



NATIONAL COUNCIL FOR AIR AND STREAM IMPROVEMENT

**THE GREENHOUSE GAS AND
CARBON PROFILE OF THE CANADIAN
FOREST PRODUCTS INDUSTRY**

**SPECIAL REPORT NO. 07-09
OCTOBER 2007**

**by
Brad Upton, Ph.D.
NCASI West Coast Regional Center
Corvallis, Oregon**

**Reid Miner
NCASI Headquarters
Research Triangle Park, North Carolina**

**Kirsten Vice
NCASI-Canada
Montreal, Quebec**

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For more information about this research, contact:

Brad Upton, Ph.D.
Project Leader
NCASI West Coast Regional Center
P.O. Box 458
Corvallis, OR 97339-0458
(541) 752-8801
bupton@ncasi.org

Reid Miner
Vice President, Sustainable Manufacturing
NCASI
P.O. Box 13318
Research Triangle Park, NC 27709-3318
(919) 941-6407
rminer@ncasi.org

Kirsten Vice
Vice President, Canadian Operations
NCASI
P.O. Box 1036, Station B
Montreal, QC H3B 3K5
(514) 286-9111
kvice@ncasi.org

For information about NCASI publications, contact:

Publications Coordinator
NCASI
P.O. Box 13318
Research Triangle Park, NC 27709-3318
(919) 941-6400
publications@ncasi.org

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PRESIDENT'S NOTE

Climate change continues to grow as an important priority for the Canadian forest products industry. Annual federal-level greenhouse gas reporting regulations were implemented in 2004, and these are soon to be accompanied by industrial greenhouse gas emission reduction standards. In addition, there is increased interest from industry stakeholders in better understanding the carbon profile of the forest products industry value chain. Characterization of the sector's profile may lead to clear opportunities for the industry to minimize its climate change "footprint."

The connections between the climate change issue and the forest products industry are more complex than for any other industry. The forests that supply the industry's raw material remove carbon dioxide from the atmosphere and store the carbon in the forest ecosystem and ultimately in forest products. Most of the industry's manufacturing facilities require fossil fuels, and these fuels generate greenhouse gases when burned. The industry obtains much of its energy, however, from carbon neutral biomass fuels. The forest products industry is one of Canada's leaders in using co-generation, also known as combined heat and power, which is far more efficient than conventional electricity generation; thus, smaller amounts of fuel are required and fewer greenhouse gases are emitted. End of life management options for forest products, ranging from recycling to landfilling and burning for energy, have important but complex greenhouse gas and carbon implications.

In this report, accepted international carbon and greenhouse gas accounting protocols have been used to characterize the carbon and greenhouse gas profile of the Canadian forest products industry. Although there are significant uncertainties associated with some of the estimates, the analysis suggests that the greenhouse gas emissions that occur throughout the industry's value chain are largely offset by sequestration. A methodology that can isolate the effects of forest harvesting and regeneration from the many other factors that affect forest carbon would help reduce the uncertainty in the profile. Avoided emissions associated with the use of biomass fuels, combined heat and power, and recycling further enhance the Canadian industry's greenhouse gas and carbon profile. An examination of the forces at work suggests that there are practical opportunities to enhance the industry's global carbon and greenhouse gas profile in the years to come.

A handwritten signature in black ink, appearing to read "Ron Yeske", is written over a light gray circular background.

Ronald A. Yeske

October 2007

MOT DU PRÉSIDENT

La problématique du changement climatique constitue de plus en plus une priorité importante pour l'industrie canadienne des produits forestiers. En 2004, le gouvernement fédéral a adopté un règlement exigeant de l'industrie qu'elle déclare annuellement ses émissions de gaz à effet de serre. Ce règlement sera bientôt suivi de normes destinées à réduire les émissions de gaz à effet de serre du secteur industriel. De plus, les parties qui s'intéressent à l'industrie veulent mieux comprendre le profil du carbone dans la chaîne de valeur de l'industrie des produits forestiers. La caractérisation du profil de ce secteur pourrait fournir des solutions claires à l'industrie afin qu'elle diminue son « empreinte » sur le changement climatique.

Les liens entre le changement climatique et l'industrie des produits forestiers sont plus complexes que ceux existant dans les autres industries. Les forêts qui fournissent la matière première pour l'industrie retire le dioxyde de carbone de l'atmosphère et emmagasine le carbone dans l'écosystème forestier et, ultimement, dans les produits forestiers. La plupart des installations manufacturières de l'industrie utilisent des combustibles fossiles qui, lorsqu'ils sont brûlés, génèrent des gaz à effet de serre. Toutefois, l'industrie obtient la majeure partie de son énergie de la biomasse qui est un combustible neutre en carbone. L'industrie des produits forestiers est un des chefs de file en matière de cogénération, aussi connue sous le nom de « production combinée de chaleur et d'énergie » (PCCE), qui est beaucoup plus efficace que la production conventionnelle d'électricité car elle nécessite moins de combustibles et génèrent moins de gaz à effet de serre. Les options de gestion des produits forestiers en fin de vie (le recyclage, l'enfouissement et la valorisation énergétique) ont des répercussions importantes et complexes sur les gaz à effet de serre et le carbone.

Dans le présent rapport, nous avons utilisé des protocoles internationaux reconnus de comptabilisation du carbone et des gaz à effet de serre afin de caractériser le profil du carbone et des gaz à effet de serre de l'industrie des produits forestiers. Bien qu'il y ait d'importantes incertitudes reliées à certaines de ces estimations, l'analyse semble indiquer que les émissions de gaz à effet de serre générées dans la chaîne de valeur de l'industrie des produits forestiers sont largement compensées par la séquestration. Une méthode qui permettrait d'isoler les effets de la récolte forestière et de la régénération des autres facteurs qui influencent le carbone forestier contribuerait à réduire les incertitudes du profil. L'utilisation des biocombustibles, de la PCCE et du recyclage permet d'éviter des émissions ce qui rehausse davantage le profil de l'industrie canadienne en matière de gaz à effet de serre et de carbone. Un examen des enjeux semble indiquer qu'il existe d'autres solutions pratiques pour améliorer au cours des prochaines années le profil mondial de l'industrie en matière de gaz à effet de serre et de carbone.



Ronald A. Yeske

Octobre 2007

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

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ABSTRACT

The Canadian forest products industry's carbon and greenhouse gas profile, composed of emissions, sequestration, and avoided emissions, was characterized for two time periods (1990 and 2005). Emissions from the forest products value chain are comprised of direct emissions from manufacturing (20 million tonnes carbon dioxide equivalent (Mt CO₂ eq.) in 1990; 14 Mt CO₂ eq. in 2005) and a number of different types of indirect emissions, including those associated with electricity purchases (7.7 Mt CO₂ eq. in 1990; 12 Mt CO₂ eq. in 2005), transport (2 Mt CO₂ eq. in 1990; 3 Mt CO₂ eq. in 2005), and methane from discarded forest products in landfills (20.3 Mt CO₂ eq. in 1990; 24.4 Mt CO₂ eq. in 2005). Carbon is sequestered in forests used to supply fibre to the industry. The forest defined as "managed" for purposes of reporting under the United Nations Framework Convention on Climate Change is a net sink for carbon except during years when large areas of forest are impacted by fire. This managed forest includes land that is harvested and regenerated as well as land that is affected by other types of human interventions not related to the forest products industry. Some of the carbon in harvested wood is subsequently stored in forest products in use and in landfills. Carbon stocks in products were increasing at rates of 59.2 Mt CO₂ eq./yr. in 1990 and 80.4 Mt CO₂ eq./yr. in 2005. Avoided emissions, which further enhance the industry's profile, are associated with the industry's use of combined heat and power (~6.3 million tonnes CO₂ avoided per year), recycling (~17.3 million tonnes CO₂ equivalents avoided per year) and product substitution effects due to the use of Canadian wood-based building products in North America of 3.7 Mt CO₂ eq. per year.

KEYWORDS

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

RELATED NCASI PUBLICATIONS

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.*

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

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

**RAPPORT SPÉCIAL N° 07-09
OCTOBRE 2007**

RÉSUMÉ

Le profil des gaz à effet de serre et du carbone de l'industrie canadienne des produits forestiers, qui se compose d'émissions, de carbone séquestré et d'émissions évitées, a fait l'objet de deux caractérisations (en 1990 et en 2005). Les émissions associées à la chaîne de valeur des produits forestiers comprennent les émissions directes provenant des activités de fabrication (20 millions de tonnes de dioxyde de carbone équivalent (Mt CO₂ éq.) en 1990; 14 Mt CO₂ éq. en 2005) et des émissions indirectes de différente nature, y compris celles associées aux achats d'électricité (7,7 Mt CO₂ éq. en 1990; 12 Mt CO₂ éq. en 2005), au transport (2 Mt CO₂ éq. en 1990; 3 Mt CO₂ éq. en 2005), et au méthane émis par les produits forestiers éliminés dans les sites d'enfouissement (20,3 Mt CO₂ éq. en 1990; 24,4 Mt CO₂ éq. en 2005). Le carbone est séquestré par les forêts qui alimentent l'industrie en fibres. Dans le rapport transmis par le Canada aux Nations Unies, la forêt "aménagée" telle que définie dans la Convention Cadre des Nations Unies sur les changements climatiques est comptabilisée comme un puits net de carbone, sauf durant les années où le feu a ravagé de vastes territoires forestiers. Cette forêt aménagée comprend les territoires récoltés et régénérés de même que les territoires perturbés par tout type d'interventions humaines non reliées à l'industrie des produits forestiers. Une partie du carbone dans le bois récolté est subséquemment stocké dans les produits du bois en usage et dans les sites d'enfouissement. Les stocks de carbone dans les produits ont augmenté de 59,2 Mt CO₂ éq./an en 1990 et de 80,4 Mt CO₂ éq./an en 2005. Les émissions évitées, qui rehaussent le profil de l'industrie, proviennent de l'utilisation de la production combinée de chaleur et d'énergie (~6,3 millions de tonnes CO₂ évitées par année), du recyclage (~17,3 millions de tonnes CO₂ éq. évitées par année) et des effets associés à la substitution de produits attribuable à l'utilisation de produits canadiens fabriqués à partir de bois destinés à la construction de bâtiments en Amérique du Nord (3,7 millions de tonnes CO₂ éq. évitées par année).

