A second viewpoint that is incorporated into many ecosystem models is that harvesting and site preparation decrease the C content of detritus and mineral soil (e.g. Harmon and Marks 2002, Seely et al. 2002). The magnitude of C loss is commonly modeled as a function of disturbance type and intensity (Harmon and Marks 2002). The assumption that harvesting does not directly affect soil C dynamics may not be valid for mature forests, especially for forests that are not subject to frequent natural disturbances such as fire. The Chetwynd forests are mature, while most forests in the Great Lakes region of the U.S. and Black Hills forests are second-growth forests. Seely et al. (2002) used a forest ecosystem process model to simulate soil C budgets for the Chetwynd Forest and estimated that harvesting released 2529 t C, or 9274 t CO_2-eq from the entire forest in 2001. The inclusion of the simulated soil C loss from harvesting had no discernable effect on the magazine chain because the absolute increase in CO_2 emission was small compared to other GHG emission sources, and only a small fraction of the annual GHG emission was attributed to the magazine chain. The fraction of the total annual emission from harvesting would increase from 2% to 4% if the additional harvest-induced CO_2 loss were included in the dimensional lumber chain. The 2001 estimates of GHG emissions immediately following harvest are based on the assumptions that the forest is managed on a sustainable basis and is comprised of

similar-sized trees for each age-class. These assumptions may not be valid for the mature Chetwynd forest that is undergoing the transition from predominantly a mature, even-aged forest to a managed forest. More studies are needed to quantify the effect of harvesting on soil C dynamics; however, it appears that our assumption that harvesting did not affect soil C had little impact on the C shadows of the two forest product chains, and thus on the overall conclusions of this study.

The final fate of unrecovered magazine and waste dimensional lumber can potentially have a large effect on the net GHG shadow of the magazine and dimensional lumber chains. However, few data are available that quantify the final fate (e.g. incineration for energy, incineration, recycled, or landfilled) of waste in the magazine and dimensional lumber chains (Skog and Nicholson 2000). Current estimates suggest 80-90% of unrecovered magazines in the U.S. and Europe are placed in landfills (Paper Task Force 1995, Denison 1996).

Opportunities for Reducing GHG Emissions

There are many opportunities to reduce GHG emissions in the magazine and dimensional lumber chains (Table 3). The socioeconomic and cultural constraints on the changes should be considered, but were beyond the scope of this project and the expertise of the authors. The list in Table 3 is not exhaustive, but illustrative of the opportunities that exist. General areas of

opportunity include harvesting, transportation of raw material to mill, mill efficiency, printer efficiency (magazine chain only), transportation of finished product to consumer and final fate/recycling. Another potential joint opportunity for society, which is beyond the scope of this study, involves purchased electrical power generation utilizing green or carbon-neutral energy sources and improving electrical power generation plant efficiency. Socioeconomic and cultural attitudes will need to drive these changes.

Improved efficiency of harvesting equipment would decrease GHG emissions, but harvesting comprised less than 2% of the total emissions for magazine and dimensional lumber chains. Therefore, this opportunity area is not an immediate high priority for decreasing GHG emissions.

Transportation of wood fiber from forest to mill is a significant cost to the forest industry (Gordon and Foran 1980). Transportation distances (and costs) will likely increase because the forest landscape is becoming more fragmented, and the demand for paper and wood products continues to increase (Parker 1995). GHG emissions from transportation of wood fiber to the mills comprised 7% and 3% of the total life cycle emissions for the magazine chain (*Time* and *InStyle*), but only a small percentage (2%) of the total emissions for the dimensional lumber chain. The large difference between the two chains is explained by the close proximity of the Chetwynd forest to the

sawmill versus the large fiber procurement region for the magazine chain (Figure 3-6). Conversely, the GHG emissions from the transportation of the final product to the consumer comprised 94% of the total emissions for the dimensional lumber chain, but the sum of the GHG emissions to transport SENA paper to the printers and printed magazines to the consumers comprised only 9% and 6% of the total GHG emissions for *Time* and *InStyle*, respectively. Clearly there are tradeoffs between having the wood fiber source closer to the mill versus having the mill closer to the greatest density of consumers.

Opportunities to decrease transportation costs and their associated GHG emissions include increased use of rail versus trucks, decreased transportation distances for of wood fiber going from the forest to mills, improved fuel efficiency of trucks, and decreased empty return loads. Transportation of wood fiber by rail emits less GHG than by truck based on the LCA boundaries we defined for this study. However, a complete life-cycle analysis of trains plus rail system versus trucks and highways would be required. Some opportunities to reduce GHG emissions may have undesirable economic or other ecological consequences.

Establishing intensively-managed high production plantations located close to mills is another possible option to minimize transportation costs, and associated GHG emissions, but there are potential adverse indirect effects that should be

avoided. Presently, forest plantations constitute only about 3.5-4% of the total world forest area (FAO 2001, Brown 1998). Plantations provide timber at lower production costs, a greater fraction of merchantable species, and greater accessibility than most natural forests. Some scientists also advocate plantation forestry because it provides an alternative source of fiber that reduces the pressure on existing native forests and facilitates forest conservation (Sedjo 1994, Sohngen et al. 1999). This assertion is only true if plantations are not the cause of natural forest clearing (e.g. Amacher et al. 1998, Coleman 1998). Plantation forestry must be demonstrated to be sustainable with little or no adverse effects on soil and water quality, long-term site productivity, and social benefits (Hopmans et al. 1998).

GHG emissions from vehicles transporting products are considered "indirect" if the vehicles are not owned by the company that manufactured the product (WRI/WBSCD 2001), as was the case for almost all the transportation in the magazine and dimensional lumber chains. Opportunities to decrease indirect emissions are more challenging because companies producing the products do not directly control many management decisions that affect transportation emissions. The forest product industry may not be able to reduce GHG emissions directly; however, cooperative efforts to use rail may offer a viable opportunity.

Pulp and paper production was the largest source for GHG emissions for the magazine chain, averaging 69% of the

total emissions for the two magazines. The pulp and paper industry is the fifth largest consumer of energy in the world (PPI 1996) and one of the largest consumers of energy in the U.S. (Gilbreath 1995, cited in Ruth and Harrington 1998). Reducing the GHG from pulp and paper production is a high opportunity area because of its large energy requirements. Potential opportunities to reduce GHG emissions include increased mill efficiency, greater energy self-sufficiency, greater use of biofuels for energy generation, and optimization of fiber sources. The first three opportunity areas are relatively straight-forward but may require moderate to substantial capital investment in more recent technologies. American Forest and Paper Association's Agenda 2020 called for a 12% reduction in GHG emission intensity by 2012 from the base year, 2000. (AFPA 2003). Energy analysis studies have suggested that energy efficiency of mills could be increased by as much as 30-50% above 1988 levels, which implies an average annual reduction in energy of 1.4-2.2% Btu per product ton (Energetics 1990).

The optimization of fiber resources is complex because different pulping processes, which differ in energy requirements, material efficiencies, and paper characteristics (i.e. brightness, strength, and opacity), are used to manufacture wood into pulp – the primary material used to make paper. The fiber used to produce paper is supplied by virgin fiber (e.g. wood) and recycled paper products. The kraft, or chemical pulping process--

used at the SENA Wisconsin Rapids Pulp Mill and Canfor Intercon Pulp Mill--requires very little purchased power because almost all (> 94%) of the required energy is derived from steam and electricity that is produced at the mill by the combustion of woodwaste in power boilers and black liquor (a by-product of kraft pulping of virgin fiber) in recovery boilers.

Mechanical pulping processes, such as groundwood and thermo mechanical pulping, used at the integrated pulp and paper Biron Mill and Whiting Mill require large quantities of energy because mechanical pulping does not generate chemical by-products that can be burned to produce steam and electricity. The energy requirements are approximately two times greater for thermo mechanical than groundwood pulp. However, the pulping yield coefficient (the fraction of paper produced per ton of wood fiber consumed) is greater for mechanical pulping (greater than 0.80, and often in the 0.90-0.95 range) than for kraft pulping (0.40-0.65) because the kraft processes extracts the lignin and other components (Ruth and Harrington 1998).

The pulp and paper industry uses mixtures of pulp (kraft and mechanical) and recycled fiber to produce products with both the *required* paper characteristics and those characteristics *desired* by consumers. For example, kraft pulp has greater strength and durability characteristics required for printing and writing paper and for packaging and construction board products. The choice of pulp source directly or indirectly affects forest

biodiversity, fiber conservation, energy conservation and the use of biomass for fossil fuel substitution.

Policy makers, pulp and paper industry managers, and society are confronted with trade-offs between pulping processes (kraft versus mechanical) and fiber source (virgin fiber versus recycled paper) that have numerous, complex implications on net energy consumption. We could not fully address the issue of what mixtures of kraft, groundwood and thermo mechanical pulp produce paper with the smallest C shadow because multiple transportation variables (transportation distance, mode of transportation, species mixture, etc.) co-varied with the pulping process, and the pulp could not always be tracked back to the exact fiber source.

