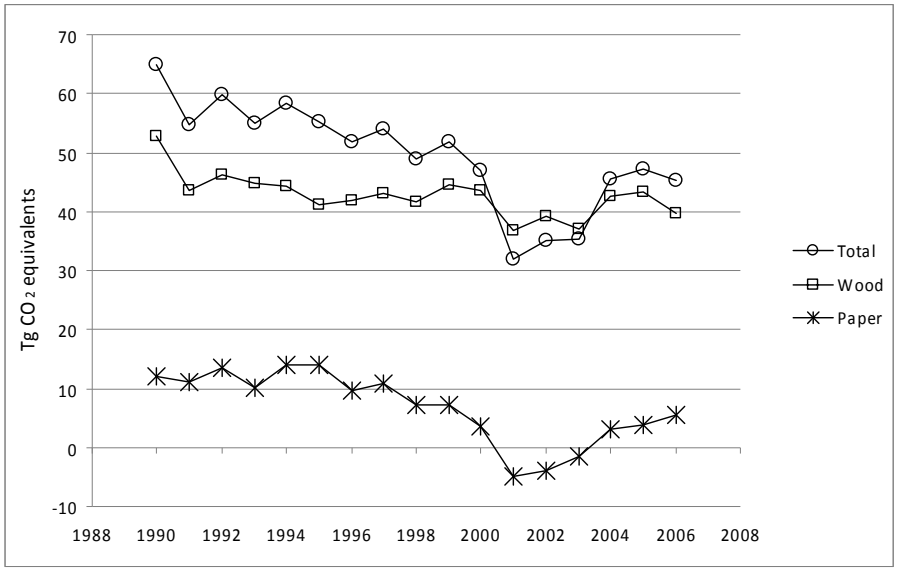

Figure 2.1 Annual Changes in Carbon in Wood and Paper Products in Use (Tg CO_2 eq.)

The total stock of wood and paper carbon in products in use is estimated to have been 1423 Tg CO_2 eq. in 2006. The uncertainty of estimates of annual changes in carbon stored in harvested wood products in use, in dumps, and in landfills is estimated to be ±24% (95% confidence interval) (USEPA 2008).

2.2.2 *Carbon Stored in Products in Landfills*

Products are recycled or discarded after use. Methods for estimating discards from use were described in Section 2.2.1. End-of-life management of waste materials varies greatly among and even within countries. An estimated 67% of wood and 31% of paper discarded from use in the U.S. is currently sent to landfills (Table 2.6).

Table 2.6 Percentages of Discarded Wood and Paper Going to Dumps and Landfills

Year	Discarded wood not going to SWDS[a]	Discarded paper not going to SWDS[a]	SWDS wood or paper to dumps	Discarded wood to landfills[b]	Discarded wood to dumps[c]	Discarded paper to landfills[d]	Discarded paper to dumps[e]
Col #	1	2	3	4	5	6	7
1900	29	29	100	0	71	0	71
1920	29	29	10	0	71	0	71
1940	30	30	96	3	67	3	67
1950	30	30	90	7	63	7	63
1960	31	48	84	11	58	9	44
1970	21	36	67	26	53	21	43
1980	9	30	25	68	23	52	17
1990	25	46	2	74	2	54	1
2000	31	62	2	67	2	37	1
2001	31	66	2	67	2	34	1
2002	30	65	2	68	2	35	1
2003	31	67	2	67	2	32	1
2004	31	68	2	67	2	32	1
2005	31	69	2	67	2	31	1

[SOURCE: Freed and Mintz 2003 using data from USEPA 2006a; Melosi 1981, 2000; and other sources]

[a] solid waste disposal sites (SWDS) include dumps and landfills

[b] Col 4 = (100 – Col 3) x (100 – Col 1) / 100

[c] Col 5 = Col 3 x (100 – Col 1) / 100

[d] Col 6 = (100 – Col 3) x (100 – Col 2) / 100

[e] Col 7 = Col 3 x (100 – Col 2) / 100

Most decay in landfills is anaerobic, where decay of forest products is limited. The lignin portion of forest products and cellulose and hemicellulose protected by lignin or coating materials are not subject to anaerobic decay. The decay limits used in these estimates were based on studies by Barlaz (1998) and Eleazer et al. (1997) as summarized by Freed and Mintz (2003). Only 23% of carbon in solid wood products and 56% of carbon in paper is estimated to be emitted over time. The half-lives for paper and wood decay in landfills are estimated to be 14.5 and 29 years, respectively, in temperate regions (IPCC 2006, vol. 5 ch. 3).

The Woodcarb II model was used to track additions to and emissions from landfills and dumps using discard factors (Table 2.6), decay limits, and decay half-lives. Resulting estimates show that net carbon additions to landfills and dumps are increasing for wood products and decreasing for paper

products (Table 2.7 and Figure 2.2). Overall, net annual additions decreased from 68 to 65 Tg CO_2 eq. between 1990 and 2006. The total stock of wood and paper carbon in landfills is estimated to have been 880 Tg CO_2 eq. in 2006. The uncertainty in estimates of annual changes in carbon storage in harvested wood products in use and in landfills is estimated to be ±24% (95% confidence interval) (USEPA 2008).

Table 2.7 Annual Changes in Carbon in Wood and Paper Products in Landfills (Tg CO_2 eq.)

Year	Wood	Paper	Total
1990	37.2	30.6	67.9
1991	41.5	28.4	69.8
1992	35.8	28.9	64.8
1993	36.3	30.4	66.7
1994	36.9	28.1	65.0
1995	40.4	23.8	64.1
1996	39.7	21.8	61.5
1997	38.9	25.4	64.3
1998	38.6	27.5	66.0
1999	39.8	28.6	68.3
2000	40.1	26.8	66.9
2001	40.4	22.1	62.6
2002	41.6	22.5	64.2
2003	41.6	18.8	60.4
2004	42.5	18.3	60.8
2005	43.4	17.8	61.2
2006	43.8	20.9	64.7

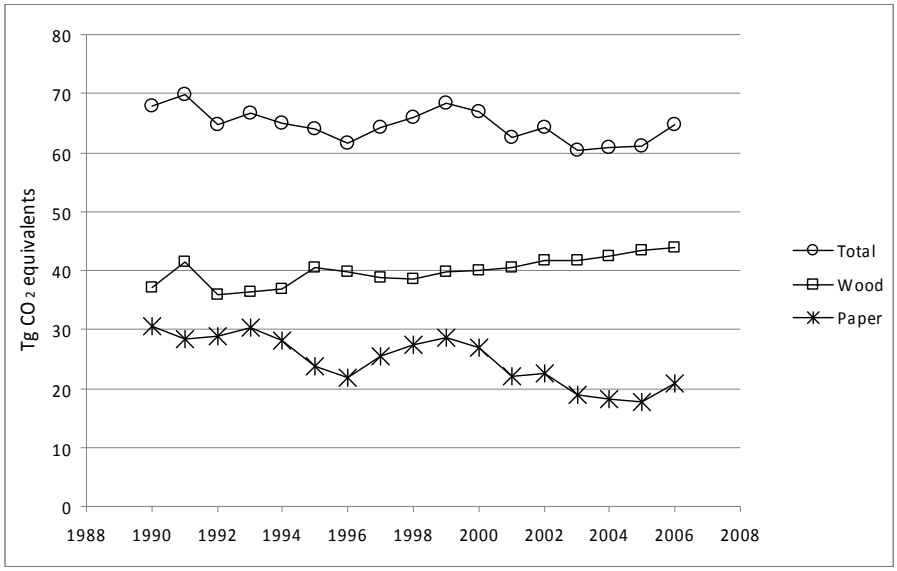

Figure 2.2 Annual Changes in Carbon in Wood and Paper Products in Landfills (Tg CO_2 eq.)

2.2.3 *Total Carbon Storage in Forest Products*

Adding net increases in stocks of carbon in products in use and in landfills yields total increases of 132.6 Tg CO_2 eq. in 1990 and 108.5 Tg CO_2 eq. in 2005.

2.3 Greenhouse Gas Emissions from Forest Products Manufacturing Facilities

2.3.1 *Direct Emissions Associated with Fuel Combustion*

Almost all direct GHG emissions from forest products industry manufacturing facilities are the result of fossil fuel combustion. The industry satisfies much of its energy requirements by also burning large quantities of biomass fuels, but CO_2 released from biomass combustion (approximately 113 Tg CO_2 based on fuel consumption data from EIA 2005) is not included in GHG totals because it contains biogenic carbon. This biogenic carbon is addressed via the calculations on the stocks and flows of forest carbon described in Sections 2.1 and 2.2. Small amounts of nitrous oxide (N_2O) and methane (CH_4) are also released during combustion of biomass fuels and fossil fuels, which are included in the GHG emission totals reported herein.