MOTS-CLÉS

carbone, changement climatique, cycle de vie, gaz à effet de serre, profil de l'industrie canadienne, séquestration

AUTRES PUBLICATIONS DE NCASI DANS CE DOMAINE

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

Rapport spécial n° 07-02 (février 2007). *Le profil des gaz à effet de serre et du carbone de l'ensemble de l'industrie des produits forestiers.*

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

1.0 INTRODUCTION

Conceptually, the forest products industry's carbon and greenhouse gas (GHG) profile can be divided into three distinct parts: emissions, sequestration, and avoided emissions. Emissions consist of transfers of GHGs to the atmosphere from forest products industry facilities or from elsewhere in the forest products industry value chain. They consist primarily of carbon dioxide from fossil fuel combustion (including indirect emissions associated with purchased electricity) and methane from decomposition of discarded products in landfills. The sequestration component consists of carbon contained in and transferred between forests, forest products, and landfills. Avoided emissions consist of emissions that would have occurred were it not for certain industry activities. Examples include emissions of methane from landfills that would have occurred if paper was not recycled, additional indirect emissions if the industry did not efficiently self generate electricity, and others.

Methods for combining these different components into an overall picture of the industry's profile remain a matter of discussion. Nonetheless, there is little question that all of these can contribute to the industry's effect on atmospheric GHGs.

Subak and Craighill (1999) examined many aspects of the industry's GHG and carbon profile at the global level. However, they did not address several aspects of carbon sequestration and avoided emissions. Since then, methods and data for estimating the different components of the profile have evolved. Therefore, NCASI (2007) recently characterized the global industry's profile. This report characterizes the components of the Canadian forest product industry's GHG and carbon profile. Specifically, the significance of emissions, sequestration, and avoided emissions associated with the Canadian forest products industry are examined. Estimates of these elements of the GHG and carbon profile were developed for 1990 and 2005.

2.0 GREENHOUSE GAS EMISSIONS FROM THE FOREST PRODUCTS INDUSTRY VALUE CHAIN

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

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

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

2.1 Direct Emissions from Forest Products Industry Manufacturing Facilities

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 the CO₂ released from biomass combustion is not included in GHG totals because it contains biogenic carbon. This biogenic CO₂ is addressed in the analysis of forest carbon, described later in this report. Small amounts of nitrous oxide (N₂O) and methane (CH₄) are also released during combustion of biomass fuels and fossil fuels.

Total direct GHG emissions from stationary combustion sources were estimated for both the pulp and paper sector and the wood products sector. Two sources of data were used to estimate pulp and paper sector emissions. The first comprised responses from a Forest Products Association of Canada (FPAC) energy consumption survey. Energy use data from that survey were used in conjunction with GHG emission factors from Environment Canada (EC 2007) with the exception of CH₄ and N₂O from biomass fuel combustion, which were estimated using emission factors from the International Council of Forest and Paper Associations and NCASI (ICFPA/NCASI) (NCASI 2005) due to errors in EC's factors for those fuels (use of ICFPA/NCASI biomass emission factors resulted in slightly higher emission estimates than would have resulted if the EC biomass emission factors had been used). Emission factors are shown in Table 2.1. Because the FPAC survey results did not include responses from pulp and paper converting operations, energy consumption data for this sector (corresponding to NAICS 322200) from the Canadian Industrial Energy End-use Data and Analysis Centre (CIEEDAC 2007a,b) were used. GHG emission estimates are expressed as CO₂ equivalents (CO₂ eq.) and include CO₂, CH₄, and N₂O, including CH₄ and N₂O from combustion of biomass fuels. Global warming potentials (GWPs) of 21 and 310 were used for CH₄ and N₂O, respectively.

Table 2.1. Greenhouse Gas Emission Factors for Fossil and Biomass Fuels

Fuel	CO ₂ Factor (kg/physical unit)	CH ₄ Factor (kg/physical unit)	N ₂ O Factor (kg/physical unit)	CO ₂ Eq. Factor (kg/physical unit)
Natural gas (1000 m ³)	1891	0.037	0.033	1901
Heavy fuel oil (m ³)	3090	0.12	0.064	3112
Middle distillates (m ³)	2830	0.006	0.031	2840
Propane (m ³)	1500	0.024	0.108	1534
Coal (t) ^a (national avg)	2480	0.03	0.02	2487
Coal (t) ^b (Ontario)	2254	0.03	0.02	2261
Coal (t) ^b (Manitoba)	1424	0.03	0.02	1431
Coal (t) ^b (BC)	2072	0.03	0.02	2079
Wood waste, dry (t) ^c	0 ^d	0.16	0.1	34.3
Pulping liquors, dry (t) ^c	0 ^d	0.033	0.027	9.06

Factors from Environment Canada (EC 2007) as cited in CSA 2007; CH₄ and N₂O factors for wood waste and pulping liquors from NCASI 2005

^a "national average" value pertains to EC value for metallurgical coke; used by CIEEDAC in computing emissions associated with coal combustion

^b province-specific coal emission factors used when estimating direct emissions based on FPAC survey data
^c NCASI 2005

^d emission factor for biomass-derived CO₂ is zero because carbon in biomass fuels is accounted for in the assessment of forest carbon (i.e., including CO₂ emissions from biomass combustion in direct emission estimates would result in double counting)

FPAC received survey responses from mills representing 25.4 million metric tonnes (Mt) production in 1990. Data from the Pulp and Paper Products Council (PPPC 2006) and from CIEEDAC (2007b) indicated total industry production in 1990 was 24.7 Mt and 23.7 Mt, respectively. Therefore it was assumed that the FPAC survey responses were representative of the full Canadian industry in 1990. In 2005 the FPAC survey responses represented 26.8 Mt production, whereas the PPPC (2006) and CIEEDAC (2007a) analyses indicated that total industry production was 30.3 Mt. Therefore, in order to arrive at a representation of the total Canadian industry the emission estimates based on 2005 FPAC survey results were multiplied by a factor of 1.13 ($30.3 \div 26.8$).

Pulp and paper industry manufacturing direct emissions from fuel consumption determined based on FPAC energy consumption data were 13.7 Mt CO₂ eq. in 1990 and 8.1 Mt CO₂ eq. in 2005. Direct emissions from converting operations (calculated from CIEEDAC data for this sector) were 0.41 Mt CO₂ eq. in 1990 and 0.49 Mt CO₂ eq. in 2005.

The second source for estimating pulp and paper industry direct emissions was energy consumption data from CIEEDAC (2007a,b) corresponding to NAICS 322000 (which in turn were developed from Statistics Canada data), in conjunction with the same emission factors from EC (2007) and ICFPA/NCASI (NCASI 2005) used in the first method of estimating emissions. In the CIEEDAC data, consumption of propane and coal were listed as confidential, but in total correspond to less than 1% of total energy consumption. Analysis of annual propane and coal consumption in 1992 through 2000 (not treated as confidential during this period) revealed that it is reasonable to assume that, on an energy content basis, the Canadian pulp and paper industry consumes twice as much coal as propane. Therefore, propane and coal consumption for 1990 and 2005 were approximated as one-third and two-thirds of the confidential energy consumption, respectively, associated with these two fuels.

Unfortunately, the fuel consumption data available from CIEEDAC were adjusted by Statistics Canada to account for electricity generation at the manufacturing facility. According to CIEEDAC (John Nyboer, Executive Director, personal communication) “the amount of fuel used to self generate [electricity] is removed [from the tabulation of fuel consumption].” Therefore, CIEEDAC fuel consumption data and the direct emissions estimates based on them may be biased low.

Based on CIEEDAC energy consumption data, pulp and paper industry direct emissions from fuel consumption during manufacturing were 15.6 Mt CO₂ eq. in 1990 and 8.6 Mt CO₂ eq. in 2005. However, these estimates include direct emissions from pulp and paper converting operations (corresponding to NAICS 322200) of 0.41 Mt CO₂ eq. in 1990 and 0.49 Mt CO₂ eq. in 2005 (estimated from disaggregated CIEEDAC data and EC emission factors). Therefore, pulp and paper manufacturing emissions without converting operations are estimated at 15.2 Mt CO₂ eq. in 1990 and at 8.1 Mt CO₂ eq. in 2005. These estimates are similar to those based on the FPAC survey responses (13.7 Mt CO₂ eq. in 1990 and 8.1 Mt CO₂ eq. in 2005).

Using a mid-point between the estimates from these data sources, Canadian pulp and paper industry direct emissions of GHGs associated with fossil fuel use are estimated to have been 14.6 Mt CO₂ eq. in 1990 and 8.1 Mt CO₂ eq. in 2005. The decrease in direct emissions associated with fuel combustion are presumed to result from implementation of energy efficiency measures and increased reliance on low-emitting biomass fuels (which displaced fossil fuels).

Energy consumption data from CIEEDAC (2007c) were used to estimate direct emissions from the wood products sector, corresponding to NAICS 321000 (FPAC did not provide energy consumption data for the wood products sector). In these data, consumption of propane and steam in 2005 were listed as confidential and in sum corresponded to less than 1% of total energy consumption. Analysis of annual propane and steam consumption in prior years (based on CIEEDAC results) reveals that it is reasonable to assume that, on an energy content basis, the Canadian wood products industry consumes four times as much propane as purchased steam (although propane use has decreased in

recent years). Therefore, propane and steam consumption in 2005 were approximated as 80% and 20% of the confidential energy consumption, respectively, associated with these two energy sources. Because self generation of electricity within the wood products sector is relatively rare, the problems with the CIEEDAC data related to how fuel consumption and electricity generation were treated should not result in a significant bias for this sector.