The net emissions of the magazine and dimensional lumber chains are extremely dependent upon on the final fate (whether landfilled, incinerated, or recycled) of the end product (Pingoud et al. 1996, Wernick et al. 1998). Carbon storage was greater when paper waste was placed in landfills than incinerated (not for energy); however, disposing of paper waste into landfills is not sustainable, nor is it endorsed by the participants of this study. Placing paper and wood wastes in landfills is an effective practice to sequester carbon because only 6% and 18% of the total carbon content of each product is released back to the atmosphere. There are several key environmental concerns that override any carbon sequestration considerations. Six of eight

environmental comparisons concluded that recycling paper is preferable to landfill disposal for a variety of environmental and public health concerns (Grieg-Gran et al. 1998). Denison (1996) reviewed environmental life cycles of recycling, landfilling and incineration for energy and concluded that production of paper using recycled fiber (versus virgin fiber) and recycling had lower solid waste output, energy use, and air emissions than landfilling or incineration. These data suggest society can play a major role in reducing GHG emissions of paper chains by promoting and adopting aggressive recycling programs. The net emissions for the dimensional lumber chain are extremely sensitive to assumptions about the final fate of dimensional lumber (Figure 8), and illustrate the opportunity of recovery and re-use to reduce the GHG shadow of dimensional lumber.

Recovered OMG could also be used as biofuel to reduce the dependence on fossil fuel or as a replacement for virgin pulp (Gaines and Stodolsky 1993, Gilbreadth 1995). However, the maximum energy content of paper and wood products cannot be realized because the materials contain moisture and other contaminants.

Pulp and paper mill biosolids, such as paper mill sludge and wood-fired boiler ash, are by-products of the papermaking industry and are produced in large quantities in the United States. In 1995 the U.S. pulp and paper industry produced 5.3×10^6 tons of paper mill biosolids and 2.5×10^6 tons of boiler ash (NCASI

1999). The wood products industry produces an additional 1.9 x 10^6 tons of boiler ash (Someshwar 1996). The amount of ash will increase if incineration of paper and wood products for energy increases in the future. The application of paper mill biosolids to forests may increase forest growth (Vance 1996). The application of wood ash to the soils of base-limited forests, especially northern hardwoods, often increases forest growth and vigor (Moore et al. 2000, Feldkirchner et al. 2002). Modifications to the pulp and paper production processes in recent years have decreased the concentrations of heavy metals in paper mill biosolids below harmful levels (Vance 1996, Camberato et al. 1997). Wood ash biowaste has low heavy metals concentrations and is therefore generally not a serious environmental concern (Vance 1996). Also, the application of paper mill biosolids to forest soils may increase long-term C storage in the soil. This management practice has not been studied to date, but fertilization does increase soil C storage (Johnson and Curtis 2001).

Future Research Direction

This LCA study provided a very detailed analysis of GHG emissions for two forest product chains. The next step toward fully understanding the GHG shadow and opportunities to reduce GHG emissions is to extend the temporal dimension of the study. The level of detail and analysis provided in this LCA study made

it extremely challenging to complete a temporal analysis with the same level of rigor. The implicit assumption of the analysis based on one year (2001) is that all C pools in the biological and industrial cycles are in steady state. This assumption is reasonable for one year. However, the validity of the assumption is less valid for time periods greater than one year because the mean residence times of C in the biological and industrial pools differ, the demand for paper and wood products continues to increase, and forest C sequestration changes during stand development (Gower et al. 1996, Gower 2003). Since 1910, 2.7 petagrams of carbon--an amount that is equivalent to 20% of the total C contained in forest trees in the U.S.--has accumulated in wood and paper products that are currently "in use" or buried in landfills, and the annual C accumulation rate is projected to increase from present day 61 Tg C yr^{-1}, to 74 Tg C yr^{-1} by 2040 (Skog and Nicholson 2000). The growing demand for wood and paper products and changes in disposal practices are the primary factors responsible for the increased rate of gross C accumulation in forest products. Wood and paper wastes were commonly disposed of in dumps and burned; however, open incineration was banned in 1986, and now waste is placed in landfills or recycled. The anaerobic conditions of landfills and the high lignin concentration of wood and paper products make forest products extremely resistant to decay. Studies are needed to quantify the final fate of discarded wood and paper products.

Life cycle analysis studies are needed for other wood and paper products, and in different geographic regions, to determine if GHG shadows differ among major paper and wood products, and if GHG shadows differ among geographic regions for a given product--and if so, why? This information could be used by forest industries to help decide which facilities should be improved, capacities increased, or locations of new facilities considered, based on the availability of clean purchased power. Adjusted emission factors to produce electricity vary by almost four–fold among the ten geographic regions in the U.S. (DOE 2002), and these differences would have a significant impact on the C shadow of paper products because of their large energy requirements.

Environmental burdens, such as the production of GHG, are an unavoidable by-product of the industrial forest C cycle. This LCA study focused on GHG and identified its sources for two forest products chains. This study also identified possible opportunities to reduce GHG emissions from the forest products chains, such as increased transportation and production efficiencies, increases in post-consumer recycling rates (paper and dimensional lumber), and decreased waste(s) throughout the product chain. Opportunities to improve the life-cycle of paper and wood products span the industrial sector, government forest management agencies, and consumers. However, opportunities to improve the biological and industrial C cycles must also consider

cultural, social, and economic factors. Society also has the opportunity to affect the GHG shadow of paper and wood product chains by determining the final fate of these paper and wood waste products. Forest products, energy, transportation, and waste management industries have the greatest understanding of and insight into their respective components of forest product chains, and scientists and policy makers must actively include members of these industries in future analyses and policy discussions.

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Table 1. Summary of Wood flow and greenhouse gas emissions for the Chetwynd Forest. All units are metric tons. Chetwynd Forest[1] is for all emissions and Chetwynd Forest[2] is pro-rated for only the fraction of wood going to the dimensional lumber chain. Values in shaded boxes are emissions associated with SENA's purchase of Intercon and other Canadian sources of kraft pulp for the magazine chain.

		Chetwynd Forest[1]			Chetwynd Forest[2]			
	Products	Emissions		Storage	Emissions		Storage	Net
Activity		C	CO_2-eq	C	C	CO_2-eq	C	
2001 WOOD	193,170							
HARVEST EMISSIONS								
road construction (10%)		322	1,182					
felling (37%)		1,153	4,229					
wood hauling (48%)		1,505	5,518					
reforestation (0%)								
support & sire preparation (5%)		131	482					
total (100%)		3,112	11,411		1,618	5,934		
transferred to magazine chain					436	1,598		
TRANSPORTATION TO SAWMILL		366	1,342		190	698		
transferred to magazine chain					51	188		
HARVEST + TRANSPORT. TOTAL		3,478	12,753		1,809	6,632		
HARVEST + TRANSPORT. TOTAL					487	1,786		
CHETWYND SAWMILL EMISSIONS								
renewable		110	401		57	209		
non-renewable		2,469	9,054		1,284	4,708		
purchased		110	401		57	209		
total		2,579	9,455		1,341	4,917		
transferred to magazine chain					361	1,324		
TRANSPORTATION OF CHIPS TO PULP MILL		298	1,091		87	318		
PULPMILL EMISSIONS								
Renewable		281,713	1,032,885					
Non-Renewable		18,542	67,950		9,642	35,334		
purchased electricity								
total		300,255	1,100,835					
transferred to magazine chain					5,411	19,828		
TRANSPORTATION OF HD D. LUMBER		63,409						
Square-edge (SE)	63,409			31,705				
Mill to HDDC/Reload		596	2,186		596	2,186		
HDDC to HD stores		34,364	126,013		34,364	126,013		
total transport emissions		34,960	128,199		34,960	128,199		
TRANSPORTATION OF OTHER D. LUMBER								
Dimensional lumber (nonHD)	100,954			50,477				
rail		15,531	56,952		15,531	56,952		
truck		7,211	26,444		7,211	26,444		
total transport emissions		22,742	83,396		22,742	83,396		
BY-PRODUCTS								
Sawdust pulp digestor	13,128			230				
Transportation		66	242		66	242		
wood waste burner	13,746							
Transportation		4	13		4	13		
incineration (assumed bioenergy - C neutral))								
trim blocks (TB)	1,654			1,654				
processing (assumed 5%)		82.7			83	303		
final fate (50:50 landfilled:incinerated)		876.62		777.38	877	3,215		
GRAND TOTAL LOSSES					61,881	223,247		
GRAND TOTAL ACCUM.					84,066	0		
[1]Disposal SE (100% land-filled)					66,812	241,036	77,251	10,439
[2]Disposal SE (75% land-filled: 25% incinerated)					87,357	315,157	57,938	-29,419
[3]Disposal SE (50% land-filled: 50% incinerated)					107,903	389,278	39,633	-68,270

Table 2. Tons of total 30 lb. weight paper (except where noted) used, tons used, tons of SENA paper used for *Time* or *InStyle*, and fraction of SENA, paper used for *Time* or *InStyle*, carbon dioxide equivalents (CO_2-eq) of emitted from each *Time* and *InStyle* printer, and printer emission SENA paper attributed to *Time* or *InStyle* printed on SENA paper. All units are metric tons.

	total 30 lb. weight paper used (tons)	total SENA 30 lb. weight paper used (tons)	SENA paper used for *Time* (tons)	Printer Emissions (t CO2-eq)	Printer Emissions attributed to *Time* or *InStyle* (t CO2-eq)
TIME					
Printer #1	24,342	7,894	2467	752	76
Printer #2	23,266	363	31	284	0.4
Printer #3	15,838	5,894	1678	489	57
Printer #4	17,836	13,575	3818	2411	516
Printer #5	23,824	22,190	6258	281	73
Printer #6 -30lb	1,393	730	273	168	32
Printer #6 -38lb	623	118	181		49
	117,399	50,647	14526		
INSTYLE					
Printer #1 (38#)	15,238	15,238	15,238	619	619
Printer #1 (40#)	7,301	7,301	7,301		
	22,539	22,539	22,539	619	619

Table 3. Possible opportunities to reduce GHG emissions for the magazine and dimensional lumber chains.