Total direct GHG emissions from fuel combustion were estimated for both the pulp and paper sector and the wood products sector. Pulp and paper sector energy consumption during 1990 and 2004 were determined from data obtained from AF&PA. GHG emission factors from IPCC (1997) were used in conjunction with these data to calculate direct emissions from fuel combustion. IPCC Tier 1 CH_4 and N_2O emission factors were used with the exception of CH_4 and N_2O from biomass fuel combustion, which were estimated using emission factors from the International Council of Forest and Paper Associations (ICFPA) and NCASI (2005a). Emission factors are shown in Table2.8. GHG emission estimates are expressed as CO_2 equivalents (CO_2 eq.) and include CO_2, CH_4, and N_2O, including CH_4 and N_2O from combustion of biomass fuels. Global warming potentials (GWPs) of 21 and 310 were used for CH_4 and N_2O, respectively. [Note that although most accepted GHG reporting programs require GWPs of 21 and 310 for CH_4 and N_2O, respectively, it is likely that these will be changed to 25 and 298 at some point in the future due to updated information].

Fuel consumption data used to estimate 1990 emissions originated from AF&PA survey responses corresponding to 91.4% of the industry's production which had been adjusted by AF&PA to represent the entire industrial sector's consumption. Available fuel consumption data for 2004 had not been scaled up by AF&PA, and were obtained from survey responses representing 76,800,000 metric tonnes of production. Total U.S. pulp and paper sector production in 2004 (including paper, paperboard, and market pulp production) was estimated to be 92,810,000 metric tonnes based on data published by AF&PA (2007). Therefore, in order to arrive at a representation of the total U.S. pulp and paper industry, the emission estimates based on 2004 AF&PA energy data were multiplied by a factor of 1.21 (92,810,000 ÷ 76,800,000).

Pulp and paper industry manufacturing direct emissions from fuel consumption were 66.9 Tg CO_2 eq. in 1990 and 57.7 Tg CO_2 eq. in 2004. The decrease is presumed to result from implementation of energy efficiency measures and increased reliance on low-emitting biomass fuels (which displaced fossil fuels). Total pulp and paper production increased during the same period, from 91.1 Tg in 1990 to 102.3 Tg in 2004.

Energy consumption by the wood products sector in 1991 was characterized using data from the Energy Information Administration's (EIA) Manufacturing Energy Consumption (MEC) survey corresponding to SIC code 24, Lumber and Wood Products (EIA 1994). The GHG emission factors in Table 2.8 were used in conjunction with these data to estimate direct emissions from fuel combustion at 4.4 Tg CO_2 eq. in 1991.

Table 2.8 Greenhouse Gas Emission Factors for Fossil and Biomass Fuels

Fuel	CO_2 Factor (kg/MMBtu HHV)	CH_4 Factor[a] (kg/MMBtu HHV)	N_2O Factor[a] (kg/MMBtu HHV)
Gasoline	68.8	0.002	0.0006
Kerosene	71.3	0.002	0.0006
Distillate oil (and diesel)	73.5	0.002	0.0006
Residual fuel oil	76.8	0.002	0.0006
LPG (propane)	62.5	0.002	0.0006
Natural gas	53.0	0.005	0.00009
Coal (assumed bituminous)	92.9	0.01	0.001
Tires and tire derived fuel	86.0[b]	0.01	0.001
Wood and wood waste	0[c]	0.012[d]	0.004[d]
Pulping liquors	0[c]	0.0025[d]	0.002[d]

[SOURCE: Emission factors are from IPCC 1997, converted from GJ LHV to MMBtu HHV basis and corrected for unoxidized carbon according to recommendations therein, unless otherwise noted.]

[a] CH_4 and N_2O emission factors are IPCC 1997 Tier 1 unless otherwise noted

[b] CO_2 factor for tires/TDF from EIA 2006

[c] emission factor for biomass-derived CO_2 is zero because carbon in biomass fuels is accounted for in the assessment of forest carbon (i.e., including CO_2 emissions from biomass combustion in direct emission estimates would result in double counting)

[d] CH_4 and N_2O factors for biomass fuels are from NCASI 2005a

The sector's energy consumption in 2004 was estimated based on data from AF&PA. However, the energy data provided to AF&PA by member companies were found to be highly variable. Therefore, the data were analyzed statistically such that emission intensity factors were developed for each of the major product categories in the wood products sector (composite panels, lumber, plywood, and "other" production). Each facility providing data was first categorized by the products made. CO_2 emissions were calculated for each facility based on reported fossil fuel consumption and were divided by the facility's production expressed in thousand cubic feet (MCF) wood equivalents, producing a facility-specific CO_2 emission intensity. A median CO_2 intensity factor for each major product category was then determined from the distribution of all reporting facilities whose production was at least 90% in that category. Use of the median limits the influence of particularly large and small values, making it a reasonable approach given the wide range of values encountered (a range of at least five orders of magnitude within each product category).

CO_2 emission intensity factors for each major product category were adjusted in order to include the other pertinent GHGs (CH_4 and N_2O) in the current analysis. A ratio of total GHG emissions (including CO_2 from fossil fuels and CH_4 and N_2O from all fuels) to fossil fuel CO_2 emissions was developed for each production category and was applied to the appropriate category median CO_2 factors. Total wood products sector emissions were estimated by multiplying each of the category-specific emission intensities by total 2004 U.S. production in the category (FAO 2008) and were summed across categories. The resulting estimate of direct fuel combustion GHG emissions from the U.S. wood products sector in 2004 was 1.8 Tg CO_2 eq. This value is significantly lower than that for 1991 (4.4 Tg CO_2 eq.). A comparison of the two estimates is complicated by the underlying uncertainty in the data and the different data sources and estimation methods used. The apparent large reduction between 1991 and 2004 may be an artifact of these factors. Emissions from the wood products sector are small compared to those from the pulp and paper sector, so the uncertainty in the wood products sector emissions has little effect on the overall emissions estimate for the forest products industry.

Total direct GHG emissions related to fuel combustion at forest products industry facilities (not including pulp and paper sector converting operations) are estimated to have been 71.3 Tg CO_2 eq. in 1990 and 59.5 Tg CO_2 eq. in 2004 (the 2004 result represents about 1% of U.S. energy-related GHG emissions, estimated at 6170 Tg CO_2 eq.) (USEPA 2008).

Although it is not possible to derive an estimate of the uncertainty in these figures, EPA reported that energy-related CO_2 emissions estimates in the U.S. national inventory are characterized by an uncertainty range of about ±15% for industrial sources (USEPA 2008).

2.3.2 *Emissions Associated with Treatment and Disposal of Liquid and Solid Mill Wastes*

There are two potential sources of GHGs associated with management of mill wastes: methane emissions from mill landfills, and methane emissions from wastewater treatment operations experiencing anaerobic conditions. Although the data available for estimating these emissions are sparse, NCASI recently completed studies to improve these estimates. NCASI's studies identified several waste management operations from which GHG emissions are insignificant. Other operations have been found to have the potential to release measureable (albeit small and highly variable) amounts of methane. The reasons for the variability are not yet understood. Given the small size of these emissions, the unexplained variability can be ignored in developing estimates of total industry emissions. The reader is cautioned, however, that the approaches discussed herein will not generate accurate estimates of individual mill emissions.

Emissions from Wastewater Treatment Operations

NCASI studies have confirmed that mechanical clarifiers and aerobic biological treatment systems with high intensity mixing, such as activated sludge treatment systems, do not generate significant amounts of methane. Anaerobic treatment systems are known to generate methane, but there are very few biological treatment systems in the U.S. forest products industry that are designed to provide treatment via the anaerobic decomposition of organic matter. There are, however, operations that can contain zones that become anaerobic, including aerated stabilization basins (ASBs), primary settling basins, and post-aeration basins.

Aerated Stabilization Basin Emissions – The year 2004 was used in these calculations because 2004 data were the most current available from AF&PA surveys of the industry's wastewater discharges. Several sources of information were used to identify 125 U.S. mills operating ASBs and the final effluent biological oxygen demand (BOD) loads from these systems. The sum of annual final effluent BOD from all mills with ASBs was used to derive an estimate of incoming BOD loads by assuming a treatment efficiency of 94% across the ASBs. NCASI studies suggest that although there is great unexplained variability between systems, on average about 1% of incoming BOD is converted to methane (NCASI 2008). Using these data, the annual mass of methane emitted from ASBs was calculated to be 4600 metric tonnes, or approximately 0.10 Tg CO_2 eq.

Due to limited information for 1990, it was necessary to use a slightly different approach. The sum of annual final effluent BOD for all mills with ASBs in 1990 was scaled back from 2004 by multiplying the 2004 mass by the ratio of 1990 total production to 2004 total production. The total final effluent BOD discharged by mills with ASBs was calculated using an estimated industry-wide final effluent BOD loading (2.99 kg/metric tonne) for 1990 obtained by interpolation from AF&PA data (AF&PA 2006). A treatment plant efficiency statistic for 1990 was obtained and used to estimate the mass of BOD removed (Miner and Unwin 1991). Finally, the ASB fraction of the total BOD removed was used to calculate the amount of BOD removed by ASBs. As with the 2004 data, 1% of incoming BOD was assumed to be converted to methane. Using these data, the 1990 annual mass of methane emitted from ASBs was calculated to be 6300 metric tonnes, or approximately 0.13 Tg CO_2 eq.