Direct GHG emissions from manufacturing operations for the wood products sector were estimated at 2.3 Mt CO₂ eq. in 1990 and 2.2 Mt CO₂ eq. in 2005. These estimates include direct emissions associated with wood product converting operations, for which disaggregated energy consumption data were not available from CIEEDAC nor FPAC. An estimate of direct emissions from wood products converting operations is presented below. As with the pulp and paper sector, total direct GHG emissions from fuel combustion decreased while production rates increased. Therefore, total direct GHG emissions related to fossil fuel combustion at forest products industry facilities (not including pulp and paper sector converting operations) are estimated to have been 16.9 Mt CO₂ eq. in 1990 and 10.4 Mt CO₂ eq. in 2005 (the 2005 forest products fuel combustion emissions result represents about 2% of Canadian energy-related CO₂ emissions, estimated at 544 Mt of CO₂ in 2005). It is important to note that if the industry used fossil fuels to satisfy the energy needs currently satisfied by biomass fuels, these direct emissions would be significantly larger.

Environment Canada reported an uncertainty range of -4 to +1% for estimates of stationary combustion emissions (EC 2007). The uncertainty range in this study is probably somewhat higher due to the need to perform a number of extrapolations of activity data.

Examination of a number of GHG inventories suggests that the only significant non-combustion-related direct emissions at forest product manufacturing facilities are methane emissions from landfills, and perhaps from anaerobic wastewater treatment plants. Methane emissions associated with manufacturing wastes in industry landfills were obtained from Environment Canada (EC 2007). EC data on emissions from landfills include both MSW landfills and “wood waste” landfills (including those at pulp and paper and wood products manufacturing facilities), expressed as CO₂ equivalents (using a GWP of 21 for methane). The wood waste landfill emissions for 2005 can be calculated at 3 Mt CO₂ eq. by subtracting emissions from MSW landfills (24 Mt CO₂ eq.) from total landfill emissions (27 Mt CO₂ eq.; includes emissions from both MSW and wood waste landfills). However, EC only provides combined emissions from MSW and wood waste landfills in 1990 (22 Mt CO₂ eq.). Therefore, to estimate emissions from industry landfills in 1990 the ratio of wood waste landfill emissions to total landfill emissions from 2005 (3:27) was applied to the total landfill emissions data provided for 1990 to arrive at an estimate of wood waste landfill emissions of 2.4 Mt CO₂ eq.

Environment Canada reported that “the uncertainty associated with CH₄ emissions from the combined municipal and wood waste landfills was estimated to be in the range of -35% to +40%” (EC 2007). Estimates of landfill emissions and emissions from wastewater treatment plants (discussed below) in this study are expected to be of comparable accuracy.

Anaerobic wastewater treatment is not commonly practiced in Canada and no data on these operations were available. Therefore, fugitive methane emissions from anaerobic wastewater treatment, anticipated to be immaterial, were not considered in this analysis.

Primary products are often further processed to yield final products. In most cases, however, these operations emit low quantities of GHGs compared to primary manufacturing. Data from the US Department of Energy, for instance, indicate that the “printing and related support industries,” which includes some facilities that print on non-paper surfaces, has direct emissions that are only 4% of those from the paper and paperboard industry (USDOE 2005). A life cycle study of magazines in North America found that GHG emissions attributable to printing were 3 to 7% of those from pulp and paper manufacturing (Gower et al. 2006). For some paper products, graphic papers for instance,

almost no additional GHGs are generated in converting the primary product; e.g., converting rolls of paper into cut sheets. Life cycle studies of houses in Europe have found that emissions resulting from house construction (not including worker transport) are less than 10% of embodied GHG emissions in the building materials (Cole 1999). In total, the available information suggests that, for purposes of developing the forest products industry's GHG profile, it is reasonable to assume that secondary manufacturing operations are responsible for emissions on the order of 10% of those from primary manufacturing, with half of these converting emissions direct and the other half indirect (e.g., corresponding to purchased electricity).

In the current analysis, emissions associated with pulp and paper industry converting operations were estimated based on energy consumption data from CIEEDAC (2007a,b) for NAICS 322200 (converted paper product manufacturing) in conjunction with the emission factors presented in Table 2.2. These emissions were 0.41 Mt CO₂ eq. in 1990 and 0.49 Mt CO₂ eq. in 2005. CIEEDAC did not provide disaggregated energy consumption data for the wood products converting sector. Therefore, for this sector direct emissions were estimated as 5% of the direct emissions for the wood product manufacturing sector, or 0.11 Mt CO₂ eq. in both 1990 and 2005. This brings the total manufacturing-related emissions to 19.7 Mt CO₂ eq. in 1990 and 13.8 Mt CO₂ eq. in 2005.

Table 2.2. Direct Emissions from the Canadian Forest Products Value Chain

Direct Emissions Source	1990	2005 Emissions ^a
	Emissions ^a (Mt CO ₂ eq.)	(Mt CO ₂ eq.)
Fuel consumption at pulp and paper mills	14.6	8.1
Fuel consumption at wood products facilities ^b	2.3	2.2
Management of mill wastes	2.4	3.0
Secondary pulp and paper sector manufacturing operations (i.e., converting primary products into final products)	0.4	0.5
Total	19.7	13.8

^a biomass-derived CO₂ 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 CH₄ and N₂O from all combustion processes are included

^b includes direct emissions from wood product sector converting operations, estimated at approximately 0.1 Mt CO₂ eq. per year

2.2 Indirect Emissions Associated with Purchases of Electricity

Emissions associated with purchased electricity can be derived from data on electricity purchases combined with region- or province-specific (or national average) purchased electricity emission factors. In the current analysis indirect emissions for the pulp and paper industry were calculated using two data sources, similar to the way direct emissions from fuel combustion were calculated.

FPAC energy consumption survey results 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). Survey responses also included information on

facility location. Province-specific purchased electricity emission factors¹ from EC (CSA 2007) were used in conjunction with net electricity purchases to calculate associated indirect emissions of 6.1 Mt CO₂ eq. in 1990 and 9.4 Mt CO₂ eq. in 2005. There are several potential reasons for the apparent increase in indirect emissions between 1990 and 2005, 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 geographic shift from regions with low emission power to regions with high emission 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.

CIEEDAC (2007a,b) also published information on pulp and paper industry electricity consumption that can be used to estimate indirect GHG emissions. Unfortunately, however, the electricity consumption data from CIEEDAC represent the sum of both purchased and self-generated electricity; therefore assumptions about indirect emissions related to purchased power based upon these data may be biased high. In addition, it is unclear whether the electricity data have been adjusted to “net out” sales/exports of self-generated electricity. Thus there is considerable uncertainty related to indirect emissions calculated from CIEEDAC data on electricity. In addition, the CIEEDAC data are not segregated by province, so it is not possible to use province-specific emission factors to estimate each facility’s indirect emissions. Use of these CIEEDAC data in conjunction with Canadian national average purchase electricity emission factors enables estimation of these indirect emissions of 10.3 Mt CO₂ eq. in 1990 and of 13.1 Mt CO₂ eq. in 2005.

Estimates based on the CIEEDAC data are 40 to 70% higher than estimates based on FPAC survey responses. Due to the uncertainty associated with the CIEEDAC approach, indirect emissions estimates based on the FPAC approach will be used in characterizing the industry’s GHG profile for the remainder of this analysis.

FPAC survey responses were not available for the wood products sector of the forest products industry. CIEEDAC (2007c) data are available (corresponding to NAICS 322000), and because wood products facilities seldom produce power on site it is reasonable to assume that electricity consumption at wood products facilities reflects electricity purchases. Indirect emissions estimated from these electricity consumption data in conjunction with Canadian national purchased power emission factors were 1.3 Mt CO₂ eq. in 1990 and 1.9 Mt CO₂ eq. in 2005.

Emissions associated with purchased power at pulp and paper secondary manufacturing facilities were estimated using CIEEDAC (2007a,b) data corresponding to NAICS 322200 (converted paper product manufacturing), in conjunction with Canadian national average purchased power emission factors, to be 0.17 Mt CO₂ eq. in 1990 and 0.38 Mt CO₂ eq. in 2005. The issues associated with CIEEDAC data on electricity consumption (combining purchased and self generated power and uncertainty regarding netting sales) are not expected to materially affect the analysis because a majority of converting plants do not self generate power and indirect emissions from this segment are small in comparison to the overall industry’s indirect emissions. For the wood products sector, the approach suggested in NCASI’s study of the global forest products industry (NCASI 2007; Miner and Perez-Garcia in press) was employed. The sum of direct and indirect emissions from converting operations was approximated as 10% of direct emissions from stationary combustion for the sector. In this analysis, emissions associated with converting operations were assumed to be divided equally between direct and indirect, such that indirect emissions from wood product converting operations

¹ CSA 2007 includes province-specific and national average purchased electricity emission factors from 1990 through 2002. Because factors for 2005 were not available, the 2002 factors were used as surrogates when estimating indirect emissions associated with electricity purchased in 2005.

were approximated as 5% of the direct emissions from stationary combustion for wood products manufacture, resulting in estimates of 0.11 Mt CO₂ eq. for both 1990 and 2005.

Adding indirect emissions from pulp and paper mills to those from wood products facilities and secondary manufacturing yields an estimated 7.7 Mt CO₂ eq. of indirect emissions associated with purchased electricity in 1990 and 11.8 Mt CO₂ eq. in 2005 (2005 forest products indirect emissions from purchased electricity estimate represents about 2% of Canadian energy-related CO₂ emissions, estimated to be 544 Mt CO₂ in 2005). The industry's indirect emissions from purchases of electrical power are summarized in Table 2.3.

In Canada's national inventory, these emissions are included in estimates from stationary combustion. Environment Canada reported an uncertainty range of -4 to +1% for estimates of stationary combustion emissions (EC 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 the use of regional or national average emission factors.

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

Indirect Emissions Source	1990 Emissions (Mt CO ₂ eq.)	2005 Emissions (Mt CO ₂ eq.)
Electricity purchases by pulp and paper mills	6.1	9.4
Electricity purchases by wood products facilities	1.3	1.9
Secondary manufacturing operations (i.e., converting primary products into final products)	0.3	0.5
Total	7.7	11.8

2.3 Emissions Associated with Procuring and Transporting Raw Materials and Products

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

Emissions associated with raw material and final product transport were estimated for both the pulp and paper and wood products sector jointly, based on an analysis conducted in 1999 by the Forest Engineering Research Institute of Canada (FERIC) (Ernie Heidersdorf, Eastern Region Research Director, personal communication). In this analysis FERIC estimated transport fuel consumption at 1 billion litres of diesel equivalent (which was correlated with the 188 million cubic metres of wood harvested in 1999). FERIC advised that transport fuel consumption can be linearly scaled to annual harvest volume in years 1990 and 2005 and noted that "shorter [haul] distances and more [fuel] efficient engines in earlier years were balanced by higher payload configurations and better logistics in recent years" (indicating that the overall fuel economy of transporting a cubic metre of wood has remained essentially constant from 1990 to 2005).