Product Chain	Possible Opportunities to reduce GHG emissions
Magazine chain	
harvesting	- fuel efficient harvesting equipment
transportation to mill	- increased use of rail - high production forest near mills - fuel efficient vehicles & no empty return loads
pulp & paper efficiency	- increased mill efficiency - greater energy self sufficiency -increased use of biomass for energy generation -optimization of fiber source(s)
transportation of paper to printer	- see "transportation to mill"
printer efficiency	- decreased printer emissions - lighter weight paper - reduced trim waste - decreased surplus magazine production
transportation of magazine to user	- see "transportation to mill"
final fate	- increased recycling -use of solid waste as energy source
Dimensional Lumber Chain	
harvesting	- fuel efficient harvesting equipment
transportation to mill	- increased use of rail - high production forest near mills - fuel efficient vehicles & no empty return loads
sawmill efficiency	- increased mill efficiency
transportation of lumber to consumer	- see "transportation to mill"
final fate	- increased recycling -use of solid waste as energy source

Figure 1. A conceptual diagram of the forest C cycle. The forest C cycle is comprised of a biological cycle (i.e. forest ecosystem) and an industrial cycle (i.e. forest products). Major components of the biological carbon cycle are: GPP = gross primary production, R_A = autotrophic respiration, NPP = net primary production, R_H = heterotrophic or microbial respiration, and R_R = root respiration. D = detritus, and H = harvest removal. From Gower 2003.

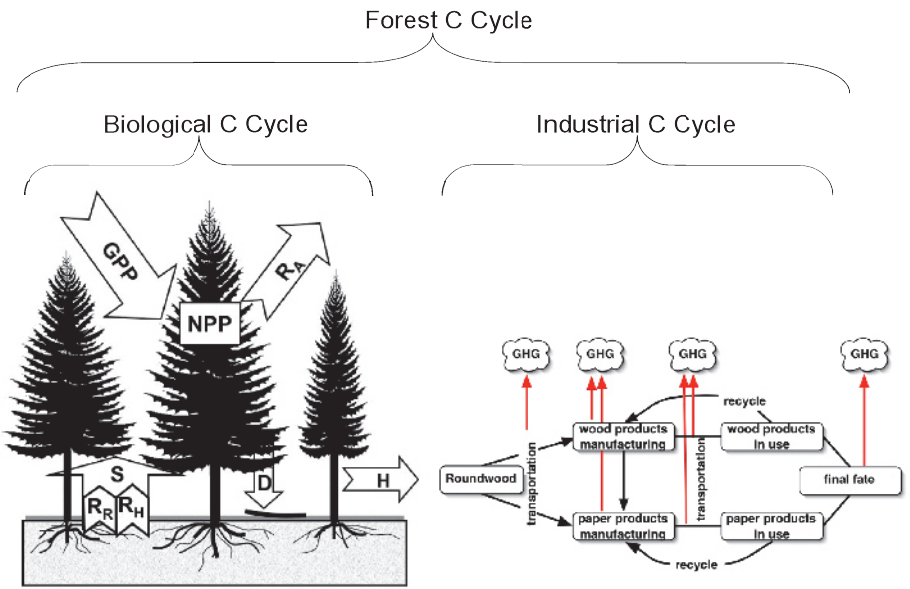


Figure 2. A schematic diagram illustrating the magazine and dimensional lumber chains examined in this study. The StoraEnso North America (SENA) fiber basket includes select forests in the Great Lakes region of the U.S. and Canada, and the Black Hills region in the U.S., that provide chips (Black Hills) and roundwood (Lake States only) for the StoraEnso. The Chetwynd Forest provides roundwood to the Chetwynd sawmill and chips to the Intercon pulp mill that provides pulp to SENA's Whiting paper mill. The SENA integrated pulp and paper mills also obtain an additional 22% of their annual kraft pulp from other Canadian pulp mills, and we assume that their chain is comparable to the Canfor pulp that we studied in this paper. SENA paper is tracked for a weekly magazine *(Time),* that is printed at six printers, and monthly magazine (InStyle), that is printed at one printer, both of which are produced by Time Inc. Dimensional wood from the Chetwynd Forest is tracked for Home Depot dimensional lumber and wholesale dimensional lumber, and waste products from the Chetwynd sawmill are tracked to their end fate. Solid lines represent fluxes that were measured by participants in the study and dashed lines depict fluxes that were estimated using industry-wide values.