Settling Pond Emissions – In lieu of mechanical clarifiers, some mills use earthen primary settling ponds to remove suspended solids from wastewater prior to entering an ASB or activated sludge treatment system. Temporary storage of solids in these ponds can result in anaerobic conditions and subsequent release of methane. Statistics presented in EPA's Technical Development Document (USEPA 1993) indicate that approximately 10% of U.S. production is at mills with such ponds. Based on this information, it was assumed that 10% of the industry's wastewater loading had the potential to cause methane emissions in these ponds. The methane generation rate used for this calculation was developed in a single NCASI study at a primary settling pond (NCASI 2008). Overall production data for 2004 and 1990 were the same as those used for ASB methane emissions. The 2004 annual mass of methane emitted from settling ponds was calculated to be 5100 metric tonnes, or approximately 0.11 Tg CO_2 eq. The 1990 annual mass of methane emitted from settling ponds was calculated to be 4400 metric tonnes, or approximately 0.09 Tg CO_2 eq.

Post-Aeration Basins – The majority of mills that operate ASBs utilize a post-ASB (quiescent) basin to allow suspended solids to settle out. In some situations where mills do not have a separate quiescent basin, they utilize a non-aerated tail end portion of the ASB to settle solids. In either arrangement, the mixing energy is low enough that solids settle into a blanket on the bottom of the basins. Storage of solids in these ponds can result in anaerobic conditions and subsequent release of methane.

Methane emission measurements from post-aeration basins are limited to one NCASI study conducted at a southern kraft mill that utilized a quiescent basin to settle solids prior to final discharge. Using annual methane emission rates for the quiescent basin and the annual production of the mill, methane emitted was calculated on a per metric tonne basis. This emission rate was multiplied by the sum of the production for all mills operating ASBs. The resulting sum of methane produced by solids in quiescent basins was 9500 metric tonnes in 2004, equal to approximately 0.2 Tg CO_2 eq.

Methane emissions for 1990 were calculated in a manner similar to the 1990 ASB methane emission rates in that a ratio of 1990 to 2004 total production was determined and used to scale back the total production of all mills with ASBs. The methane emission rate on a per metric tonne of product for 1990 was assumed to be the same as in 2004. The resulting sum of methane produced by solids in settling ponds was 8200 metric tonnes in 1990, or approximately 0.17 Tg CO_2 eq.

Total Wastewater Management-Related Emissions – Combined emissions of methane from industry wastewater management systems are estimated to have been 0.40 Tg CO_2 eq. in both 1990 and 2004 (Table 2.9).

Table 2.9 Annual Treatment Plant Methane Releases

Treatment Source	1990	2004
Aerated stabilization basin[a]	6,300	4,600
Primary settling pond[a]	4,400	5,100
Post-aeration pond[a]	8,200	9,500
Total as methane[a]	19,000	19,000
Total (Tg CO_2 eq.)	0.40	0.40

[a] metric tonne CH_4

Emissions from Landfills Receiving Mill Wastes

Survey information on the quantity of solid waste generated and the fraction of that waste that is landfilled was used to derive an industry-wide estimate of the quantities each year from 1970 through 2005. These were used in a first order decay equation, along with appropriate k and L_o values, to calculate 1990, 2004, and 2005 forest products industry landfill methane emissions using the NCASI GHG calculation tool, which is based on IPCC calculation methods (NCASI 2005b). Separate estimates were made for pulp and paper mills and wood products plants.

Pulp and Paper Mills – For pulp and paper mills, wastewater treatment residuals and ash constitute the vast majority of the solid residuals landfilled (NCASI 1999). Ash is essentially inert, so only wastewater treatment plant (WWTP) residuals were considered. NCASI and others have documented that residuals collected in primary treatment alone degrade in landfills very slowly or not at all (NCASI 2005c), probably because of a lack of essential nutrients (particularly phosphorus and nitrogen) to support anaerobic biological activity. Only after 1970, when the practice of combining biological solids with primary solids prior to disposal started to become more common, did landfilled WWTP residuals have much potential to produce methane. Therefore, only residuals landfilled since 1970 were considered.

Survey data relevant to landfilling of WWTP residuals are available as far back as 1979 (NCASI 1983, 1991, 1999; AF&PA 2006). The quantity landfilled was calculated as the product of the quantity of WWTP residuals generated and the landfilling rate. Where the quantity generated was not known, it was estimated from the product of the generation rate and the total paper, paperboard, and market pulp production for the year (AF&PA 2007). For years in which the quantity generated was unknown and could not be estimated from the generation rate, it was estimated by interpolation between the most recent values before and after that year. Quantities before 1975 were extrapolated from values in 1985 and 1975. Where the landfilling rate was unknown it was obtained by interpolation. The landfilling rate in 1970 was assumed to be 95%.

Wood Products Facilities – Wood products facilities almost never have WWTPs as such, so the vast majority of solid residuals they produce result from handling and processing of wood. Available data for quantities landfilled by these facilities are sparse and the record is not as long as for pulp and paper mills (AF&PA 2006). As with pulp and paper mills, the quantity generated was calculated as the product of the generation rate and the total wood products production of lumber and panels (FAO 2008). For years between 1999 and 2006 for which generation rates were unknown, they were estimated by interpolation between the nearest known values. For years prior to 1999, generation rates were assumed to be the same as that documented in 1999. For years between 1999 and 2006 for which landfilling rates were unknown, they were estimated by interpolation. For years prior to 1999, landfilling rates were estimated by interpolation between the 1999 rate and an assumed rate in 1970 of 10%. The 1970 assumed landfilling rate is so much lower than the 95% assumed for pulp and paper mills because it is long-standing common practice for wood products mills either to burn their solid waste or to provide it to pulp mills as a fiber source.

Methane Emissions Calculations – As noted, methane emissions were estimated using a first order decay model (IPCC 2007). The first order model requires estimates of the first order generation rate constant (k) in units of inverse years, and the ultimate methane generation potential (L_o) in units of standard cubic meters of methane per dry megagram (Mg or metric tonne) of deposited material. NCASI studied four different pulp and paper mill WWTP residuals both in the laboratory and in the field to learn what values to use for these coefficients. The coefficients have been found to be highly variable between residuals for reasons that are not yet understood. For purposes of this study, the average observed values for k ($0.013 year^{-1}$) and L_o ($80.5\ m^3/Mg$) were used for both WWTP residuals and wood products residuals. It was assumed for all years that 10% of methane generated was

oxidized before it was released to the atmosphere (IPCC 2007) and that there was no collection or burning of landfill methane.

Results – Estimates of methane released from landfills receiving forest products solid wastes are shown in Table 10. A global warming potential of 21 was used to convert methane to CO_2 equivalents. Methane releases in 1990 were estimated to have been approximately 1.6 Tg CO_2 eq., increasing to 2.2 Tg CO_2 eq. in 2005. These emissions are offset, to some degree, by carbon storage in these same landfills.

Table 2.10 Estimated Methane and Equivalent Carbon Dioxide Emissions from Forest Products Industry Landfills

Year	Methane (metric tonnes)	Tg CO_2 Eq.
1990	74,200	1.56
2004	103,000	2.17
2005	104,000	2.18

Long-Term Landfill Carbon Sequestration and Emissions – As noted in the calculations of the fate of forest products in landfills, some carbon that enters a landfill remains sequestered for very long periods. It is useful, therefore, to examine the net balance between this long-term storage and long-term methane emissions. The ultimate methane generation value cited (L_o of 80.5 m^3 CH_4/dry metric tonne landfilled) is equivalent to 161 m^3 landfill gas/dry metric tonne landfilled (assuming that landfill gas is 50% methane and 50% carbon dioxide). This gas (161 m^3 landfill gas) corresponds to 86 kg of carbon per dry metric tonne landfilled. Mill residuals associated with this L_o had an average carbon content of about 25% (i.e., 250 kg carbon per dry metric tonne landfilled), the large majority of which was organic carbon. For WWTP residuals, therefore, about 35% (86 ÷ 250 = 0.35) of landfilled carbon is lost as landfill gas, meaning that about 65% of landfilled carbon is sequestered. Wood and wood waste carbon content averages about 50%, which for the same L_o implies that about 83% of landfilled carbon is sequestered (1 – 0.35 / 2 = 0.825). When these relations are applied to the estimated quantities of WWTP residuals and wood waste landfilled annually, estimated quantities of carbon sequestered can be calculated. To calculate long-term methane emissions, the fraction of carbon *not* sequestered is assumed to be emitted (under oxidation and collection conditions cited herein) as landfill gas that is 50% (by volume) methane.