The emission factor for diesel fueled heavy duty trucks (including CO₂, CH₄, and N₂O all expressed as CO₂ equivalents) from the Canadian GHG Challenge Registry (CSA 2007) was used to calculate GHG emissions from this level of diesel consumption. The 1999 transport fuel consumption estimate from FERIC was linearly scaled based on total production tonnage (pulp and paper plus wood products) estimated from data from CIEEDAC (2007a,b,c) and PPC (2006) to arrive at transport fuel consumption estimates for 1990 and 2005. The resulting estimates of indirect emissions associated with transport and harvesting operations are 2 Mt CO₂ eq. in 1990 and 3 Mt CO₂ eq. in 2005 (Table 2.4).

The fuel consumption estimate from FERIC did not include fuel consumed during harvesting operations. This represents a low bias to the estimate. However, it is anticipated that the low bias associated with omitting consideration of harvest-related fuel consumption would be relatively minor compared to total transport plus harvest fuel consumption (FERIC agrees with this assessment). Sonne (2006) found that harvesting-related emissions are less than one-half of those associated with transport of wood to the mill for forests in the North West US.

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

Harvest- and Transport-Related Emissions	1990 Emissions (Mt CO ₂ eq.)	2005 Emissions (Mt CO ₂ eq.)
Total	2	3

2.4 Methane Emissions Attributable to Forest Products in Landfills

When exposed to anaerobic conditions, as exist in most MSW landfills, forest products can degrade, resulting in the formation of methane and carbon dioxide. Because the carbon dioxide 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 due to updated information it is likely to be changed to 23 at some point in the future).

The 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 that are discarded
- amounts of discarded products that are landfilled rather than being recycled, burned, or used for other purposes
- amounts of landfilled products that are 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 product decomposes

- f) landfill's design and operating features that result in destruction of some methane into biogenic CO₂ (accounted for in the assessment of forest carbon) before it can escape to the atmosphere

Methane emissions corresponding to decay of forest products in landfills were estimated using a modification of the IPCC methods based on amounts of used forest products discarded every year, which were estimated by developing a time series of carbon stocks in products in use. This time series reflects each year's new production and the eventual removal from use of previously manufactured products. Time in use was determined using a linear relationship similar to that in the Carbon Budget Model of the Canadian Forest Sector (Kurz et al. 1992; Apps et al. 1999), with the annual rates at which forest products are assumed to be taken out of service shown in Table 2.5. As noted herein, a significant fraction of the output of the Canadian forest products industry is used and disposed of in the United States (US). Nonetheless, with few exceptions, the parameters and modeling equations used in this study are those used in the Canadian national GHG inventory. The implications of these selections and the exceptions to their use are discussed in the appropriate sections of this report.

Table 2.5. Annual Rates at which Forest Products are Taken Out of Service

Product	Percent of Original Production Taken out of Service per Year
Sawn wood	1
Panels	5
Paper products	50
Other industrial wood use	1

If US GHG inventory values for time in use had been used the amounts of discards would have been lower, because US values generally suggest that forest products remain in use longer than suggested by the values in Table 2.5.

To the extent that carbon stocks in products in use increase more slowly than carbon added in new production, the difference represents a discard of carbon in forest products. Discards are managed in a number of ways, with a fraction going into landfills. Most of the assumptions regarding the fraction discarded in landfills in Canada used in this analysis are very similar to those used in the Carbon Budget Model of the Canadian Forest Sector (Kurz et al. 1992; Apps et al. 1999). The values used in this analysis are shown in Table 2.6. Recovery of used paper products was assumed to vary linearly from 0 in 1900 to 19.8% in 1980 (the first year for which recovery data were available); from 1980 through 2000 recovery statistics from PPPC (updated every five years) were used (linear interpolation was used to estimate recovery rates between published values); from 2000 through 2005 annual recovery rates from PPPC were used. This is expected to result in estimates of discards that are biased high because recovery rates in the US are assumed to be equal to those in Canada whereas they have historically been somewhat higher. This, in turn, would result in estimates of methane generation and carbon in storage in landfills that are biased high.

Table 2.6. Disposition of Forest Products at End of Life

Product Category	Fraction Recovered	Unrecovered Fraction to Landfill
Wood products (lumber, panels, other industrial wood)	0.05	0.85
Paper products	0 to 0.46	0.95

Using this approach with time in use values for forest products suggested by CFS and production data from FAO (2007), a time series was developed from 1900 through 2005. Many of the parameters used in the estimates were obtained from CFS, with others based on IPCC default values (IPCC 2003, 2006). It was assumed that all landfilled forest products remained under anaerobic conditions. The degradation rates used in the calculations were 1% of the original deposited amount per year for all forest products, similar to those used in the Canadian government calculations for harvested wood products (Kurz et al. 1992; Apps et al. 1999).

The value used in the current analysis to describe the fraction of carbon that is degradable in landfills was different than the value used in the Canadian calculations for harvested wood products because new information is available that was not available at the time the Carbon Budget Model of the Canadian Forest Sector was first developed. In the current analysis, the fraction of carbon degradable in landfills was determined from summary values reported by Barlaz (2004), values that are based on the same research used in a 2005 study for Natural Resources Canada and Environment Canada (ICF 2005). Barlaz showed values for the fraction of carbon in different types of paper that is degradable under the anaerobic conditions that exist in municipal solid waste landfills. An overall value was determined for the combined paper stream being landfilled based on Canadian MSW composition data (MWIN 2006). The weighted average degradable fraction for the combined paper going to landfills was between 0.5 and 0.6. This was rounded to 0.5, which is also the default value recommended by IPCC (2006). Based on Barlaz and the default recommendations of IPCC, the same value (0.5) was used for wood waste. The value used in this study for paper (0.5) is similar to that now being used by the US in its national inventory (0.56), but the value used for wood products (0.5) is higher than the value used in the US inventory (0.23) (USEPA 2006a). If the US values had been used for the fraction of discards that are landfilled in the US, methane estimates would be lower and carbon storage estimates would be higher than shown herein.

Another very important factor affecting methane emissions estimates is the fraction of MSW landfills that are equipped with methane collection systems. An analysis of waste management activities in Canada indicated that approximately 37% of Canadian landfills were equipped with methane collection and destruction systems in 2005 (ICF 2005). A somewhat different value is used in Canada's national inventory (EC 2007) wherein it is reported that in 2005 21% of gas from MSW landfills was collected and burned. Many of the forest products made in Canada are used and disposed of in the US, where 43% of landfill capacity had capping systems in 2000 and 45% in 2005 (USEPA 2002, 2007). In this study, therefore, it was assumed that 40% of the methane generated from disposed products made by the Canadian forest products industry in 2005 were captured and burned to prevent methane release. In addition, it was assumed that no collection systems were in place prior to 1980, and from 1980 through 2005 the percentage increased linearly to 40%. The analysis assumed that the percentage of forest products placed in landfills with collection systems mirrored the percentage of landfills with collection systems. These assumptions yielded estimates of methane emissions attributable to the decomposition of Canadian forest products in landfills of 20.3 Mt CO₂ eq. in 1990 and 24.4 Mt CO₂ eq. in 2005. The complete time series of methane emissions is shown in Figure 2.1.

Environment Canada reported that "the uncertainty associated with CH₄ emissions from the combined municipal and wood waste landfills was estimated to be in the range of -35% to +40%" (EC 2007). The estimates of landfill emissions in this study are expected to be of comparable accuracy.

Because materials in landfills decay slowly, the methane from landfilled forest products is released over a long period of time. If the number of landfills with capping systems remained unchanged, the products landfilled in 1990 would ultimately release 65.2 Mt CO₂ eq. and the material landfilled in 2005 would ultimately release 61.0 Mt CO₂ eq. The amounts ultimately released by the material deposited in 1990 is larger because in 1990 landfill capping systems were assumed to be used less

often than in 2005. The actual ultimate releases will probably be lower than these estimates due to the additional use of landfill gas capture systems.

It is important to note that since the early 1990s landfill methane emissions have been declining in many countries as a result of efforts to divert organic material from landfills (e.g., by increasing the recovery of used forest products) and requirements for landfills to capture and burn methane (European Commission 2005; USEPA 2006a; MOE 2006). For instance, emissions of methane from MSW landfills have decreased by about 35% in Europe and Japan and by 18% in the United States since 1990. In Canada, however, methane emissions from solid waste disposal on land increased between 1990 and 2005, suggesting that Canada may have opportunities to reduce landfill methane emissions.

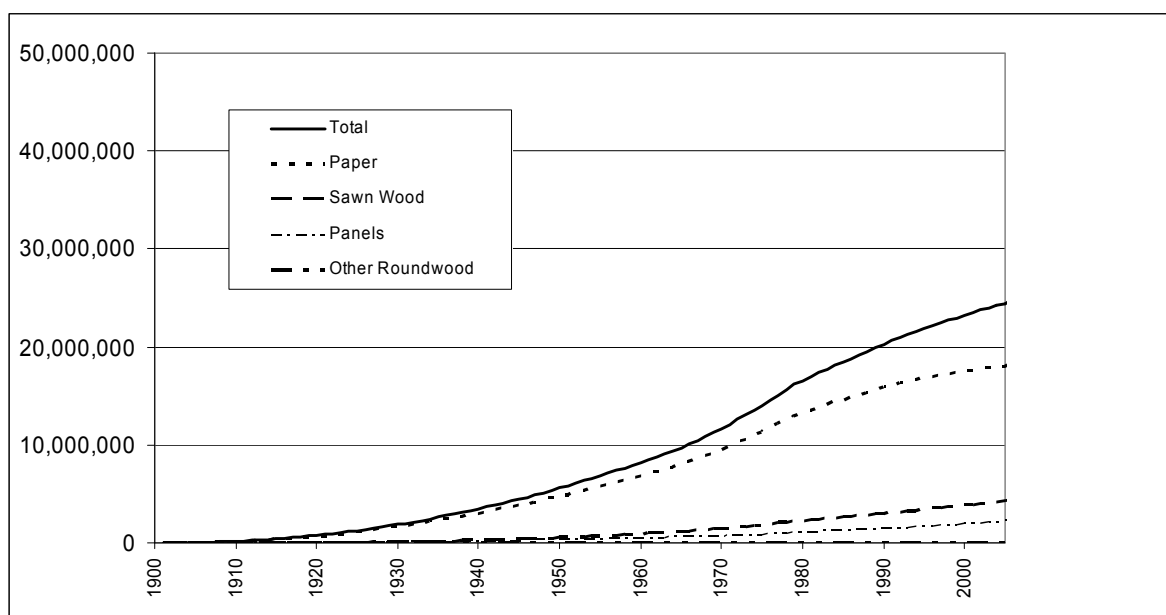


Figure 2.1. Methane Emissions Attributable to Canadian Forest Products in Landfills (t CO₂ eq.)