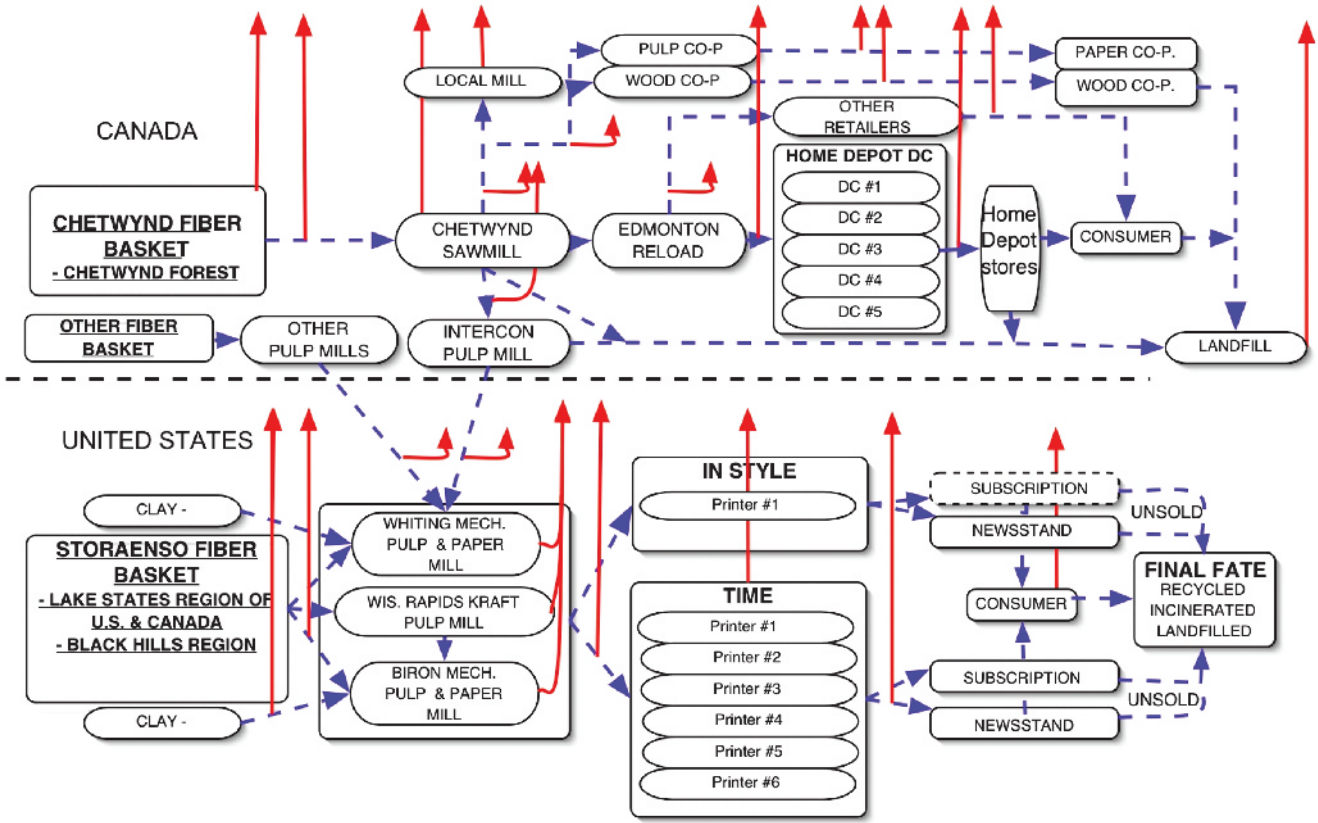

CANADA
CHETWYND FIBER BASKET
- CHETWYND FOREST
OTHER FIBER BASKET
OTHER PULP MILLS
LOCAL MILL
CHETWYND SAWMILL
INTERCON PULP MILL
PULP CO-P
WOOD CO-P
EDMONTON RELOAD
OTHER RETAILERS
HOME DEPOT DC
DC #1
DC #2
DC #3
DC #4
DC #5
Home Depot stores
PAPER CO-P.
WOOD CO-P.
CONSUMER
LANDFILL
UNITED STATES
CLAY -
STORAENSO FIBER BASKET
- LAKE STATES REGION OF U.S. & CANADA
- BLACK HILLS REGION
CLAY -
WHITING MECH. PULP & PAPER MILL
WIS. RAPIDS KRAFT PULP MILL
BIRON MECH. PULP & PAPER MILL
IN STYLE
Printer #1
TIME
Printer #1
Printer #2
Printer #3
Printer #4
Printer #5
Printer #6
SUBSCRIPTION
NEWSSTAND
UNSOLD
CONSUMER
FINAL FATE
RECYCLED
INCINERATED
LANDFILLED
SUBSCRIPTION
NEWSSTAND
UNSOLD

Figure 3. Wood fiber procurement region for the SENA Wisconsin Rapids Pulp Mill. The star denotes the location of the SENA Wisconsin Rapids Pulp Mill.

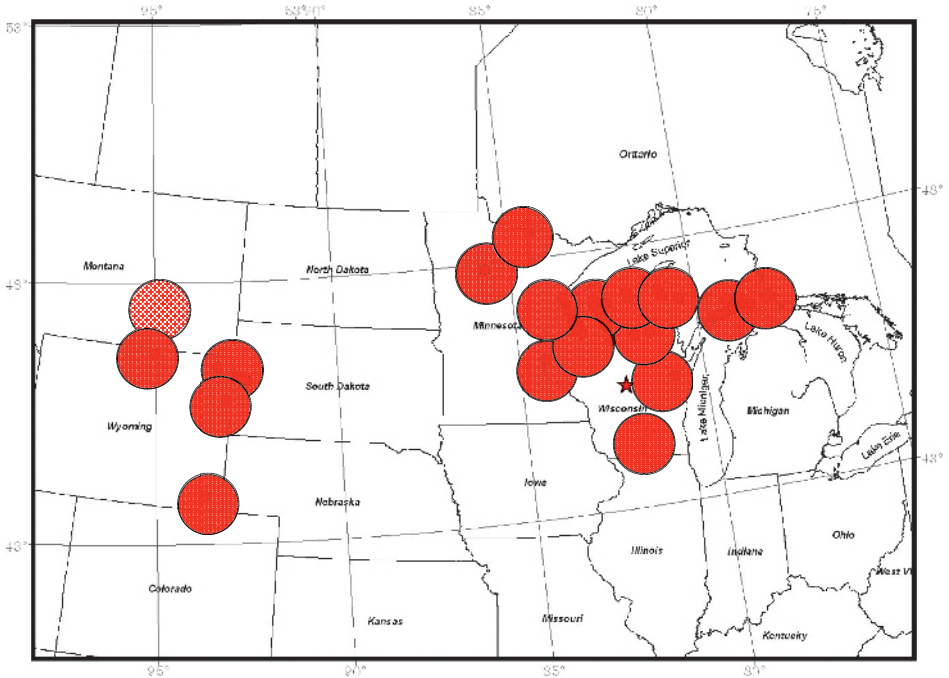


Figure 4. Wood fiber procurement region for the SENA integrated pulp and paper Whiting Mill. The star denotes the location of the SENA Whiting Mill.

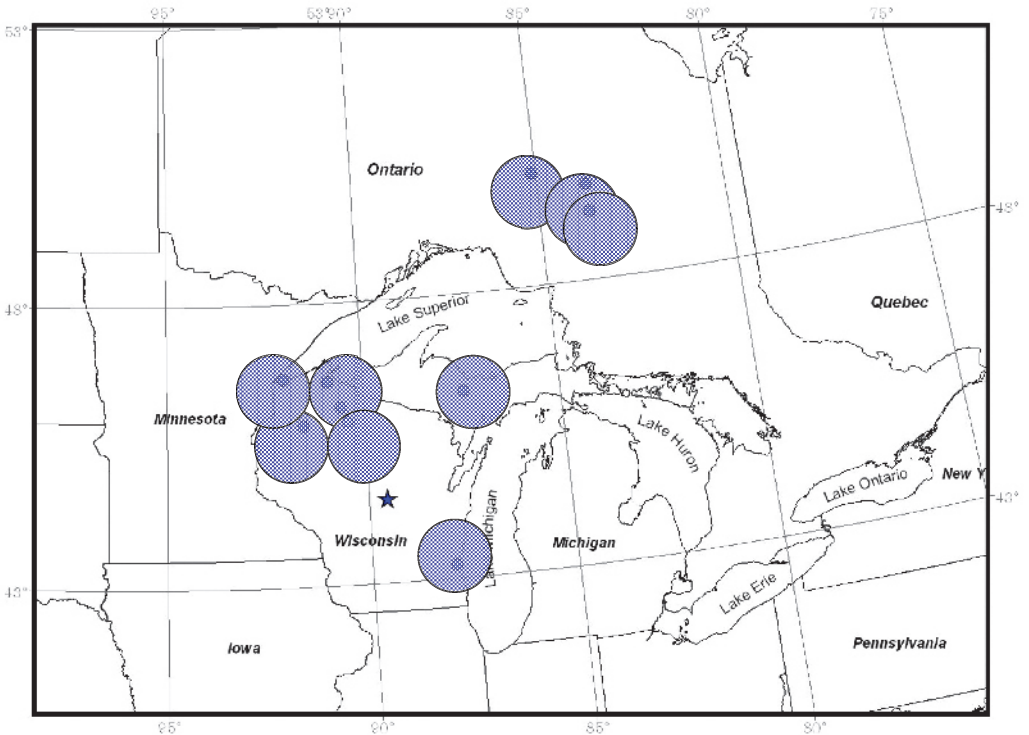


Figure 5. Wood fiber procurement region for the SENA integrated pulp and paper Biron Mill. The star denotes the location of the SENA Biron Mill.

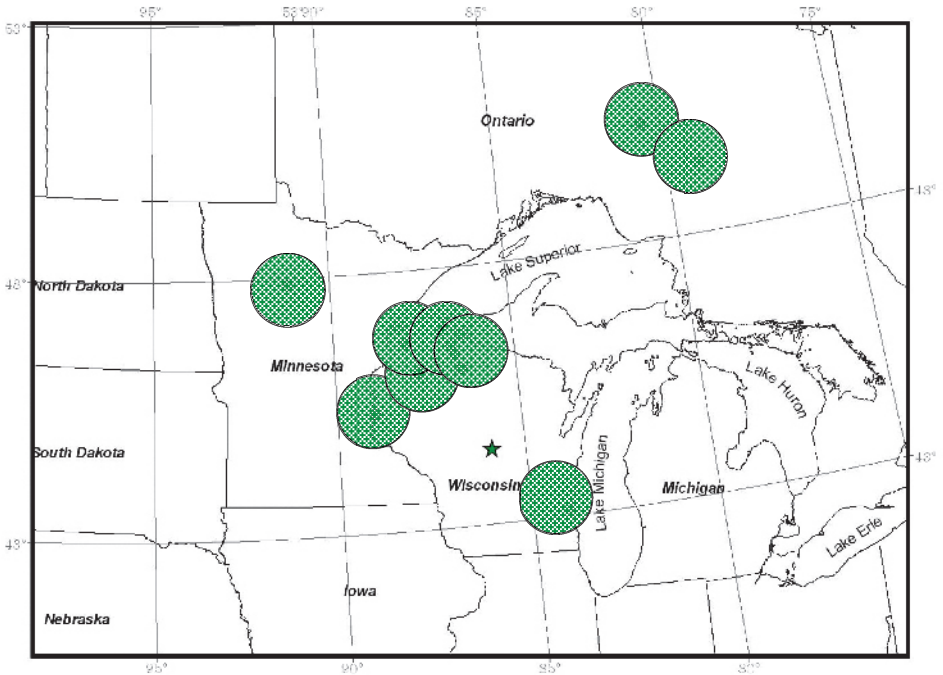


Figure 6. Map of the Chetwynd Forest, the fiber procurement region for Canfor.