Results of those calculations indicate that in 1990, long-term sequestration (approximately 6.1 Tg CO_2 eq.) was about equal to long-term methane emissions (approximately 6.6 Tg CO_2 eq.). However, in 2004 and 2005, long-term methane emissions (approximately 3.3 Tg CO_2 eq.) were greater than long-term sequestration (approximately 2.3 Tg CO_2 eq.). The difference was due to the materials going to landfills in 1990 being made up of a larger proportion of wastes from wood products manufacturing compared to pulp and paper mills. Overall, it appears that approximately 70% of long-term methane emissions are offset by long-term sequestration. This sequestration is small enough to be ignored in estimates of overall value chain sequestration, but large enough to significantly affect net emissions from mill landfills. In spite of the carbon storage accomplished in mill landfills, these landfills are still net long-term emitters of GHGs.

2.3.3 *Emissions Associated with Final Manufacturing Operations*

Primary pulp and paper products are often further processed to yield final products. In most cases, however, these operations (converting and assembly) emit low quantities of GHGs compared to primary manufacturing. A lifecycle study of magazines in North America, for instance, found that GHG emissions attributable to printing were 3 to 7% of those from pulp and paper manufacturing

(Gower et al. 2006). A European study of corrugated box manufacturing found that CO_2 emissions associated with assembling the final box from paperboard represented approximately 13% of the cradle-to-gate emissions of fossil fuel-derived CO_2 (FEFCO 2006). For some paper products, copy paper for instance, almost no additional GHGs are generated in converting the primary product (e.g., converting rolls of paper into cut sheets). Lifecycle studies of houses in Europe have found that emissions resulting from house construction (not including worker transport) are less than 10% of embodied GHG emissions in the building materials (Cole 1999). In the current analysis, emissions associated with pulp and paper industry converting operations in 1991 were estimated based on energy consumption data from the EIA (MECs) corresponding to SIC code 27, printing and publishing (EIA 1994) and 2002 emissions were based on energy consumption corresponding to NAICS code 323, printing and related support (EIA 2005) in conjunction with the emission factors presented in Table 8. Emissions were 2.8 Tg CO_2 eq. in 1991 and 2.5 Tg CO_2 eq. in 2002.

2.3.4 *Total Greenhouse Gas Emissions Associated with Forest Products Manufacturing Facilities*

Various direct emissions associated with forest products manufacturing facilities are summarized in Table 2.11, which indicates that total emissions were 76.1 Tg CO_2 eq. in 1990 and 64.6 Tg CO_2 eq. in 2005.

Table 2.11 Direct Emissions Associated with U.S. Forest Products Manufacturing Facilities

Direct Emissions Source	1990 Emissions[a] (Tg CO_2 eq.)	2004 Emissions[a] (Tg CO_2 eq.)
Fuel consumption at pulp and paper mills	66.9	57.7
Fuel consumption at wood products facilities	4.4[b]	1.8
Management of mill wastes	2.0[c]	2.6[c]
Secondary pulp and paper sector manufacturing operations (i.e., converting primary products into final products)	2.8[b]	2.5[d]
Total	76.1	64.6

[a] biomass-derived CO_2 is dealt with in the assessment of forest carbon because biogenic carbon is analyzed separately from fossil fuel carbon, an emission factor of zero is used here to avoid double counting; emissions of CH_4 and N_2O from all combustion processes are included

[b] estimates based on 1991 fuel consumption data

[c] includes methane from mill landfills and from anaerobic zones of wastewater treatment plants, not considering the offset due to carbon storage in mill landfills (which would lower these numbers)

[d] estimates based on 2002 fuel consumption data

2.4 Greenhouse Gas Emissions Associated with Producing Fiber

Emissions are generated in the forest before, during, and after harvest. Emissions can be associated with use of fertilizers during planting and growth. EPA estimated that N_2O emissions related to fertilizer use in U.S. forests were 0.1 Tg CO_2 eq. in 1990 and 0.3 Tg CO2 eq./year from 2004 to 2006 (USEPA 2008). Other pre-harvest emissions are not significant (Sonne 2006).

Harvesting and burning are the other significant sources of GHG emissions related to obtaining forest fiber. Sonne (2006) found that fuel consumption by harvesting equipment emits 8.3 kg CO_2 eq./m^3 harvested wood. In 1990 approximately 427,200,000 m^3 of industrial round wood were harvested in the U.S., while the harvest in 2005 was approximately 423,456,000 m^3 (FAO 2008). These values suggest that approximately 3.5 Tg CO_2 eq. were emitted during harvesting in 1990 and 2005.

Pile burning is sometimes used to clear harvest debris and prepare a site for replanting and regeneration. Where it is used, it can generate methane and nitrous oxide emissions that are 60% of those associated with fuel combustion in harvesting equipment (Sonne 2006). In western Washington and Oregon, pile burning is used about 20% of the time (Sonne 2006). Applying these two factors to harvesting emissions estimates yields an estimate of 0.4 Tg CO_2 eq./year of emissions associated with pile burning. Pile burning may be more or less prevalent in other parts of the country, but these emissions are so small that additional precision is not necessary for purposes of this study.

Overall, therefore, it appears that producing virgin fiber in 1990 and 2005 resulted in emissions of 4.0 Tg CO_2 eq. and 4.2 Tg CO_2 eq., respectively.

While there may be some small emissions associated with sorting recovered fiber, most of the emissions from recovered fiber can be attributed to transport, which is estimated separately in this report.

2.5 Greenhouse Gas Emissions Associated with Producing Non-Fiber Inputs and Fuels

Wood fiber constitutes the vast majority of the raw materials associated with forest products manufacturing. One source (Diesen 1998) indicated that wood and recovered fiber account for 85% of the raw materials for pulp and paper manufacture (not including water). A lifecycle study of paper bags in Europe found that non-water inputs to the mill consisted of fiber (82%) and fuels (14%), while other raw materials represented less than 4% of non-water inputs (Löfgren 2005). A lifecycle study of corrugated boxes found that non-fiber additives represented only approximately 5% of non-fuel raw materials (not including water) (FEFCO 2006). Some printing and writing grades contain non-fiber fillers at relatively high levels (10% of sheet weight or more). In these cases, non-fiber, non-fuel inputs may represent a larger fraction of total raw materials but these highly filled grades represent a relatively small fraction of the industry's output of paper and paperboard. Non-fiber inputs are even less important in wood products manufacture. In the case of oriented strand board (OSB), for instance, which contains more non-wood components than most wood products, wood and bark comprise over 95% of the raw materials (Kline 2004).

To estimate upstream emissions associated with non-fiber, non-fuel inputs, NCASI developed lists of the amounts of these inputs used in paper, paperboard, market pulp, and panel production. The lists for paper, paperboard, and market pulp were supplied by Fisher International based on its proprietary database [Fisher International, 50 Water Street, South Norwalk, CT 06854 USA]. The lists included all non-fiber inputs representing at least 1% of the total mass of all mill inputs. In several cases, these lists were lengthened to include additional chemicals based on expert judgment and consultation of the ecoinvent® lifecycle database [Swiss Centre for Life Cycle Inventories, Swiss Federal Laboratories for Materials Testing and Research, Überlandstrasse 129 CH-8600 Dübendorf, Switzerland]. nputs to panel manufacturing (primarily resins) were obtained from the ecoinvent® database. Upstream loads for pulp, paper, market pulp, and panel manufacturing were obtained from the ecoinvent® database.

Using these data, NCASI examined upstream loads associated with the predominant products manufactured by the U.S. forest products industry and determined that for purposes of this study, it was reasonable to assume that upstream loads associated with non-wood, non-fuel inputs were 100 kg CO_2 per metric tonne for paper, paperboard, and market pulp and 200 kg CO_2 per metric tonne for panels. The non-fiber, non-fuel inputs to sawn wood are so small that they were not included in the analysis.

These factors were applied to the relevant 1990 and 2005 production quantities (presented in Section 2.7). The resulting non-fiber, non-fuel upstream emissions for paper, paperboard, and market pulp produced in 1990 and 2005 were 8 and 9 million tons CO_2 eq., respectively. Those for panel production in 1990 and 2005 were 4 and 5 million tons CO_2 eq., respectively. The totals, therefore, were 12 and 14 million tonnes CO_2 eq. in 1990 and 2005, respectively.

Data for upstream emissions associated with fossil fuels were obtained from the U.S. Life-Cycle Database maintained by the USDOE National Renewable Energy Laboratory (http://www.nrel.gov/lci/database/default.asp; accessed June 20, 2008). Based on these data, upstream emissions for coal, residual oil, distillate oil, and natural gas were estimated to be 6.0, 12.8, 12.9, and 12.3 kg CO_2 eq. per GJ LHV, respectively. Using information on the pulp and paper sector's fuel consumption in 1990 and 2004 (primarily coal, residual oil, and natural gas), weighted average factors were developed indicating that upstream emissions related to production and transport of fossil fuels were approximately 15% of the combustion-related emissions in both years. A similar analysis was performed based on information on the wood products sector's fuel consumption in 1991 (primarily natural gas and distillate oil), with results indicating that upstream fossil fuel emissions were approximately 21% of combustion emissions (this relation was applied in estimating pre-combustion fuel emissions related to wood products production for both 1991 and 2004). The upstream fuel emission factor for natural gas was used in estimating these emissions from final manufacture of paper and board products (22% of combustion emissions). Accordingly, the total upstream fuel-related emissions from all three of these sectors were estimated to have been 11.6 Tg CO_2 eq. in 1990 and 9.6 Tg CO_2 eq. in 2004.