Table 2.7 presents a summary of indirect emissions associated with the Canadian forest products industry, including methane from forest products in landfills.

Table 2.7. Indirect Emissions from the Canadian Forest Products Value Chain

Indirect Emissions Source	1990 Emissions (Mt CO ₂ eq.)	2005 Emissions (Mt CO ₂ eq.)
Purchased electricity	7.7	11.8
Harvest and transportation	2	3
Methane from forest products in landfills	20.3	24.4
Total	30.0	39.2

3.0 CARBON SEQUESTRATION IN THE FOREST PRODUCTS INDUSTRY VALUE CHAIN

3.1 Accounting for Forest Carbon

Carbon dioxide is removed from the atmosphere by trees and stored for a period before being returned to the atmosphere. The sequestered carbon is stored not only in the forest ecosystem, but also in forest products for periods ranging from days to centuries. If the amounts of carbon removed from the atmosphere by forests are exactly balanced by the amounts of forest-derived carbon returning to the atmosphere (as a result of biomass combustion and the decay of organic matter in forests and wood products) the net effect on the atmosphere is zero – i.e., atmospheric levels of CO₂ do not change. In any given year, however, the amounts of carbon removed from the atmosphere by forests may not match the amounts returned to the atmosphere, so methods are required to estimate the effects of forest carbon movement on atmospheric levels of CO₂.

There are two basic approaches to tracking forest carbon through the forest products value chain. The first looks at the transfers (or flows) of carbon to and from the atmosphere within national boundaries, and is called the atmospheric flow approach. The second method looks at stocks of sequestered carbon within national boundaries and estimates transfers of carbon to or from the atmosphere based on changes in these stocks. Therefore, it is called the stock change approach (IPCC 2006). A variation of stock change accounting, called production accounting, looks at stock changes that are associated with the wood that originates within national boundaries, regardless of where those stocks reside.

At the global level, the various approaches yield identical estimates of effects on atmospheric CO₂. The methods are different, however, in how they calculate the net transfer of carbon to (or from) the atmosphere. In the atmospheric flow approach, the carbon removed from the atmosphere in the forest is netted against all of the transfers back to the atmosphere along the value chain. Under the stock change approach, the net transfer of carbon to or from the atmosphere is calculated by summing all the changes in the stocks of carbon in forests, products in use, and products in landfills. Because the stock change calculations include all major pools of forest-derived carbon, the net change in global carbon stocks across all pools is mathematically equal to the mass of carbon transferred to or from the atmosphere globally. When applied within national boundaries, however, the approaches can yield different results due to the effects of imports and exports (IPCC 2006).

In this analysis, we have chosen to use the production approach variant of the stock change accounting because (a) it is more aligned with the available data (which mostly consist of stock change estimates); (b) it more readily allows examination of the role of carbon in different pools along the forest products value chain; and (c) it focuses on the source of production (the intent of this analysis) rather than national boundaries.

3.2 Carbon Sequestration in Forests

Forests and other wooded land (402.1 million ha) make up about 46% of Canada's land mass (NRCan 2006). Canada's 236 million ha managed forest was defined for the purposes of UNFCCC reporting by CFS in consultation with all provinces and territories as including those forested land areas that are either managed for timber or non-timber forest resources or are under intensive protection against natural disturbances (EC 2007). The portion of forest used by the forest sector for commercial purposes is approximately 143 million ha (NRCan 2006).

The Canadian forest contains large amounts of carbon, both above and below ground. A number of factors influence the amounts of carbon in the managed forest of Canada. Chief among these are losses of forest carbon due to decay, fire, and harvesting, and gains of new carbon by tree regrowth. It is the net balance between these losses and gains that determines whether forests are sources or sinks of CO₂.

It is difficult to isolate the impacts to Canadian forest carbon stocks that are specifically and solely related to the forest products industry. Land managed by the industry for fibre is often affected by management activities that are supported or undertaken in part by the industry but are the primary responsibility of other entities such as provincial, territorial, or federal governments. Fire management and suppression and pest management are the most notable examples. In addition, in many cases other industries or interests such as oil and gas companies, mining operations, and public and commercial recreational users have a presence on the same land base.

In recent years, fires have caused more losses of carbon from Canada's forests than any other type of natural disturbance. The average yearly area disturbed by fire in the managed forest from 1990 to 2005 was 0.68 million ha. Insect- and disease-affected areas were typically larger but associated carbon losses were generally smaller, as is evident in comparing the 2001 and 1995 data points shown in Figure 3.1 (CFS 2007a). The average yearly area harvested during this same period was 0.96 million ha.

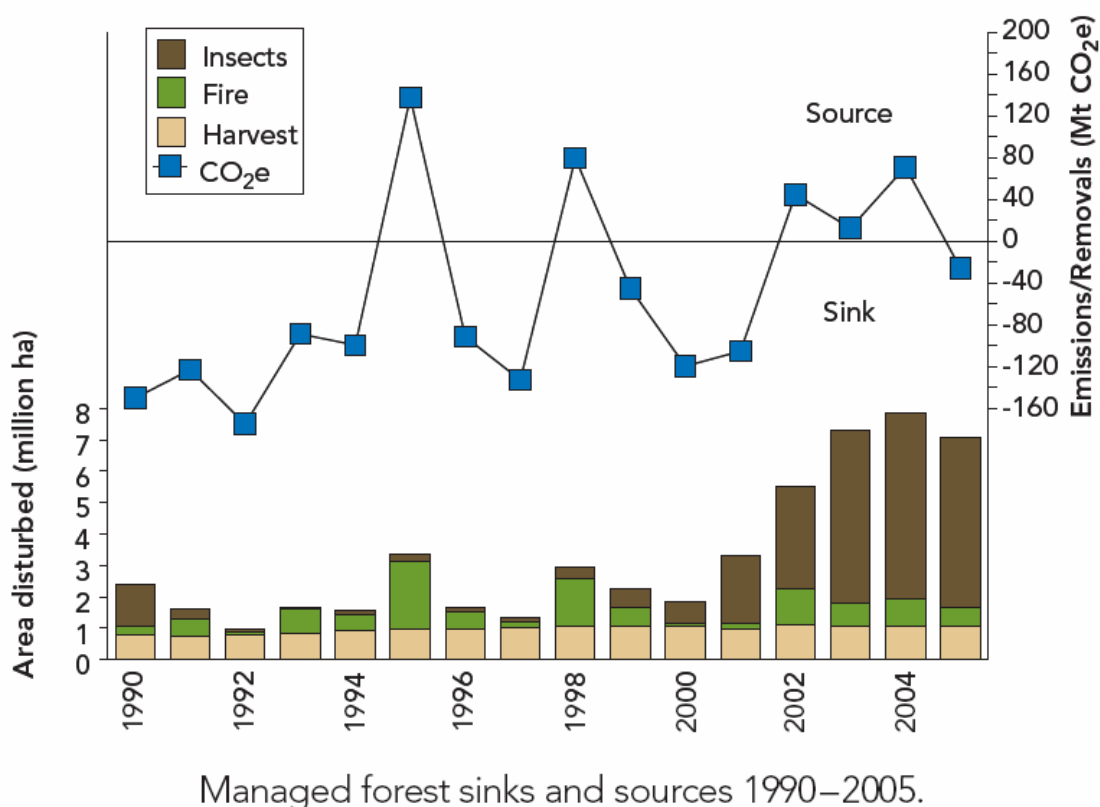


Figure 3.1. Managed Forest Sinks and Sources, 1990 to 2005 (CFS 2007a)

Forests that experience only natural disturbances (generally due to fires and insect damage in the Canadian context) usually store more carbon than those where harvesting is the primary disturbance. A study of the effects of shifting from a regime of only natural disturbances to a regime involving harvesting in Canadian forests (Kurz et al. 1998) found that the effects are highly dependent on the type of forest and the extent to which carbon stocks had already been impacted by natural disturbances when harvesting was initiated. The same study noted that some of the harvested carbon was transferred to long-lived products that continue to store carbon. The study also found that once an area has

undergone the change from a solely natural disturbance regime to a regime involving harvesting and regeneration, the carbon stocks on each stand fluctuate (reflecting harvest and regrowth cycles), but over the long term “the annual change in most C pools approach[es] zero...indicating that C pools are sustained, albeit at a different level than during the natural disturbance regime.”

The Canadian forest products industry positively affects carbon in Canada’s forest by establishing new forests on unforested land (afforestation), a land use change that significantly increases carbon stocks. The impacts on forest carbon are substantial in afforested areas, but they do not have a significant effect on the total Canadian forest carbon budget because of the relatively small amounts of land involved (White and Kurz 2005). While data specific to the forest sector have not been collected, the total cumulative area of land converted to forest between 1990 and 2005 was 185,000 ha, averaging about 12,000 ha per year (EC 2007). In contrast, deforestation due to all causes averaged approximately 55,000 ha per year, with the most common causes being conversion to agriculture and urban development (EC 2007). Areas of deforestation specifically attributable to the forest sector averaged approximately 5000 ha per year, primarily associated with the construction of permanent primary and secondary roads. The annual change in Canada’s forested area lies within the range used by FAO to describe countries with stable forests, a range encompassing changes in forested area from +0.5% per year to -0.5% per year (FAO 2006; EC 2007).