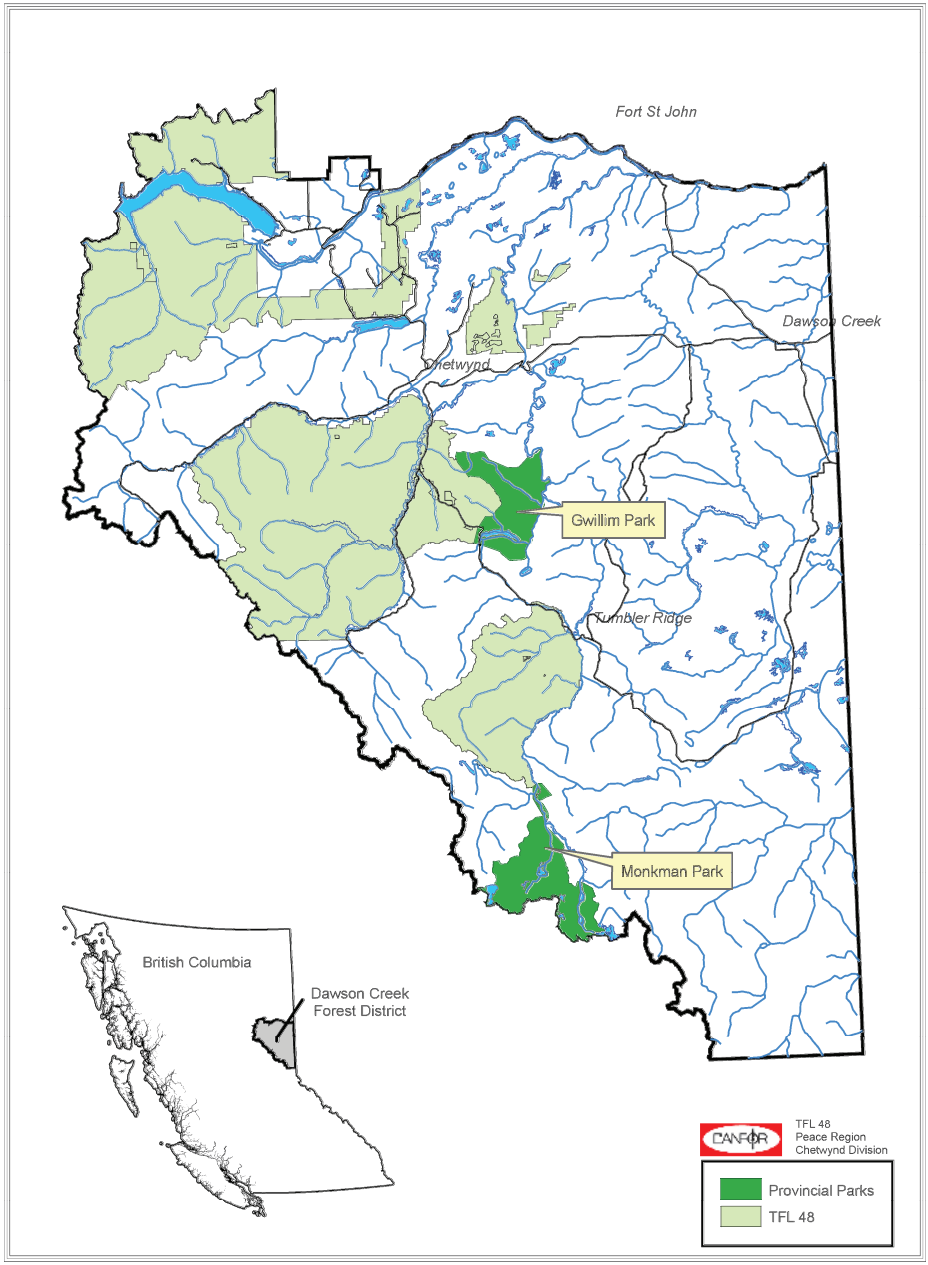


Figure 7. Fraction (upper panel) and absolute greenhouse gas emissions (expressed in CO_2 –eq/t lumber) for the major processes in the dimensional lumber chain. Abbreviations for the processes in the chain are: H = harvest, TM = transportation of wood fiber to the mill, ME = sawmill emissions, TC = transportation to consumer, and FF = final fate.

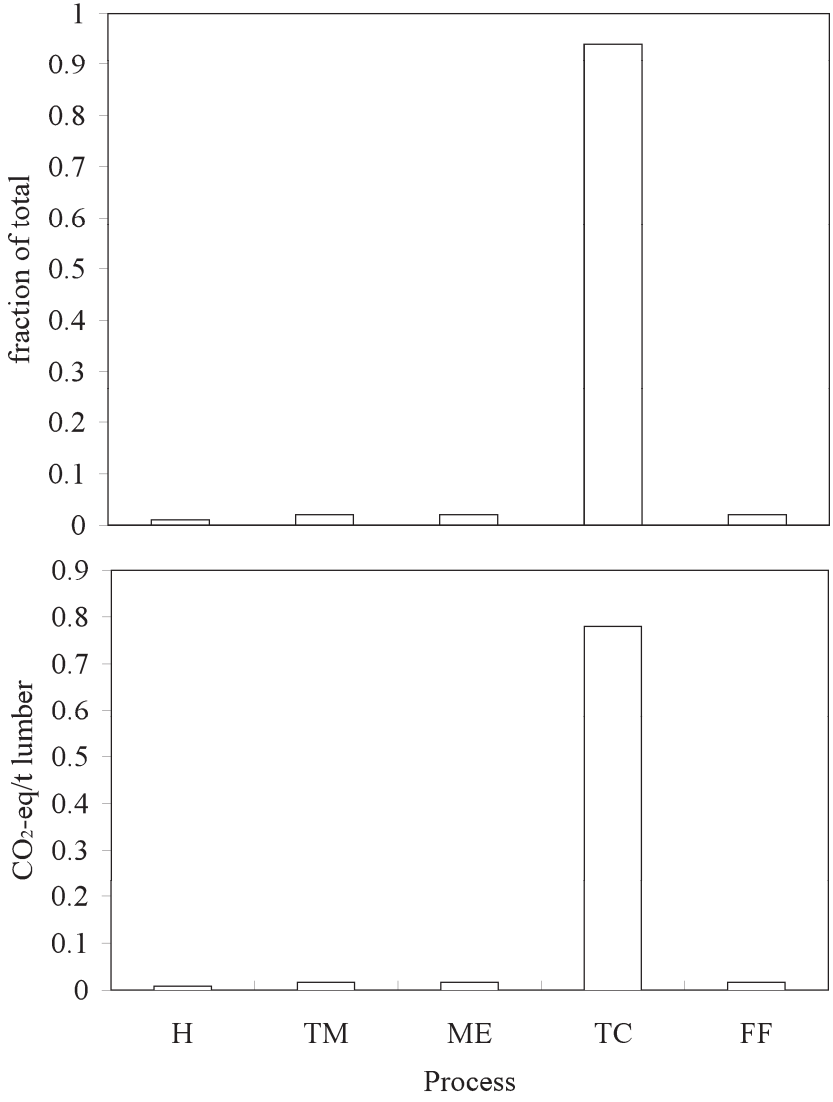


Figure 8. The effect of final fate on CO_2-eq emissions for the dimensional lumber chain. The X axis is the ratio of the dimensional lumber that is landfilled versus incinerated.

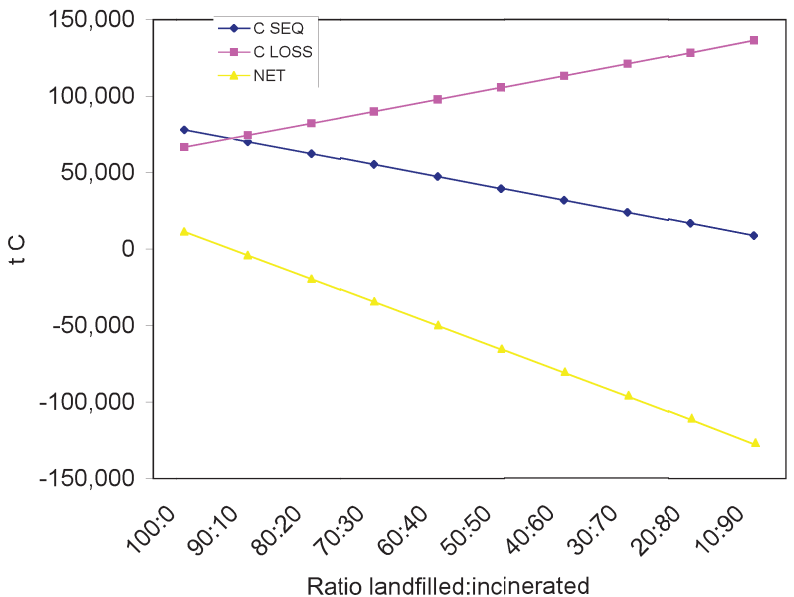


Figure 9. Schematic diagram illustrating the flow of wood fiber and associated CO_2-eq emissions from the SENA and Chetwynd wood fiber procurement regions to the Wisconsin Rapids Pulp Mill, Biron Mill, Whiting Paper Mills, and the Intercon (plus other Canadian kraft pulp mills that supplied kraft pulp to make SENA paper). (1) harvest, (2) transportation of wood and clay (second number for Biron Mill and Whiting Mill) to the pulp mills, (3) CO_2-eq emissions from pulp production (WRPM and Intercon + other Canadian kraft pulp) or pulp + paper (Biron Mill and Whiting Mill). Values in parentheses below box #2 depict CO_2-eq emissions from purchased power. (4) sawmill emissions credited to magazine chain. (5) Transportation emissions of Canadian kraft pulp to Whiting Mill. The two values reported for the Chetwynd forest are for the dimensional lumber and magazine chain, respectively.