In total, therefore, upstream emissions associated with non-fiber inputs to manufacturing are estimated to have been 24 Tg CO_2 equivalents in 1990 and 2005.

2.6 Indirect Emissions Associated with Purchases of Electricity

Emissions associated with purchased electricity were derived from data on electricity purchases and sales, combined with a national average purchased electricity emission factor. The CO_2 emission factor used (177.5 kg CO_2/MMBtu) is from USDOE's Updated State-Level Greenhouse Gas Emission Coefficients for Electricity Generation 1998-2000 (EIA 2002), and represents a three-year weighted average for electrical utilities in the U.S. CH_4 and N_2O are not included in this factor.

The pulp and paper sector energy consumption data from AF&PA included information on amounts of purchased electricity and amounts of sold or exported electricity. From this information it was possible to calculate net electricity purchases (purchases minus exports). These data were used to calculate indirect emissions associated with net electricity purchases of 22.2 Tg CO_2 eq. in 1990 and 25.4 Tg CO_2 eq. in 2004. There are several potential reasons for the apparent increase in indirect emissions between 1990 and 2004, including a strategic decision by mills to reduce self generation and increase purchases of power to achieve either lower direct GHG emissions or better economics (e.g., through pricing incentives for purchased power); a shift in production grades from those whose manufacturing processes do not require high amounts of electricity (e.g., kraft) to those with a high demand for electricity combined with limited opportunity to self-generate (e.g., mechanical); and potentially others.

Net electricity consumption by the wood products sector in 1991 was characterized from data from EIA (MECs) corresponding to SIC code 24, Lumber and Wood Products (EIA 1994). The statistical method of estimating wood products sector direct emissions from fuel combustion (discussed in Section 2.3.1) was applied to estimate indirect emissions associated with the sector's net electricity purchases in 2004. Indirect emissions estimated from these electricity consumption data were 10.8 Tg CO_2 eq. in 1991 and 9.3 Tg CO_2 eq. in 2004.

Emissions associated with purchased power at pulp and paper secondary manufacturing facilities in 1991 were estimated using EIA data corresponding to SIC code 27, printing and publishing (EIA 1994), and for 2002 they were estimating using EIA data corresponding to NAICS code 323, printing and related support (EIA 2005). They were 9.4 Tg CO_2 eq. in 1991 and 8.9 Tg CO_2 eq. in 2002.

Adding indirect emissions from pulp and paper mills to those from wood products facilities and secondary manufacturing yields an estimated 42.4 Tg CO_2 eq. of indirect emissions associated with purchased electricity in 1990 and 43.6 Tg CO_2 eq. in 2004 (forest products indirect emissions associated with electricity purchases represents about 0.7% of U.S. energy-related GHG emissions in 2004, estimated at 6170 Tg CO_2 eq.) (USEPA 2008). The industry's indirect emissions from purchases of electrical power are summarized in Table 2.12.

Table 2.12 Indirect Emissions Attributable to Purchases of Electrical Power by the U.S. Forest Products Industry

Indirect Emissions Source	1990 Emissions (Tg CO_2 eq.)	2004 Emissions (Tg CO_2 eq.)
Electricity purchases by pulp and paper mills	22.2	25.4
Electricity purchases by wood products facilities	10.8[a]	9.3
Secondary manufacturing operations (i.e., converting primary products into final products)	9.4[a]	8.9[b]
Total	42.4	43.6

[a] estimates based on 1991 fuel consumption data
[b] estimates based on 2002 fuel consumption data

In the U.S. national inventory, these emissions are included in estimates from fossil fuel combustion. EPA reported an uncertainty range of -2 to +5% for estimates of these emissions (USEPA 2007). The uncertainty range in this study is probably somewhat higher due to the need to perform a number of extrapolations of activity data and to the use of regional or national average emission factors.

2.7 Transport-Related Greenhouse Gas Emissions

As discussed in Section 2.5, the vast majority of inputs into forest products are associated with fiber and water, with wood and recovered fiber accounting for 85-95% of raw materials for pulp and paper and wood product manufacturing (not including water). Large quantities of water are transported through mills to produce paper, but emissions associated with this transport are included in the mill's direct and indirect emissions. The industry's primary products (e.g., rolls of paper) must be transported to facilities that make final products (e.g., books) and final products must be distributed to retailers.

In this report, emissions related to transport of raw materials, transport of primary products to secondary manufacturing facilities, and transport of final products to market are estimated.

The U.S. government periodically collects data on transport of commodities and publishes them in "Commodity Flow Surveys." The two most recent were conducted in 1997 and 2002 (U.S. Census Bureau 1999, 2004). Table 2.13 contains summary data from those surveys. The 2002 survey was used for all materials except wood; 1997 survey data are used for wood because the 2002 survey lacked information (due to a 2002 "sample frame" that did not include forestry establishments). The categories in the Commodity Flow Surveys do not align perfectly with inputs and outputs of the industry, but are felt to align well enough for the purposes of estimates developed herein. The least well aligned is the category for recovered fiber, where the Standard Classification of Transported Goods (SCTG) Commodity Code contains a large number of non-paper waste materials.

Table 2.13 Transport Statistics for Inputs and Products of the Forest Products Industry

Material Transported[a]	Transport Mode; Average Distance One Way[b]	
Primary paper and paperboard products	72% by truck;	156 miles
SCTG 27 – Pulp, newsprint, paper, paperboard	28% by rail;	857 miles
Final paper and paperboard products; weighted average of:	99% by truck;	168 miles
SCTG 28 – Paper, paperboard articles	1% by rail;	1075 miles
SCTG 29 – Printed products		
Wood products (primary and final)	85% by truck;	149 miles
SCTG 26 – Wood products	15% by rail;	1007 miles
Virgin fiber inputs	98% by truck;	62 miles
SCTG 25 – Logs and other wood in the rough[c]	2% by rail;	233 miles
Recovered fiber inputs	100% by truck;	268 miles
SCTG 412 – Nonmetallic waste and scrap, except from food processing		

[a] descriptions of SCTG codes from U.S. Census Bureau 2001; all data from U.S. Census Bureau 2004 unless otherwise noted

[b] percentages calculated assuming U.S. Census "other" category is divided between truck and rail in proportions shown in survey

[c] data from U.S. Census Bureau 1999

The Commodity Flow Surveys do not include data on transport in foreign countries (i.e., for imports and exports), so it was necessary to apply domestic transport distances and modes to all raw materials and products of the industry. This results in an understatement of transport distances for the fraction of the industry's inputs and outputs that are imported or exported. The downward bias, however, is expected to be relatively small. Only 1% of domestic pulpwood production is exported and only 2% of domestic pulpwood consumption is imported (FAO 2008). Pulp imports and exports represent only about 11% of domestic consumption and production, and only about 10% of the domestic production of paper and paperboard is exported (AF&PA 2007).

Transport distances in the Commodity Flow Surveys are one way. Estimates herein assume that return trips for raw materials delivery (wood and recovered paper) are empty so the emissions associated with round trips are all attributed to transport of wood and recovered paper. For products, however, it is assumed that return trips involve transport of different products outside the forest products industry's value chain; thus only one-way transport emissions are attributed to the product. In addition, it is assumed that the quantity of final product is equal to the quantity of primary product (i.e., there is no loss of material in converting primary products into final products).

Fuel consumption factors for trucks and trains are taken from the U.S. Energy Intensity Indicators Program (USDOE 2006). Energy intensity factors and diesel fuel emission factor used to convert energy intensity into GHG intensity are shown in Table 2.14. Methane and nitrous oxide emissions are not estimated because they are small compared to the uncertainty in the estimates of CO_2 emissions. Quantities of material transported are described in Table 2.15.

Based on this information and assuming that wood and recovered fiber are responsible for 85% of raw material transport-related emissions, the total transport-related emissions for 1990 and 2004 are estimated to be 16.8 and 19.6 Tg CO_2/year, respectively. Details are shown in Table 2.16.