In examining the situation since 1990, the Canadian government has determined that Canada’s managed forest was an overall sink except for five years characterized by large natural disturbances (CFS 2007a). Source years were due mainly to emissions from extensive forest fires. For the period 1990 through 1994, during which the fire and insect damage was not particularly severe, net sequestration in the managed forest equaled 120 Mt CO₂ eq. During the period 2000 through 2004, during which fire damage was extensive, net sequestration dropped to 19 Mt CO₂ eq. (Werner Kurz, Canadian Forest Service, personal communication). Harvesting levels remained relatively stable throughout this period. Compared to the year-to-year variability due to fires, the impacts of harvesting and regrowth on forest carbon are small and primarily affect the baseline balance of carbon sources and sinks. The link between natural disturbances in the sequestration or emissions attributable to Canada’s forest is clearly shown in Figure 3.1 (CFS 2007a).

In the context of the complete value chain, Natural Resources Canada (NRCan) has concluded that reducing harvesting would have very little impact on CO₂ emissions because harvested areas are regenerated, reduced harvesting in Canada would simply shift harvesting elsewhere, and reduced availability of forest products would increase consumption of more GHG-intensive alternatives (CFS 2007b).

Nonetheless, there may be opportunities to reduce emissions associated with forestry activities. NRCan suggests that reducing the forest disturbance associated with harvesting, reducing road widths, and helping trees get re-established faster after harvest are examples of forest management practices that reduce carbon emissions (CFS 2007b).

3.3 Carbon Stored in Forest Products in Use

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

The significance of carbon in products in use can be estimated using a number of IPCC-derived approaches, all of which provide the same estimates at the global level (although not at the national level) (IPCC 2006). The approach used in this study is similar to IPCC’s production approach, which examines carbon in products and emissions from products from the standpoint of the country from

which the wood is harvested regardless of where the products are used and disposed. This approach is well suited to a study of the carbon and greenhouse gas impacts of the Canadian forest products industry because we are interested in the fate of products from the Canadian industry regardless of where they are used and disposed. The IPCC methods involve development of a time series of carbon stocks using the methods described herein.

Stocks of carbon in products in use were estimated using FAO (2007) data and modified IPCC methods and, in most cases, default parameters similar to those used in the Carbon Budget Model of the Canadian Forest Sector (Kurz et al. 1992; Apps et al. 1999) and IPCC. The expected times in use for various types of forest products were described using a modification of IPCC's method (IPCC 2006), utilizing a linear decay rate determined by coefficients used in the Canadian national inventory that vary by product type (Table 2.5) rather than by the IPCC default first order decay relationship based on half-lives. Stocks of carbon in products in use were estimated for the period from 1900 to 2005, with the results, expressed as annual changes in stocks, shown in Figure 3.2. Annual growths in stocks of carbon in products in use were estimated at 22.4 Mt CO₂ eq. in 1990 and 39.8 Mt CO₂ eq. in 2005. If the time in use values used by the US government in its GHG inventory had been used for the fraction of the Canadian industry's output that is consumed in the US, estimates of carbon storage in products in use would have been larger.

In this analysis, total stocks of product carbon in use in 1989 were estimated to be 240 Mt carbon. This can be compared to the results of the analysis by Apps et al. (1999) wherein those stocks were estimated to be close to 300 Mt carbon in 1989.

USEPA characterized the uncertainty of estimates in carbon storage in harvested wood products as +/-40% (USEPA 2007). The estimates in this report of carbon storage in products in use are probably of comparable accuracy.

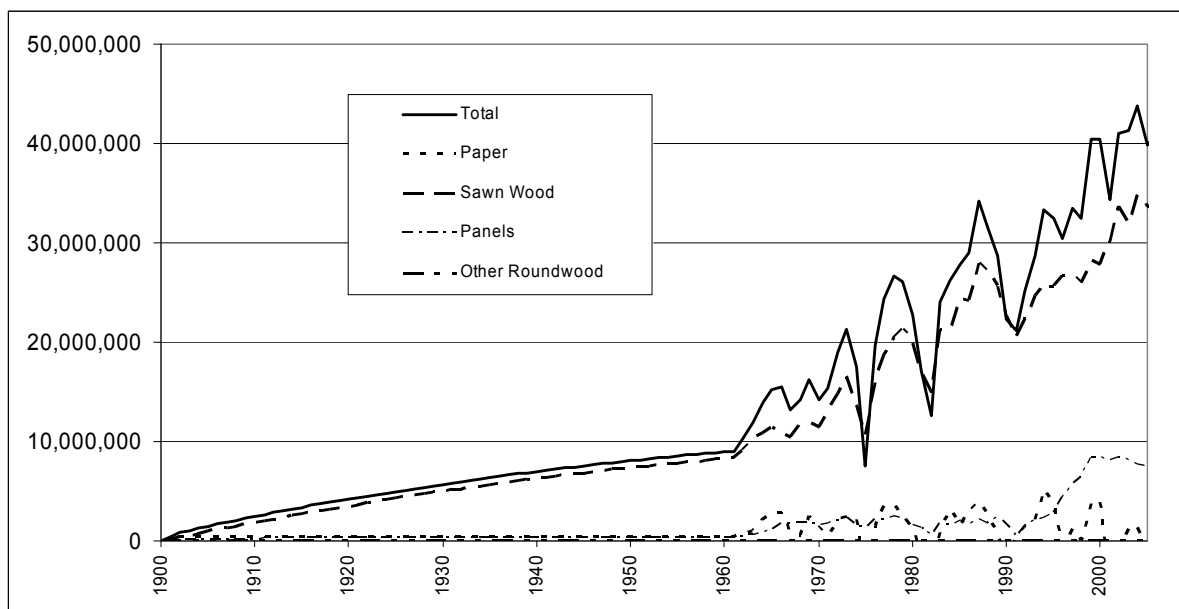


Figure 3.2. Annual Carbon Stock Changes in Products in Use (t CO₂ eq./year)

3.4 Carbon Stored in Forest Products in Landfills

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

A modification of the IPCC-endorsed methods was used to estimate the accumulation of carbon in MSW landfills. The modification included use of a linear decay relationship similar to those used in the Carbon Budget Model of the Canadian Forest Sector calculations on harvested wood products (Kurz et al. 1992; Apps et al. 1999) rather than the IPCC-recommended first order decay relationship, as described in Section 2.4. Essentially, the methods involve developing a landfill mass balance for carbon. The carbon in new discards to landfills is netted against carbon lost in gas, both in methane and in carbon dioxide, with the lost carbon evenly divided between the two gases. If losses of carbon in gas are smaller than carbon in new discards, stocks of carbon in the landfills increase. Using the methods described, it is estimated that stocks of carbon in forest products in landfills increased by 36.8 Mt CO₂ eq. in 1990 and by 40.6 Mt CO₂ eq. in 2005. The complete series of estimates of annual carbon stock changes in landfills is shown in Figure 3.3.

In this analysis, the total stocks of product carbon in landfills in 1989 were estimated to be 320 Mt carbon. This can be compared to the results of the analysis by Apps et. al. (1999) wherein these stocks were estimated to be almost 300 Mt carbon in 1989 (estimated from figures in Apps et al. 1999).

USEPA has characterized the uncertainty of estimates in carbon storage in harvested wood products as being +/- 40% (USEPA, 2007). The estimates in this report of carbon storage in landfills are probably of comparable accuracy.

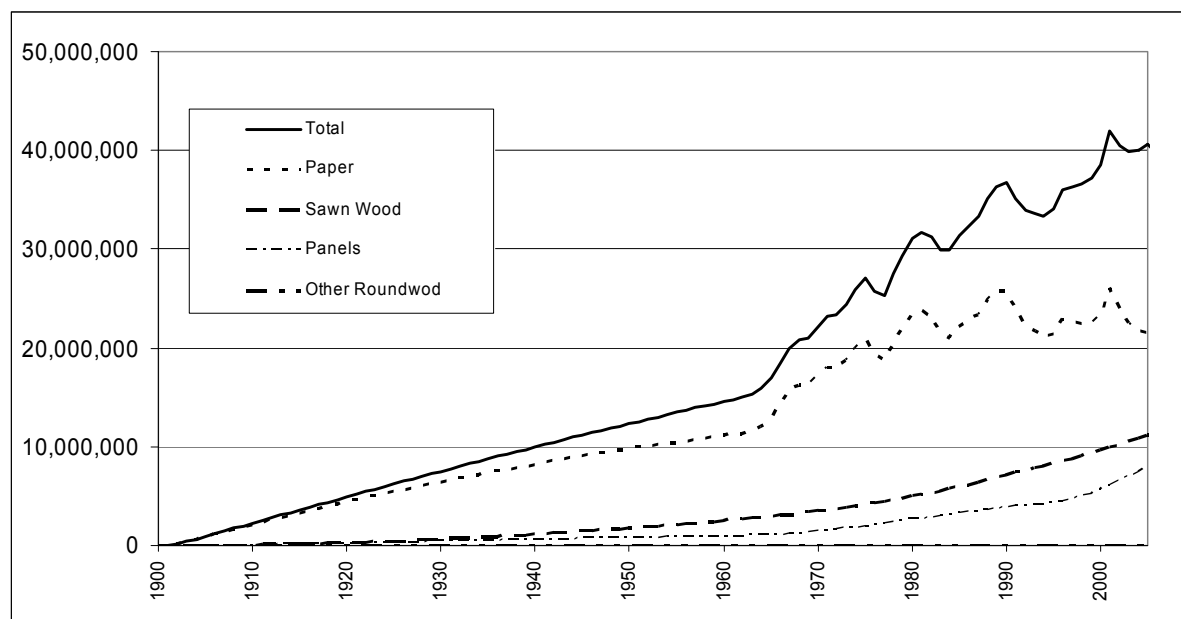


Figure 3.3. Annual Carbon Stock Changes in Products in Landfills (t CO₂ eq./year)

As noted, the degradable carbon in landfills decays very slowly, so long-term storage is only a fraction of that seen in years that immediately follow placement in a landfill. Ultimately, the long-term storage accomplished by materials deposited in 1990 is 21.8 Mt CO₂ eq. and the long-term storage accomplished by the materials deposited in 2005 is 25.4 Mt CO₂ eq.