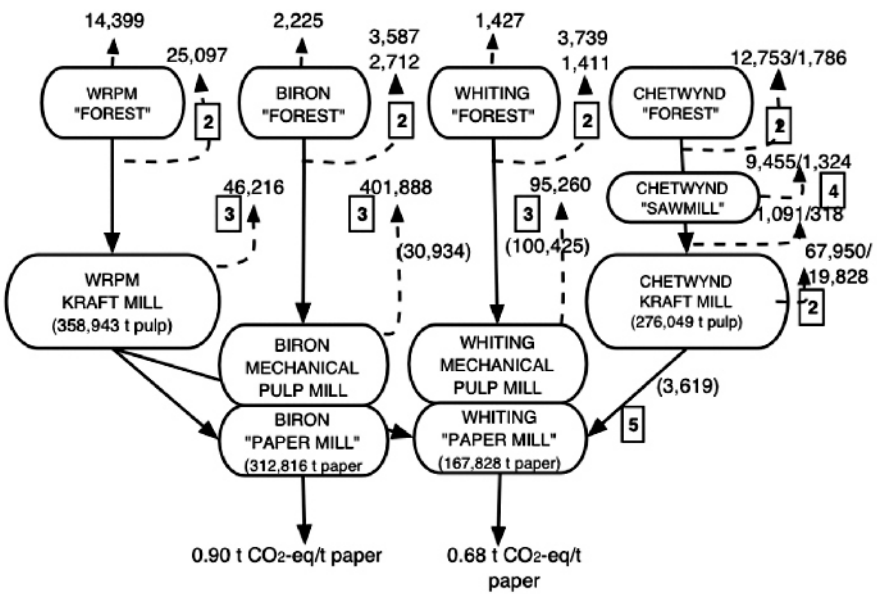


Figure 10. Summary of relative CO_2-eq (emissions per ton of wood) to transport wood from the SENA forests to the SENA mills. LTM = landing trucked to mill, TDM = truck delivered to mill, and RDM = rail delivered to mill.

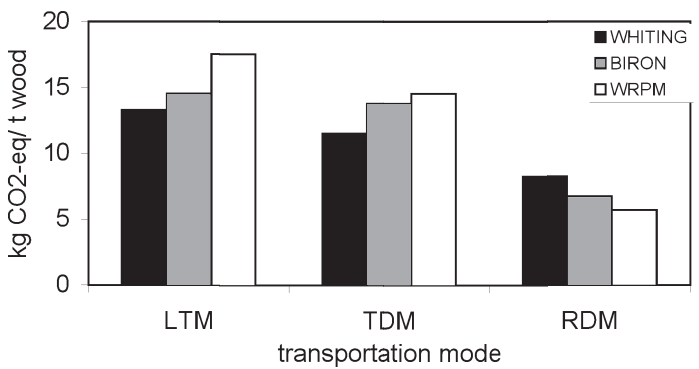


Figure 11. Relative and absolute CO_2 —eq emissions for *TIME* (striped bars) and *InStyle* (open bars) magazines. Analyses were restricted to 2001 because this was the most recent year that data for all the processes were available. Processes include management + harvest (H), transportation to mill (TM), mill emissions (ME), transportation of paper to printer (TP), printer emissions (PE), transportation to consumer (TC) and final fate (FF).

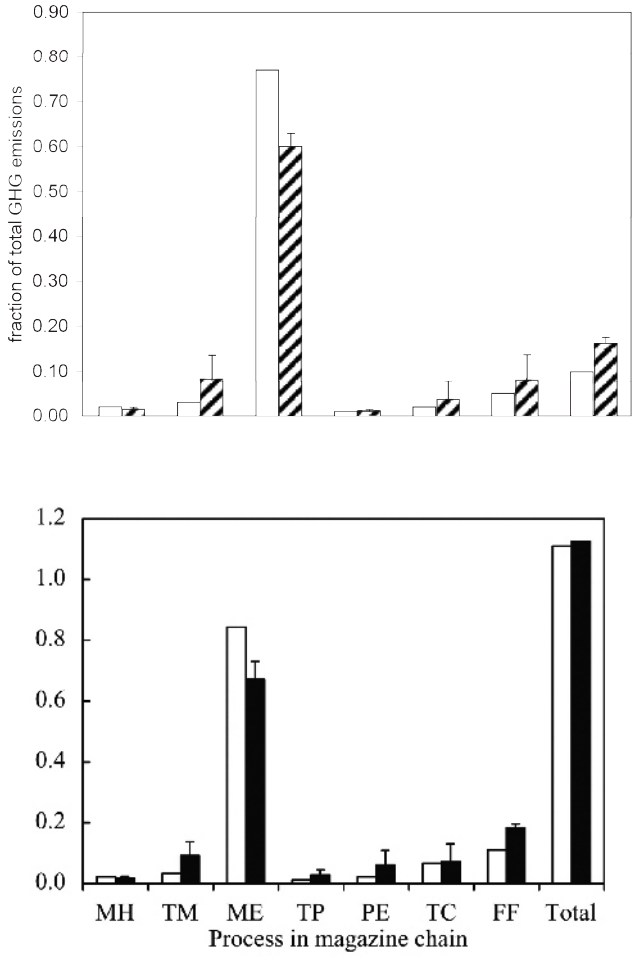


Figure 12. Annual CO_2-eq emissions for the four pulp and paper mills. Non-renewable (NR) emissions are derived rom the combustion of fossil fuel, and renewable emissions (R) are produced from the combustion of black liquor, a by-product of the kraft pulping process, and wood waste at the mill. Renewable and non-renewable definitions follow WRI/ WBCSD (2001).

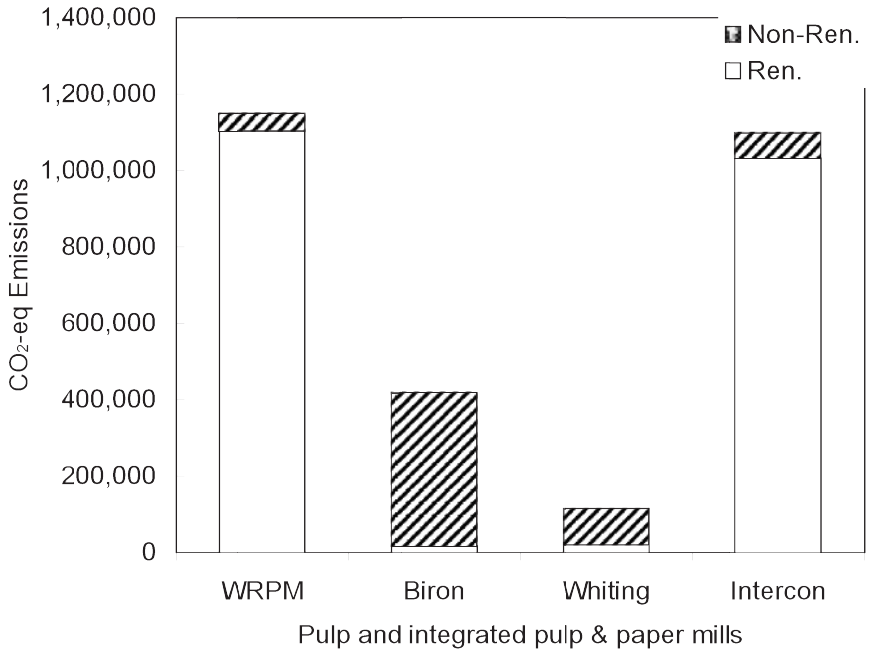


Figure 13. Annual production (tons), distribution, and final fate of *InStyle* magazines. Estimates were based on a 17% recovery of sold subscription and newsstand magazines and a 95% recovery of unsold newsstand magazines. *InStyle's* sell-through rate of newsstand magazines is 59%.