Table 2.14 Energy Intensity and Carbon Dioxide Emission Factors for Freight Transport

	Fuel Intensity (Btu HHV/ton mile)[a]		CO_2 Emissions (per ton-mile)[b]	
Transport Mode	1990	2004	1990	2004
Combination truck[c]	2766	2801	0.205	0.208
Rail	397	325	0.0295	0.0241

[a] from USDOE 2006

[b] based on emission factor for diesel fuel of 74,100 kg CO_2/TJ NCV (IPCC 2006)

[c] defined by Bureau of Transportation statistics as "A power unit (truck tractor) and one or more trailing units (a semitrailer or trailer)"

Table 2.15 Wood Products Quantities Transported in 1990 and 2005

	Metric Tonnes of Material		
Material	1990	2005	Source of Information
Pulp, paper, paperboard – primary products	79,955,455	92,260,000	AF&PA Annual Statistics Reports[a] (AF&PA 1992, 2007)
Pulp, paper, paperboard – final products	79,955,455	92,260,000	AF&PA Annual Statistics Reports[b] (AF&PA 1992, 2007)
Wood products	73,910,825	85,085,191	FAO statistics database[c] (FAO 2008)
Wood (virgin fiber)	233,323,640	239,895,791	FAO statistics database[d] (FAO 2008)
Recovered fiber	19,760,000	30,863,636	AF&PA Annual Statistics Reports[e] (AF&PA 1992, 2007)

[a] total of paper and paperboard shipments and market pulp production

[b] assumed to equal quantity of primary products

[c] total of sawn wood and wood-based panels; assumed density 0.585 metric tonne/m^3 (average of saw timber and panels); from FAO http://www.fao.org/docrep/x5341e/x5341e0g.htm

[d] total industrial round wood consumption estimated as production plus imports minus exports; assumed density 0.575 metric tonne/m^3 (average of pulpwood and saw logs); from FAO http://www.fao.org/docrep/x5341e/x5341e0g.htm

[e] recovered paper used at pulp and paper mills in U.S.

Table 2.16 Transport-Related Emissions Associated with Major Inputs and Outputs of the U.S. Forest Products Industry

Material	Emissions (Tg CO_2)	
	1990	2005
Pulp, paper, paperboard – primary products	2.4	2.7
Pulp, paper, paperboard – final products	2.8	3.2
Wood products	2.2	2.5
Wood (virgin fiber)	5.9	6.1
Recovered fiber	2.2	3.4
Total	15.4	17.9
Total assuming wood and recovered fiber transport represents 85% of raw material transport-related emissions	16.8	19.6

[NOTE: Due to rounding, totals may not equal sum of individual components]

2.8 Emissions Associated with Product Use

Emissions associated with forest products use are assumed to be zero. Paper and paperboard do not require energy to use, and so are not responsible for emissions during the use phase. Wood products are used in structures that must be heated and cooled, but these emissions are normally attributed to the heating and cooling systems rather than to the materials used to assemble the structures.

2.9 Emissions Associated with Product End-of-Life

Forest products can degrade when exposed to anaerobic conditions that exist in most municipal solid waste (MSW) landfills, resulting in formation of methane and carbon dioxide. Because the CO_2 is biogenic in origin and will be accounted for in estimating stock changes in forests and products it is not considered in GHG totals (IPCC 2006), but the methane is considered in GHG totals because its GWP is over twenty times that of carbon dioxide (a GWP of 21 is used for methane in current reporting, but is likely to be changed to 25 at some point in the future due to updated information).

Methane released from MSW landfills is a result of 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 GHG profile. Instead, it is necessary to estimate the amounts of methane that are released as a result of decomposition of forest products only.

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

- amounts of used products discarded
- amounts of discarded products landfilled rather than being recycled, burned, or used for other purposes
- amounts of landfilled products placed in anaerobic landfills (anaerobic conditions are required for methane production)
- 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)
- rate at which degradable carbon in the products decomposes
- landfill design and operating features that result in destruction of some methane into biogenic CO_2 (accounted for in assessment of forest carbon) before it escapes to the atmosphere

Methane emissions corresponding to decay of forest products in landfills were estimated using the Woodcarb II model. Woodcarb II estimates changes in harvested wood products held in end uses, discards from use, deposits in dumps and landfills, and decay in dumps and landfills. Discards to landfills were estimated by developing a time series of wood products added to and discarded from the products in use pool. For estimates of methane emissions shown herein, the source of the methane was wood and paper products that came from wood harvested in the U.S., including exported wood and paper products and excluding imported products. Tracking carbon in wood harvested in the U.S. is called the "production [accounting] approach" by IPCC (2006).

As discussed in Section 2.2.1, additions to products in use are based on production and trade data from various sources (U.S. Census Bureau 1976; AF&PA 1999a, 1999b; Hair 1958; Hair and Ulrich 1963; Howard 2003, 2007; Steer 1948; Ulrich 1985, 1989). Estimates were made of amounts of wood and paper in end uses from 1990 to 2006 as well as amounts of products discarded each year.

A key determinant of discard rates is the time various products remain in use. Discard rates from use were estimated to follow a first order decay function with half-lives for various uses shown in Table 2.4. The half-life estimates were developed so that Woodcarb II produced estimates of carbon in housing in 2001 that match Census-based estimates, while also producing estimates of wood and paper discards to landfills that match EPA estimates from 1990 to 2001. It was assumed that the limited portion of exported wood and paper products have the same use life, discard disposition, and decay features in solid waste disposal sites in other countries as in the U.S..

Wood and paper discarded from use is estimated to go to dumps (prior to the mid 1980s), landfills, recovery for recycling, composting, and burning as noted in Table 2.6. These disposition fractions were prepared by Freed and Mintz (2003) using data from EPA and other sources.

Wood and paper discarded to landfills are subject to limited decay because the lignin portion and the cellulose and hemicellulose protected by lignin are not subject to anaerobic decay. Decay limits are based on studies by Barlaz (1998) and Eleazer et al. (1997) as summarized by Freed and Mintz (2003). Only 23% of carbon in wood products and 56% of carbon in paper is estimated to be emitted over time. The half-lives of paper and wood decay in landfills are estimated to be 14.5 and 29 years, respectively, in temperate regions (IPCC 2006, vol. 5 ch. 3). About half the degradable carbon is emitted as methane (IPCC 2006, vol. 5 table 3.5).

Another important factor affecting methane emissions estimates is the fraction of MSW landfills that are equipped with methane collection systems. The fraction of emitted methane that is recovered or oxidized before it reaches the atmosphere has increased from 20% in 1990 to 50% in 2006 (USEPA 2007).

Estimated methane emissions from wood and paper in landfills (where wood came from U.S. forests) are shown in Table 2.17. Estimated methane generated has increased almost 50% between 1990 and 2006, but the fraction recovered or oxidized has more than doubled from 20 to 50%. As a result, estimated net emissions decreased from 61 Tg CO_2 eq. in 1990 to 56 Tg CO_2 eq. in 2005.

Uncertainty in these estimates is probably at least as great as the overall estimate of total methane emissions in the U.S., or -41% to +34% (95% confidence interval) (USEPA 2008). As a point of reference, EPA estimated gross 2006 methane emissions from U.S. landfills to have been 249 Tg CO_2 eq. (USEPA 2008, Table 8-3) and NCASI estimated gross methane emissions from wood and paper products to have been 114 Tg CO_2 eq. (Table 2.17), or about 46% of gross emissions. This is consistent with data from EPA (USEPA 2006a) for 2005, which indicate that approximately 50 to 60% of decomposable materials in municipal solid waste (after recovery for recycling or composting) are wood and paper products.

Table 2.17 Methane Emitted from Wood and Paper Products in Landfills; Products Made from Wood Harvested in the U.S.

	Methane Generated ($Tg\ CO_2$ eq.)			Fraction Recovered/	Net Methane Emitted ($Tg\ CO_2$ eq.)		
Year	Wood	Paper	Total	Oxidized	Wood	Paper	Total
1990	17.1	59.1	76.2	0.20	13.7	47.2	60.8
1991	18.0	62.0	80.0	0.22	14.1	48.5	62.6
1992	18.8	64.8	83.6	0.23	14.4	49.7	64.1
1993	19.5	67.7	87.2	0.25	14.7	50.8	65.4
1994	20.2	70.1	90.4	0.27	14.9	51.5	66.4
1995	21.0	72.0	93.0	0.28	15.1	51.7	66.8
1996	21.8	73.5	95.3	0.31	15.0	50.6	65.6
1997	22.4	75.4	97.8	0.34	14.8	49.6	64.3
1998	23.1	77.3	100.4	0.37	14.5	48.5	63.0
1999	23.8	79.2	103.0	0.40	14.2	47.3	61.5
2000	24.4	80.8	105.3	0.43	13.8	45.8	59.7
2001	25.0	82.0	107.0	0.46	13.5	44.1	57.6
2002	25.7	83.0	108.7	0.46	13.8	44.6	58.3
2003	26.3	83.7	110.0	0.46	14.1	45.0	59.2
2004	26.9	84.2	111.1	0.49	13.8	43.1	56.8
2005	27.5	84.7	112.2	0.50	13.7	42.1	55.8
2006	28.1	85.4	113.5	0.50	14.1	42.7	56.8

2.9.1 *Long-Term Carbon Sequestration and Methane Emissions Attributable to Forest Products in Landfills*

Because only 23% of carbon in wood products and 56% of carbon in paper are estimated to be emitted over time, the remainder represents a landfill sink of carbon. It is useful, therefore, to examine the net balance between long-term carbon storage in landfills and long-term methane emissions from landfills. The material that is degraded is converted into equal amounts of methane and carbon dioxide. The fraction of emitted methane that is recovered or oxidized before it reaches the atmosphere was 50% in 2006. Putting these factors together, it appears that although the materials deposited in landfills in 2005 contained over 65 Tg CO_2 eq. of non-degradable carbon, long-term methane emissions (at current levels of landfill gas control) were expected to be almost 75 Tg CO_2 eq. This suggests that used forest products placed in landfills in 2005 will be a net source of GHGs over the long term.