While there is significant uncertainty in this estimate, it is less than those associated with estimates of methane emissions because a number of factors affecting landfill methane emissions do not affect estimates of carbon in landfills; e.g., the fraction of methane collected and destroyed.

3.5 Net Contribution of Forest Products in Landfills

The net effect of landfills on atmospheric GHGs is governed by four phenomena: permanent storage of non-degradable carbon; temporary storage of degradable carbon; slow conversion of about half the degradable carbon to methane; and destruction of methane in landfill cover systems by natural oxidation and via the use of methane control systems. When forest products are placed in landfills the storage benefits are immediate, but they slowly dissipate over time until only the permanently non-degradable carbon remains stored. Conversely, cumulative methane releases are small at first but become significant over time as the degradable carbon is slowly converted to methane (50% of carbon) and CO₂ (the other 50% of carbon). The effects of methane control systems are immediate.

In this assessment, methane emissions attributable to paper and wood products are currently more than offset by net storage in landfills attributable to those same products. This finding is similar to that in a study of forest products and waste management in Finland (Pingoud, Savolainen, and Seppälä 1996). It is also consistent with the findings of an NCASI study of the carbon profile of the global forest products industry (NCASI 2007; Miner and Perez-Garcia in press).

Looking at the long-term effects of materials being landfilled, however, gives a somewhat different picture. If collection of methane from landfills remains unchanged, materials landfilled in 1990 will end up resulting in net emissions (i.e., long-term methane emissions minus long-term landfill storage) of 43.4 Mt CO₂ eq. and the material deposited in 2005 will be associated with net long-term emissions of 35.6 Mt CO₂ eq.

Ultimately, reducing the impact of landfill emissions on the industry's GHG profile will require diverting degradable materials from landfills as well as improving methane capture at landfills. Using the same data as used above, it can be shown that if the capping of landfills for methane collection can be extended to approximately 95% of landfills receiving Canadian forest products, long-term releases of methane can be reduced to a point where they are essentially offset by long-term storage in the landfill.

Table 3.1 provides a summary of carbon sequestration and storage for forest products in the value chain.

Results of earlier analyses based on the Carbon Budget Model of the Canadian Forest Sector indicated that in 1986 carbon stocks in products (in use and in landfills) were increasing by 21.1 Mt carbon per year, equivalent to 77.4 Mt CO₂ eq./yr (Kurz et al. 1992). The modeling done for the current study estimates that in 1986 carbon stocks in products were increasing at a rate of 61.2 Mt CO₂ eq./yr, a value in reasonable agreement with the Kurz et al. estimate.

Table 3.1. Carbon Sequestration along the Canadian Forest Products Industry Value Chain

	1990 Sequestration (Mt CO ₂ eq./yr.)	2005 Sequestration (Mt CO ₂ eq./yr.)
Carbon accumulation in managed forests	?	?
Carbon sequestration resulting from establishment of new managed forests	?	?
Carbon storage in products in use	22.4	39.8
Carbon storage in products in landfills	36.8	40.6
Total	?	?

4.0 AVOIDED EMISSIONS ASSOCIATED WITH THE FOREST PRODUCTS INDUSTRY VALUE CHAIN

Avoided emissions are those that would have occurred in the absence of an activity. They are fundamentally different from the other components of the industry's profile. Direct emissions, indirect emissions, and movements of forest carbon into and out of the atmosphere do not require assumptions about alternative activities or speculation about what might have happened if things had been done differently. Avoided emissions, on the other hand, represent what might have happened if things had been done differently. The most appropriate way to address these avoided emissions in the balance sheet of the industry's carbon profile has not yet been determined.

Estimates of avoided emissions are inherently uncertain because they require assumptions about events that would have occurred were it not for activities that are in place or assumed to occur under business as usual conditions. Nonetheless, avoided emissions estimates can provide insights into important attributes of the forest products industry's carbon and GHG profile and the public policies that influence it. As of this writing, some preliminary estimates of avoided emissions are shown herein. How these emissions should be used in the industry's footprint, however, remains to be determined.

It should be noted that avoided emissions could become more important as attempts are made to examine the future impacts of changes in the forest products value chain, because some of the changes made to reduce societal emissions might not reduce emissions in the forest products industry's footprint. For example, if the industry increases exports of low carbon-intensity electricity, the benefits of displacing more carbon-intensive electricity from the grid are not reflected in the industry's footprint unless avoided emissions are included.

4.1 Avoided Emissions Associated with Combined Heat and Power Systems

Combined heat and power (CHP) systems use fuel to produce both electricity and heat (usually in the form of steam that is used in pulping and paper making processes). CHP systems extract far more usable energy from fuels than systems that produce steam and electricity separately. USEPA indicated that CHP systems typically increase overall efficiencies by perhaps 50% and reduce fuel requirements by 35% (USEPA 2006b). The Confederation of European Paper Industries estimated that CHP systems in the European pulp and paper industry allow energy savings of 30 to 35% (CEPI 2005).

To estimate avoided emissions associated with the industry's use of CHP, one must assume a scenario representing the industry's activities in the absence of CHP systems. For purposes of estimating avoided emissions, it is assumed that if the industry did not use CHP systems it would use the current fuel mix to generate process steam and would not generate electricity.

In the global profile, NCASI (2007) used information from the US and Europe as the basis for an assumption that, globally, the industry produces 40% of its net electricity demand in CHP systems.

Using the same value in Canada, one can estimate the increase in electricity purchases and associated indirect emissions from pulp and paper mills that would occur if CHP systems were not used.

Indirect emissions associated with purchased electricity at pulp and paper mills were estimated to have been 9.4 Mt CO₂ eq. in 2005. If these were associated with 60% of the net demand, increasing purchases to cover all of the demand would increase indirect emissions to 15.7 Mt CO₂ eq., an increase of 6.3 Mt CO₂ eq., which represents the avoided emissions associated with using CHP.

4.2 Avoided Emissions Associated with Recycling Recovered Paper

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

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

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

The Canadian government has commissioned a series of studies on the emissions associated with different methods for managing used paper and other discarded products. The most recent report was issued in 2005 (ICF 2005). These studies have attempted to address the range of impacts related to recycling, including impacts on forest carbon. The 2005 report made the following observation regarding estimation of forest carbon impacts:

When paper products are recycled, trees that would otherwise be harvested are left standing. In the short term, this results in a larger amount of carbon remaining in the forest pool, because the standing trees continue to store carbon, whereas paper production and use tends to release carbon. In the long term, some of the short-term benefits disappear as market forces result in less planting of new managed forests than there would otherwise be, so that there is comparatively less forest acreage in trees that are growing rapidly (and thus accumulating carbon rapidly).

As a result of the difficulties associated with accurate forecasting of long-term effects in the forest, the ICF analysis examined only short-term effects. Because these important long-term impacts were not addressed in the 2005 ICF study (in fairness, they would be very difficult to estimate with reasonable accuracy), the analysis herein did not use the ICF forest carbon results to estimate avoided emissions associated with paper recycling. Instead, avoided emissions calculations were based only on avoided methane generation, using data similar to that used by ICF (described above in the section explaining the landfill methane calculations). Because landfill processes are time dependent, avoided emissions were calculated over a period long enough to allow all of the methane to be released so that

only non-degradable carbon remains in the landfill. Avoided emissions were calculated using the assumption that the extent of use of landfill gas capture systems would remain at the levels in place in the year that the materials were landfilled or recycled. This probably results in an overestimation of avoided emissions, as the capping of landfills is expected to increase in the future.

Using these assumptions, materials landfilled in 2005 were calculated to result in long-term methane emissions of 61.0 Mt CO₂ eq. offset by long-term storage equal to 25.4 Mt CO₂ eq., for a net long-term impact on the atmosphere of 35.6 Mt CO₂ eq. If materials recovered for recycling in 2005 had been landfilled instead, the net long-term impact on the atmosphere would have been 17.3 Mt CO₂ eq. higher.

4.3 Avoided Emissions Associated with Product Substitution Effects

Forest products compete in the marketplace with alternative products that often have very different GHG and carbon profiles. NCASI recently conducted a global review of literature on the lifecycle energy and greenhouse gas profiles of different home construction materials (NCASI 2006; Upton et al. in press). That review found that studies designed to compare embodied energy in systems with comparable thermal performance almost always found wood-based wall systems and buildings to have lower embodied energy and CO₂ emissions than comparable building systems using concrete, steel, or brick (e.g., Borjesson and Gustavsson 2000; Athena 2004; Scharai-Rad and Welling 2002; Pierquet, Bowyer, and Huelman 1998; Lenzen and Treloar 2002; Gustavsson and Sathre 2006; Richter and Sell 1993; Gustavsson, Pingoud, and Sathre 2006; Consortium for Research on Renewable Industrial Materials (CORRIM) studies described in Lippke et al. 2004; Perez-Garcia et al. 2005; Puettmann and Wilson 2005).

In the context of the US, assuming 1.5 million housing starts per year, NCASI estimated that the use of wood-based wall systems results in avoided emissions of approximately 9.6 Mt CO₂ eq. per year (NCASI 2006; Upton et al. in press). Over the years, Canada has supplied the US with a significant fraction of its wood-based building materials, so some of these avoided emissions are logically attributed to the Canadian forest products industry. To estimate this for 2005, one can compare Canadian exports of sawnwood and panels [about 55 million m³ (FAO 2007)] to apparent US consumption [production plus imports minus exports = 198 million m³ (FAO 2007)] to estimate that about one-quarter of US consumption of wood products was attributable to Canadian industry exports in 2005. This suggests that in 2005 one-quarter of 9.6 Mt CO₂ eq., or about 2.4 Mt CO₂ eq., in substitution effects in the US housing sector were attributable to the Canadian forest products industry.

In addition, if it is assumed that substitution effects in Canada are similar to those in the US, and using a value for Canadian housing starts of 0.2 million per year (Statistics Canada, <http://www40.statcan.ca/101/cst01/manuf05.htm>), it can be estimated that avoided emissions due to use of wood-based building materials in Canada are approximately 1.3 Mt CO₂ eq. per year. This suggests a combined substitution effect due to the use of Canadian wood-based building products in North America of 3.7 Mt CO₂ eq. per year.