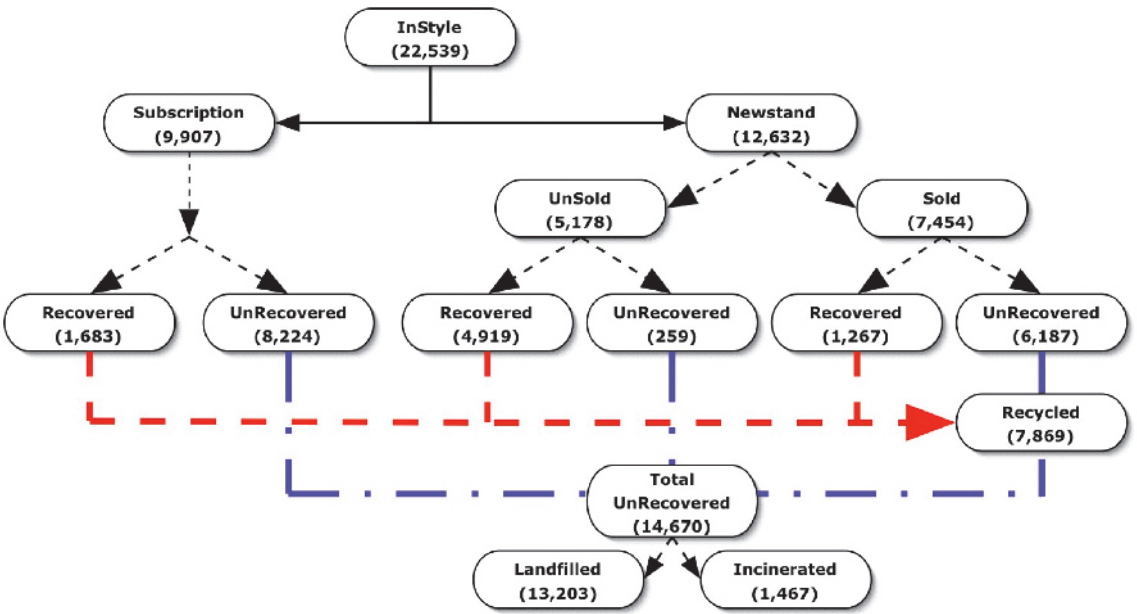


Figure 14. Annual production, distribution, and final fate of *Time* magazines. Estimates were based on 17% recovery of sold subscription and newsstand magazines and a 95% recovery of unsold newsstand magazines. *Time's* sell through rate of newsstand magazines was 35%.

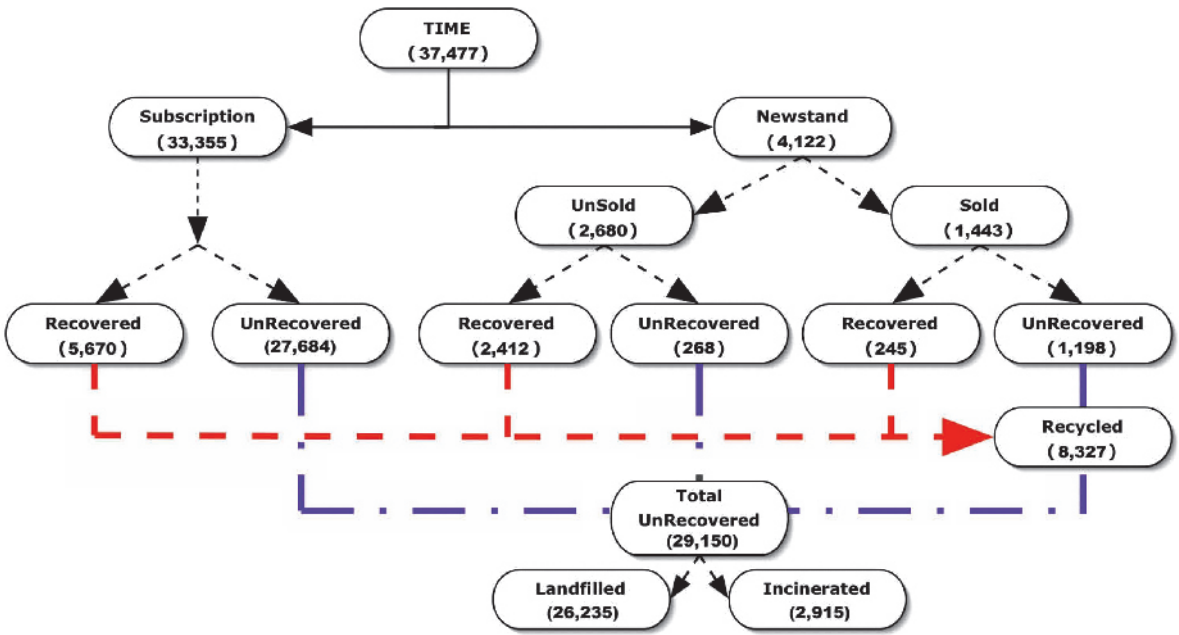


Figure 15. Summary of (a) net elemental C emission per ton of magazine and (b) CO_2-eq emissions per ton of magazine for *Time* and *InStyle*. GHG emissions were tracked through each of the six printer chains for *Time*.

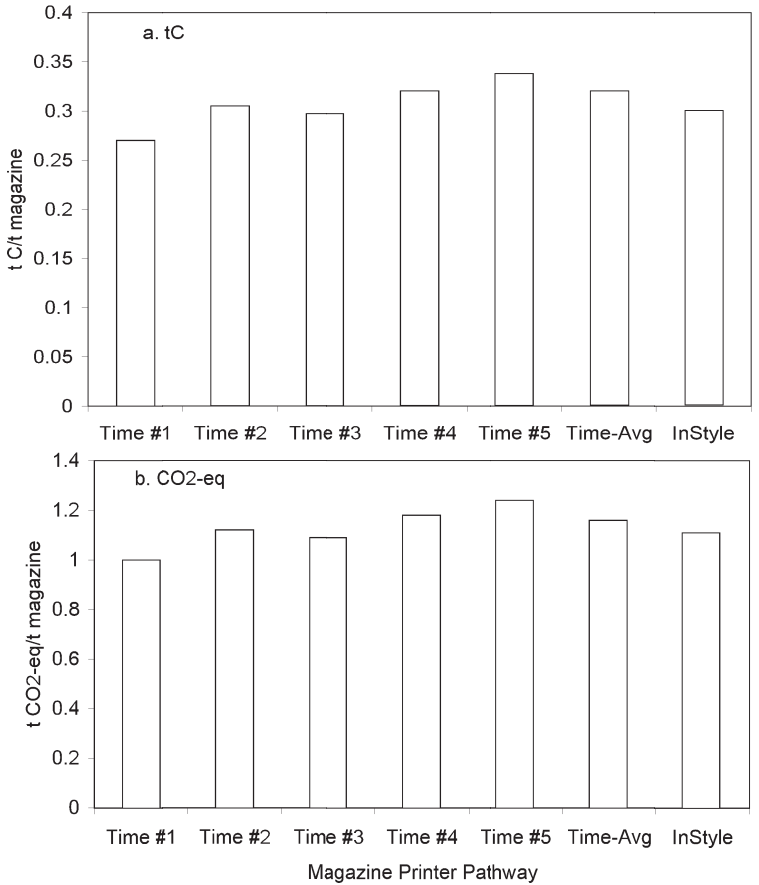
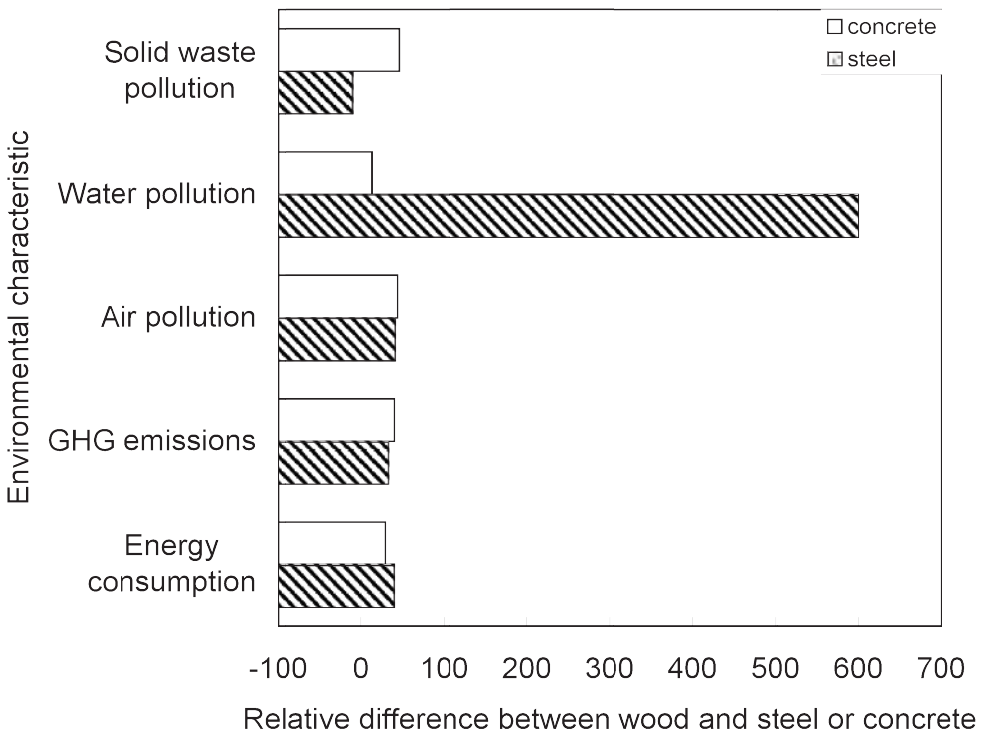


Figure 16. The relative differences of select environmental shadows for dimensional lumber versus steel or concrete for home construction. Adapted from CORRIM 2001.