This finding obscures a large difference between the behavior of wood products and that of many paper products. With current practice, landfills appear to be a net long-term sink for carbon in wood products while they appear to be a significant long-term source of GHG emissions from paper products. On a CO_2 equivalents basis, wood products emit only about 60% of what they store, while methane emissions from paper products are more than twice the long-term carbon sequestration attributable to those materials. There are also important differences among paper products, with those high in lignin and coated grades behaving more like wood products than paper.

2.10 Avoided Emissions

A variety of activities associated with the forest products value chain can result in avoided GHG emissions. Some of the avoided emissions addressed in lifecycle studies include

- Avoided emissions due to use of efficient combined heat and power systems to produce power (for use or sale) that would otherwise have been generated by methods that are more GHG-intensive
- Avoided emissions associated with use of used forest products as biomass fuels, displacing fossil fuels
- Avoided emissions associated with use of methane from MSW landfills as a biomass fuel, displacing fossil fuel
- Avoided emissions associated with substituting wood-based building materials for more GHG-intensive materials (on a lifecycle basis)
- Avoided emissions of methane from MSW landfills due to recycling rather than landfilling paper
- Avoided emissions associated with providing an economic incentive to keep land in forest that would otherwise be converted to uses that store little or no carbon

Avoided emissions require assumptions about the activities that would have occurred in the absence of the activity causing the avoidance. Because of these assumptions, and because of concerns about double counting emission reductions, the use of avoided emissions to offset direct or indirect emissions can be controversial.

This study attempted to calculate only one category of avoided emissions: those associated with decreased methane emissions attributable to recycling. It is important to understand these because it is possible to misinterpret the role of landfills in the industry's GHG and carbon profile when the alternatives are not discussed. In addition, the report includes avoided emissions associated with the use of wood-based building materials. These avoided emissions were estimated from results of separate studies involving several of the authors of the work reported herein (NCASI 2007; Upton et al. 2008).

Although other avoided emissions are not addressed, it is important to note that they can be very important in certain circumstances and should be considered when evaluating climate change policies.

2.10.1 *Avoided Emissions Associated with Paper Recycling in the United States*

Paper that is no longer being put in landfills in the U.S. is being recycled or burned for energy, displacing fossil fuels in many cases. EPA has developed the Waste Reduction Model (WARM) for comparing the GHG implications of different waste management options on a lifecycle basis. The documentation for the model, which was used in this study, is contained in a series of reports, the most recent of which was released in 2006 (USEPA 2006b). The model examines the effects of recycling by considering a range of lifecycle impacts. For forest products that are kept out of landfills, the model considers reduced methane emissions and reduced carbon storage. For forest products that are recycled, the model considers the difference in GHG intensity of virgin and recycled manufacturing processes as well as the additional carbon that is stored in the forest as a result of reducing the demand for virgin fiber. For forest products that are burned for energy, the model considers the effects of displacing fossil fuels.

An examination of WARM reveals that the most important factors associated with increased recycling are additional storage of carbon in the forest, and reduced methane emissions and reduced carbon storage associated with keeping forest products out of landfills. The modeling of effects in the

forest is highly sensitive to assumptions about the export of recovered fiber and does not address a variety of market-related impacts that would affect the decisions of forest owners. The model does not, for instance, consider potential effects related to land owner decisions to convert pulpwood stands to saw timber stands or to non-forest uses in the face of diminished demand for pulpwood. Thus, the modeling of these effects is considered less robust than other aspects of the model, and results of the analysis are expressed herein as a range (corresponding to estimates made with and without the benefits of additional forest carbon). The range of benefits associated with recycling the recovered paper used by U.S. mills in 2006 is 13 to 115 Tg CO_2 eq., depending on whether model estimates for increased forest carbon are included.

3.0 DISCUSSION

Estimates of the U.S. forest products industry GHG and carbon profile in 1990 and 2004-2005 are shown in Table 3.1 and Figure 3.1. The profile is dominated by carbon storage in products (in use and in landfills), manufacturing-related emissions (both direct emissions and emissions associated with purchased power), and methane emission from MSW landfills attributable to decaying forest products.

Carbon stocks in industry-owned timberlands may have declined slightly between 2000 and 2005 (by approximately 11 Tg CO_2 eq.), but it is likely that this was offset by increases on other private timberland that benefit directly and indirectly from the industry's sustainable forest management activities. For the purpose of this study, therefore, the net change in forest carbon stocks on land affected by the industry's activities is assumed to be zero.

Table 3.1 Greenhouse Gas and Carbon Profile of the U.S. Forest Products Industry

	Greenhouse Gas Emissions (Tg CO_2 eq.; negative numbers indicate sequestration)	
Profile Element	1990	2004 to 2005
Changes in stocks of carbon in forests	0[a]	0[a]
Changes in stocks of carbon in forest products	-132.6	-108.5
Direct emissions from forest products manufacturing	76.1	64.6
Emissions associated with producing fiber	4.0	4.2
Emissions associated with non-fiber inputs	24	24
Indirect emissions associated with purchased electricity	42.4	43.6
Emissions related to transport of raw materials and products	16.9	19.6
Emissions associated with product use	0	0
Emissions associated with product end-of-life	61	56
Net transfers to the atmosphere	91.8	103.5
Avoided emissions associated with recycling recovered paper	not estimated	13 to 115
Avoided emissions associated with using wood-based building materials[b]	not estimated	7.2

[a] between 2000 and 2005 carbon stocks on industrial timberlands were estimated to have decreased by approximately 11 Tg CO_2 eq./yr, but it is likely that they were offset by increases in sequestration on other private timberlands that were attributable to industry activities; year-to-year changes in carbon stocks on industrial timberlands are inevitable due to responses to market condition, forest age class distribution, and other factors; over longer periods, however, an assumption of stable long-term carbon stocks is consistent with use of sustainable forest management practices that are in place on industrial timberlands in the U.S.

[b] from NCASI 2007; Upton et al. 2008

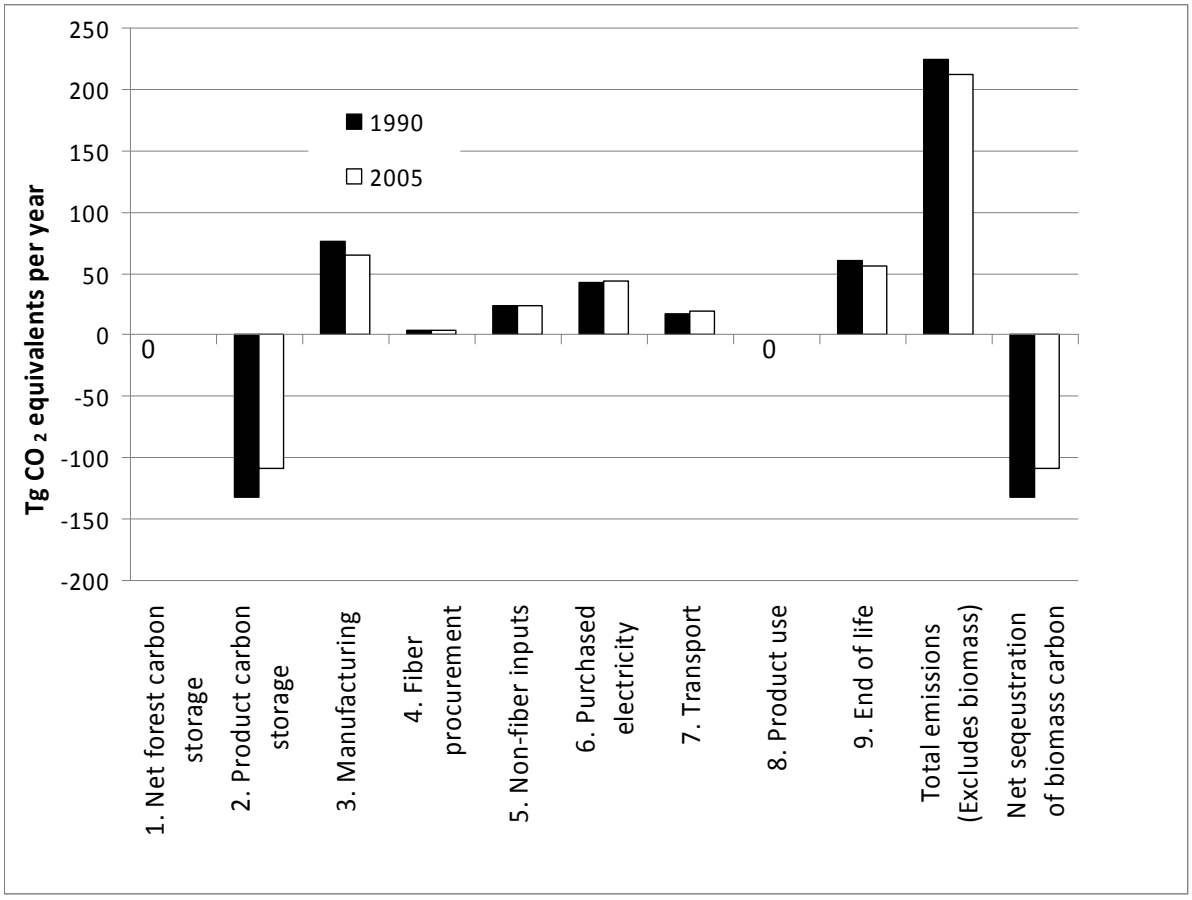

Figure 3.1 Greenhouse Gas and Carbon Profile of the U.S. Forest Products Sector – 1990 and 2004/2005