The substitution effects related to building materials are only one of many possible substitution effects that might be related to the use of forest products made in Canada. Other product substitutions probably result in avoided emissions due to the use of forest products, while some may result in avoided emissions attributable to the use of alternative materials.

4.4 Other Avoided Emissions

A number of other types of avoided emissions can be identified in the forest products value chain, such as use of non-recyclable paper as biomass fuel (displacing fossil fuel) and use of landfill-derived methane as biomass fuel (also displacing fossil fuel). It is important to note, however, that the greenhouse gas benefits of these practices can only be captured by including avoided emissions in the profile.

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

The size of the individual components of the industry's GHG and carbon profile are summarized in Table 5.1. The table illustrates the many complex and important connections of the forest products industry to the climate change issue.

Table 5.1. Summary of Greenhouse Gas and Carbon Profile of Canadian Forest Products Industry

Parameter	Mt CO ₂ eq. per year in 1990 ^a	Mt CO ₂ eq. per year in 2005 ^a
Direct Emissions		
Fuel consumption at pulp and paper mills	14.6	8.1
Fuel consumption at wood products facilities ^b	2.3	2.2
Management of mill wastes	2.4	3.0
Secondary pulp and paper manufacturing operations (i.e., converting primary products into final products)	0.4	0.5
Total Direct Emissions	19.7	13.8
Indirect Emissions		
Electricity purchases by pulp and paper mills	6.1	9.4
Electricity purchases by wood products facilities	1.3	1.9
Electricity purchases by secondary manufacturing operations (i.e., converting primary products into final products)	0.3	0.5
Harvest and transport emissions from pulp and paper and wood products value chain	2	3
Methane emissions from forest products decomposition in anaerobic municipal solid waste landfills	20.3	24.4
Total Indirect Emissions	30.0	39.2
Sequestration (changes in carbon stocks)		
Forests ^c	?	?
Products in use	-22.4	-39.8
Products in landfills	-36.8	-40.6
Total Sequestration	?	?
Avoided Emissions		
Avoided emissions related to use of combined heat and power systems		-6.3
Avoided emissions associated with recycling paper		-17.3
Avoided emissions associated with product substitution effects (building products only)		-3.7

a negative emissions indicate net sequestration via increases in carbon stocks

b includes direct emissions from wood product sector converting operations, estimated at approximately 0.1 Mt CO₂ eq. per year

c see Section 3.2

Direct emissions are an important part of the Canadian industry's profile, estimated at about 20 Mt CO₂ eq. in 1990 and 14 Mt CO₂ eq. in 2005.

In most parts of the world, the forest products industry's direct emissions intensity (i.e., direct emissions per tonne of production) has decreased over the years. This has been accomplished by improving energy efficiency and substituting biomass fuels for fossil fuels. In Canada emissions intensity since 1990 has improved faster than production has grown, providing reductions in both emissions intensity and absolute emissions (FPAC 2006).

Indirect emissions associated with purchased electricity are a significant component of the Canadian industry's GHG profile, amounting to an estimated 7.7 Mt CO₂ eq. in 1990 and 11.8 Mt CO₂ eq. in 2005.

Transportation-related emissions, estimated to be 2 to 3 Mt CO₂ eq. per year, are not a dominant feature of the Canadian forest product industry's GHG and carbon profile. For specific products or companies, however, these emissions can be significant, so they cannot be ignored. In addition, continued globalization of the industry and the trend to move production from consuming countries to low-cost regions that are distant from major markets suggest that transportation-related emissions may become more important to the industry's GHG and carbon profile in the future.

In spite of the uncertainties in the estimates, it is clear that methane emissions from MSW landfills are a significant feature of the Canadian forest products industry's GHG and carbon profile. In this study, it is estimated that these emissions amounted to approximately 20.3 Mt CO₂ eq. in 1990 and 24.4 Mt CO₂ eq. in 2005. Methane emissions are large primarily because of economic forces and public policies that result in many used forest products being disposed in MSW landfills, and the still modest extent of use of systems to capture and burn landfill methane.

At present, landfill methane emissions attributable to Canadian forest products are more than offset by net storage of carbon in forest products deposited in landfills. This overall balance, however, obscures the different effects of different types of forest products. Available information suggests that most of the methane is probably attributable to products that are low in lignin, are uncoated, or are otherwise unprotected against microbial attack. On the other hand, most of the storage in landfills is probably due to materials that are high in lignin (e.g., wood and newsprint) or are in a physical form that discourages microbial attack (e.g., pieces of solid lumber or coated papers).

In the long term, the contributions of landfills to atmospheric GHGs can be reduced by limiting the amounts of degradable materials going to landfills and by increasing the extent to which landfill capping systems are used to destroy methane before it can reach the atmosphere. Using the assumptions and parameters described, it appears that expanding the capture and burning of methane to approximately 95% of landfills receiving Canadian forest products would result in MSW landfill methane releases being reduced to a point where they would be equal to the storage occurring in landfills due to non-degradable carbon—i.e., Canadian forest products in landfills would become zero net contributors to atmospheric greenhouse gases.

In this study, total value chain emissions are estimated to have been approximately 49.7 Mt CO₂ eq. in 1990 and 53.0 Mt CO₂ eq. in 2005, although there is considerable uncertainty in this estimate due to uncertainty in the amounts of methane attributable to the decomposition of forest products in landfills. In 2005, these emissions were comprised of direct emissions (26%), indirect emissions associated with purchased power (22%), transportation-related emissions (6%), and methane from forest products in MSW landfills (46%). Adding direct emissions and emissions related to purchased power, one finds that 48% of the 2005 value chain emissions were manufacturing related, with most of the remaining value chain emissions related to methane from forest product decay in landfills.

Canada's managed forest has been defined for the purposes of UNFCCC reporting by CFS in consultation with all provinces and territories as including forested land areas that are managed for timber or non-timber forest resources or are under intensive protection against natural disturbances (EC 2007). For 1990 through 1994, during which the fire and insect damage was not particularly severe, net sequestration in the managed forest equaled 120 Mt CO₂ eq. per year. From 2000 through 2004, during which fire damage was extensive, net sequestration dropped to 19 Mt CO₂ eq. per year. Harvesting was relatively constant over this period, but it is not yet possible to isolate the effects of the industry's harvesting and regeneration activities on forest carbon sequestration and emissions. For land that is regenerated and harvested, however, long-term carbon stocks are expected to be fairly stable. Carbon stocks in forest products in use and in landfills were increasing at a rate equivalent to 80.4 Mt CO₂ eq. per year in 2005, representing net removals of CO₂ from the atmosphere. The carbon stored in forest products is extremely important to the carbon profile of the forest products industry, and will almost certainly become even more important over time as consumption of forest products increases due to growing population and increasing standards of living.

6.0 CONCLUSIONS

The forest products industry has more complex connections to the climate change issue than any other industry. Its carbon and GHG profile is composed of emissions, sequestration, and avoided emissions. Emissions from the Canadian forest products industry value chain are comprised of direct emissions (approximately 20 Mt CO₂ eq. in 1990; 14 Mt CO₂ eq. in 2005), indirect emissions associated with electricity purchases (7.7 Mt CO₂ eq. in 1990; 12 Mt CO₂ eq. in 2005), harvest- and transport-related emissions (2 Mt CO₂ eq. in 1990; 3 Mt CO₂ eq. in 2005), and methane from discarded forest products in landfills (20.3 Mt CO₂ eq. in 1990; 24.4 Mt CO₂ eq. in 2005). Value chain emissions totaled approximately 49.7 Mt CO₂ eq. in 1990 and 53.0 Mt CO₂ eq. in 2005. Manufacturing-related emissions were reduced over that period, but the reductions were more than offset by increases in methane emissions related to decomposing products in landfills.

The managed forest in Canada (an area that includes land affected by harvesting as well as land impacted by a number of activities not related to the forest products industry) experiences large year-to-year variability in emissions (or net sequestration) due primarily to fires. From 2000 through 2004, during which fire damage was extensive, net sequestration dropped to 19 Mt CO₂ eq. per year. The effects of harvesting on forest carbon stocks are relatively constant, but it is not yet possible to isolate the effects of the industry's harvesting and regeneration activities on forest carbon sequestration and emissions. For land that is harvested and regenerated, however, long-term carbon stocks are expected to be fairly stable. Stocks of carbon in forest products in use and in landfills are increasing (annual product carbon stock increases of 59.2 Mt CO₂ eq. in 1990 and 80.4 Mt CO₂ eq. in 2005), representing net removals of CO₂ from the atmosphere.

At present, landfill methane emissions are offset by sequestration in landfills. In the future, however, MSW landfills are expected to become net emission sources unless there is a significant increase in the use of methane capture systems because (a) a sizeable fraction of degradable carbon will slowly convert to methane; and (b) carbon sequestered in landfills will diminish until only the non-degradable fraction remains. Over the long term, impacts of landfills on atmospheric greenhouse gases can be reduced by increasing diversion of degradable material from MSW landfills. In addition, long-term impacts of materials already in landfills can be greatly reduced by increasing the use of landfill capping systems. It appears that if landfill gas capture systems were used at approximately 95% of the landfills receiving used Canadian forest products, forest products in MSW landfills would become net zero contributors to atmospheric GHGs.

Avoided emissions, which represent important connections between the industry and the global carbon cycle, have been estimated for the industry's use of combined heat and power, recycling, and product substitution effects. It has not yet been determined how or whether these avoided emissions should be included in the balance sheet of the industry's footprint. In examining options for changing the industry's value chain to reduce societal emissions, however, it may be important to include a number of avoided emissions because these opportunities would not otherwise be reflected in the industry's footprint.

Available data demonstrate that GHG emissions along the forest products industry value chain are largely offset by sequestration accomplished in forest products. Due to data gaps and uncertainties in estimates, especially with regard to carbon in forests and methane emissions from landfills, it is not clear whether sequestration is somewhat larger or somewhat smaller than emissions along the value chain. Additional work is needed to reduce uncertainties in estimates of emissions or sequestration at several points in the forest products industry value chain. Uncertainties are especially large for transportation-related emissions, carbon sequestration in land owned, controlled, or managed by the industry, and methane emissions attributable to decomposition of forest products in landfills.

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