Appendix 1. The Canadian National Standard on Sustainable Forest Management (CAN/CSA Z809)

Canada's National Standard on Sustainable Forest Management Standard, CAN/CSA Z809, was developed in response to heightened awareness about forest management practices. The Canadian Standards Association (CSA) is one of Canada's accredited standards development organizations.

Sustainable Forest Management (SFM) refers to the way a forest is managed to maintain and enhance the long-term health of forest ecosystems for current and future generations. This Standard, which utilizes a continual improvement approach, requires extensive public participation, practical demonstration of sustainable forest management practices, and management commitment. SFM takes into account environmental, social and economic factors. The Standard gives the community a voice in the way its forests are managed.

The CSA Standard required extensive public participation in its development. It was first published in 1996, following years of discussions and work through an open and inclusive process managed by the CSA. One quarter of the CSA SFM Technical Committee was comprised of forest producers, including woodlot owners, while the remainder were scientists, academics, and representatives from the provincial and federal governments, as well

as environmental, consumer, union, and aboriginal representatives. In the fall of 1995, special consultations with non-governmental and environmental organizations were conducted to allow input into the development of the standards.

Performance --The CSA Standard requires adherence at the local forest level to the best suite of broadly accepted Canadian forest values generated to date-that is, the Canadian Council of Forest Ministers set of sustainable forest management criteria.

For details see: http://www.certificationcanada.org/english/csa/

The criteria address many key aspects of forest management, including maintenance of biological diversity, forest ecosystem and productivity maintenance, soil and water protection, ecological cycles, benefits to society, and the rights of aboriginal forest communities. The CCFM criteria and elements are fully consistent with those of the Montréal and Helsinki processes, both of which are recognized by governments around the world.

Third-Party Independent Audit -- To become certified to the Standard, an organization must go through a third-party, independent audit of the SFM Requirements in the Standard. A registrar accredited by the Standards Council of Canada conducts the audit. In addition to the initial audit, there are mandatory annual reviews, which include both a document review as well as spot-checks in the field to ensure progress is being made towards the

achievement of objectives and that the SFM Requirements are upheld. In addition, a full re-registration audit is required every three years following the initial audit.

CSA at Canfor – All of the area-based tenures in which Canfor operates, including the Chetwynd Tree Farm Licence which this report tracks, have had their SFM plans certified under the CSA SFM Standard.

Appendix 2. Stora Enso and AF&PA Sustainable Forestry Initiative

Stora Enso in North America U.S. wood supply operations has followed the principles of the American Forest and Paper Association Sustainable Forestry Initiative® (SFI) since its inception in 1995. SFI is a comprehensive system of principles, objectives and performance measures that integrate perpetual growing and harvesting of trees with the protection of wildlife, plants, soil and water quality. Our forest management and wood procurement activities have been third-party certified to the SFI standard. Since most of our wood comes from lands we do not own, we recognize our responsibility to extend our commitment to sustainable forestry to our wood suppliers. We require logging contractors and contract holders to complete SFI core curriculum training. Internal audits are conducted annually of a random sample of our wood suppliers to provide assurance that the SFI standard is being followed in the field. For more information about SFI please link to http://www.aboutsfi.org. Our forestry management procurement operations have also implemented third-party certified ISO 14001 Environmental Management System. U.S. Wood Supply operations have been chain-of-custody certified to the Forest Stewardship Council© (FSC) standard. Stora Enso's Canadian forestlands located in Nova Scotia are certified to the ISO 14001 standard and to the Canadian Standards Association Sustainable Forest Management standard and the Sustainable Forestry Initiative®.

Appendix 3. Glossary.

Anthropogenic – produced from human activity.
By-product -- a commercially useful material that is not the primary product being produced in the manufacturing process of the chain. Also referred to as co-product.
Co-product -- see by-product.
Disposal -- discarding of raw materials, by-products, or final product without using being recycled or re-used.
Decomposition – Annual loss of carbon from the soil surface as a result of oxidation of detritus and soil components.
Detritus -- Sum of dead organic matter contained in the forest floor, downed coarse woody debris, and standing dead trees. Biomass will be converted to carbon content by multiplying forest floor organic matter content by 0.45 and woody detritus by 0.50 (Gower et al. 1999).
Forest Management Emissions – Greenhouse gases emitted to the atmosphere from forest establishment and management activities.
Fuel Cycle Emissions –emissions from all the steps in the use of a fuel, from production (extraction), and refining to distribution (transportation), and final use.
Greenhouse gases (GHG) -- Greenhouse gases include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). These gases trap outgoing longwave radiation near the surface of the Earth and warm the air. GHG are commonly compared on the basis of their calculated potential to cause global warming. Global Warming Potentials (GWPs) have been developed to convert non- CO_2 greenhouse gases (GHG) into an amount of CO_2 of equivalent warming potential (NCASI 2002). Methane (CH_4) and nitrous oxide (N_2O) were multiplied by 21 and 310 to account for their greater GHG-forcing potential than carbon dioxide (CO_2) (IPCC 1996).
Harvest Emissions (CH) – Emission of GHG to the atmosphere from all mechanized equipment used to harvest and transport logs to the primary logging deck.
Harvest Residue – Carbon content of logging waste (foliage, branches, cull trees, fine and coarse roots) left on site following harvest.

Landfill Accumulation -- Carbon accumulated in the soil because of incomplete decomposition of waste disposed into landfills.
Landfill Emissions -- GHG emitted to the atmosphere from decomposition of waste disposed into landfills.
Litterfall – Annual transfer of litterfall (leaf, fine and coarse woody debris and fine root turnover) from vegetation to detritus. Biomass will be converted to carbon using coefficients described for Vegetation.
Non-renewable energy -- energy derived from a non-natural resource such as fossil fuel.
Post-consumer solid waste -- material that has been discarded and becomes part of the waste stream.
Renewable energy -- energy derived from a natural resource, or by-product of a natural resource.
Site Preparation – forest management practices of preparing the site for natural regeneration or hand or mechanized planting. Examples of site preparation include piling or windrowing harvest debris, burning debris, disking, and bedding.
Soil Carbon – Carbon content of surface litter, or forest floor, and mineral soil to a depth of 1 meter or maximum depth, depending upon data availability.
Transportation Emissions – GHG emitted to the atmosphere from the transportation of wood fiber to mills and transportation of finished product to consumers.
Vegetation – All above- and belowground tissues of the live overstory and understory. Biomass converted to carbon content by multiplying foliage and fine root biomass by 0.45 and other woody tissue (stem, branches and coarse roots) by 0.50 (Gower et al. 1999).

Appendix 4. Calculation of CO_2-eq emissions associated with the transportation of recovered OMG to final fate as newsprint.

Recovered OMG is commonly recycled to make newsprint. Trucks, trains, and ships are used to transport recycled magazines. Approximately 71% of the total OMG recycling market is domestic, and the OMG is transported to newsprint mills by diesel truck (90%) and train (10%). Average transportation distances (weighted by percent mass by each mode of transportation) of OMG by diesel trucks and rail for domestic markets were assumed to be 520 and 640 km, respectively. These distances would double if trucks and trains returned empty. The average emission was 54.37 kg CO_2 per ton OMG. Accounting for emissions of CH_4 and N_2O, and their respective effectiveness as a greenhouse gas, total emission was 55.02 kg CO_2-eq per ton OMG.

Approximately 29% of the total recovered OMG is sold to newsprint mills in Korea and China. On average, 25% and 45% of the OMG were trucked 120 km and 640 km, respectively, with the balance (30%) transported minimal distances to ports. OMG sold overseas is shipped on vessels that burn bunker grade C fuel. Ships originating from the east are 4,000 twenty equivalent units (TEU = 20 ft container) size. Ships originating from the west coast are 5,000 TEU size. An additional 30% of OMG is transported by rail 3,250 km to coastal ports. Diesel fuel emissions were estimated as the product of fuel efficiency, distance traveled, and fuel- and engine-specific CO_2-eq emissions per unit of fuel combusted. Transporting

OMG overseas required on average 380 km of truck transportation and 3,296 km of train transportation to ports on the east and west coasts, an average of 12,605 km transportation by 4,000 and 5,000 TEU size vessels, and 120 km truck transportation to a newsprint mill. CO_2 transportation emissions to international markets were 81.11 kg CO_2 per ton OMG, or 82.07 CO_2-eq per ton OMG.

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