Carbon sequestration attributable to growth of carbon stocks in products in use manufactured by the U.S. forest products industry declined by 27% between 1990 and 2005 primarily due to increased reliance on imported forest products. The annual growth in stocks of carbon in products in landfills decreased by 10%, primarily due to reduced amounts of forest products going to landfills. Overall carbon sequestration associated with carbon in products made from wood harvested in the U.S. decreased by 18%. [Note: Because some of the wood used by U.S. manufacturing factilities is imported, basing the calculations on wood harvested in the U.S. slightly underestimates the carbon stored in products attributable to U.S. manufacturing. The error is small, however, because between 1990 and 2005, less than 1% of roundwood used to make lumber and panels in the U.S. was imported and less than 0.2% of roundwood used to make wood pulp was imported. During the same period, 10% or less of pulp used to make paper and paper board was imported.]

Between 1990 and 2004/2005, direct emissions from manufacturing were reduced by 15%. Over this same period, industry production increased by approximately 15% (explored in Section 2.7, Table 2.15). Reductions in direct emissions from manufacturing are attributable to improved energy efficiencies and switching to less GHG-intensive fuels.

Emissions of methane from MSW landfills attributable to decaying forest products were reduced by 8% between 1990 and 2004/2005. The reductions are attributable to increased use of methane capture systems on MSW landfills and reduced amounts of paper being discarded in landfills due to increased recovery of used paper for recycling.

Emissions related to purchased electricity increased slightly between 1990 and 2004/2005 (about 3%). Industry production, however, increased by 15% over this period, so these indirect emissions decreased on an intensity basis.

Transport-related emissions increased by about 15% over this period, a direct result of increases in industry production.

Total manufacturing-related emissions (i.e., direct plus indirect emissions related to purchased electricity) decreased by almost 9% over this period (to 108 from 118 Tg CO_2 eq.). Total value chain emissions decreased by about 6% between 1990 and 2004/2005 (to 212 from 224 Tg CO_2 eq.). As noted, industry production increased by approximately 15% over this same period.

Over half of emissions from the U.S. forest product industry's value chain are offset by sequestration (59% in 1990 and 51% in 2005). Considering this sequestration, net transfers to the atmosphere from the U.S. forest products industry value chain increased from 91.8 Tg CO_2 in 1990 to 103.5 Tg CO_2 in 2005, with the increase due to reduced storage of carbon in products in 2005 (attributable to increased imports and reduced quantities of paper going to landfills).

The benefits of a range of avoided emissions are difficult to quantify with certainty, but it is clear that they serve to further reduce the societal impact of the industry's profile. Recycling alone accomplishes an estimated 13 to 115 Tg CO_2 eq./yr in avoided emissions. Substitution effects involving wood-based building materials have also been shown to be significant, amounting to 9.6 Tg CO_2 eq. in the U.S. housing market in 2005, of which 2.4 Tg CO_2 eq. can be attributed to Canadian production (i.e., substitution effects due to the U.S. forest products industry were approximately 7.2 Tg CO_2 eq. in 2005).

The results of this profile can be compared to a comparable profile developed for the global forest products industry (Miner and Perez-Garcia 2007). In that study, carbon sequestration appeared to offset a larger fraction of value chain emissions than in this study of the U.S. industry. A comparison of the profiles found that production-normalized estimates for most of the key elements were within approximately 25% of each other. In particular, estimates were in good agreement for manufacturing emissions, methane emissions from MSW landfills, and carbon storage in products in use.

The difference in estimates of carbon storage in landfills, however, was large enough to result in profiles that are somewhat different. Production-normalized estimates in the global forest products industry study were approximately 25% larger than those estimated in this profile of the U.S. forest products industry. It appears that the primary reason is the difference in assumptions about the fraction of used products that are landfilled, especially in recent years, which are most important to the carbon storage calculation results. In recent years the fraction of paper discarded to landfills in the U.S. (as a percentage of discards before recovery of paper for recycling) was about 30-35%, whereas for the global study it was about twice that. In spite of this, methane results are close. This appears to be because the fraction of discards put into landfills in earlier periods, which are more important to current methane emissions, were more similar for the two studies.

Overall, the global study suggested that a somewhat larger fraction of value chain emissions were offset by sequestration than suggested in the U.S. study. The primary reasons are a) relatively larger manufacturing emissions for the U.S. study, b) relatively less carbon being added to landfills in the U.S. study, and(c) upstream emissions for fuels and non-fiber inputs being included in the U.S. study but not in the global study. The results of this study confirm that improvements in the U.S. industry's carbon and GHG profile can be achieved by focusing on several areas.

- Continue to reduce direct and indirect emissions attributable to manufacturing operations.
- Expand efforts to keep easily degradable materials (especially uncoated and chemical pulp-derived paper products) out of landfills.
- Make more extensive use of landfill cover systems that capture and destroy methane.
- Increase the use of forest products, especially in long-lived applications, manufactured from domestically grown wood; in many applications these products not only provide carbon sequestration benefits, but also avoid emissions by substituting for more GHG-intensive alternatives in the marketplace.

4.0 CONCLUSIONS

A greenhouse gas and carbon profile was developed by examining the fluxes of CO_2 and other GHGs to the atmosphere from the U.S. forest products industry value chain. An analysis of carbon stocks on industry-owned timberlands, essentially all of which are managed under sustainable forest management principles, suggests that between 2000 and 2005, these lands may have been small net sources of CO_2, with carbon stocks declining by the equivalent of approximately 11 Tg CO_2 eq./year. In the same time period, however, forest ecosystem carbon stocks on all private timberlands (including industry-owned timberlands) increased by 129 Tg CO_2 eq./year. For purposes of this study, therefore, the net flux of CO_2 attributable to the industry's effects on forest ecosystem carbon was assumed to be zero. Carbon sequestration along the value chain, including forest products in use and in landfills after end of use, amounted to an estimated 108.5 Tg CO_2 eq. in 2005.

Total emissions through the value chain in 2004 to 2005 were estimated to be 212 Tg CO_2 eq. Direct emissions from manufacturing, almost all due to burning of fossil fuels at primary manufacturing facilities, amounted to 64.6 Tg CO_2 eq. in 2004. Indirect emissions associated with purchased electricity for 2004 were estimated to be 43.6 Tg CO_2 eq. Emissions associated with production of raw materials were approximately 28 Tg CO_2 eq./year. Emissions associated with transporting raw materials, finished products, and recovered fiber in 2005 were estimated to total 20 Tg CO_2 eq. Methane emissions attributable to decomposing forest products were 56 Tg CO_2 eq.

Between 1990 and 2004/2005, a period over which the industry's production increased by about 15%, total value chain emissions decreased by about 6%. Some elements of the profile improved over this period and others did not. Overall carbon sequestration decreased by 18%, primarily reflecting an increased reliance on imported wood and products and reduced amounts of used paper going to landfills. Direct emissions from manufacturing were reduced by 15% and those attributable to purchased electricity increased by 3%, representing a combined reduction of 9%. Emissions of methane attributable to decaying forest products were reduced by 8% and transport-related emissions increased by about 15%, a direct result of increases in industry production.

In 2005 the growth in product carbon stocks was equivalent to the annual sequestration of 108.5 Tg CO_2 eq. About 40% of this growth was in products in use while 60% was in products in landfills. he net sequestration accomplished along the U.S. forest products value chain was sufficient to offset all direct emissions plus all indirect emissions associated with purchased electricity (over half of total value chain emissions). Net transfers to the atmosphere from the U.S. forest products industry value chain, considering emissions from the value chain and net sequestration of biomass carbon, increased from 91.8 Tg CO_2 in 1990 to 103.5 Tg CO_2 in 2005, with the increase being attributable to reduced storage of carbon in products in 2005. While there are varying degrees of uncertainty associated with the estimates herein, the estimates are adequate for understanding the overall magnitudes and relative magnitudes of emissions and additions to carbon sinks.

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