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NATIONAL COUNCIL FOR AIR AND STREAM IMPROVEMENT

AN ANALYSIS OF THE METHODS USED TO ADDRESS THE CARBON CYCLE IN WOOD AND PAPER PRODUCT LCA STUDIES

SPECIAL REPORT NO. 04-03

AUGUST 2004

by
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PRESIDENT'S NOTE

A variety of tools have been used to examine the potential greenhouse gas implications of public policy and purchasing decisions involving forest products. Of the available tools, life cycle assessment (LCA) is perhaps the best suited for examining overall effects along the value chain.

A recent series of NCASI studies have demonstrated the importance of carbon sequestration to the forest products industry. Of particular note have been the findings regarding the large amounts of carbon sequestered in forest products during use and in landfills. Given the importance of carbon sequestration to this industry, and the growing role of LCA in examining greenhouse gas issues, it is important to document the methods being used in LCAs that characterize carbon sequestration, especially those addressing forest products in use and in landfills.

NCASI retained Franklin Associates, Ltd. to collect and review the recent LCA literature to determine the methods being used to characterize carbon sequestration and to discover whether a common set of methods was being used in LCA studies. The review was global in scope and covered the literature published since 1990. Relatively few LCAs were found that specifically address carbon sequestration in products in use and in landfills. Thirteen studies were selected for detailed review because they addressed carbon sequestration or landfill emissions attributable to forest products.

This review confirms that there are no broadly used or generally accepted methods for characterizing carbon sequestration in LCA studies. Methods are generally specific to each study and are developed by the organizations performing the studies. Products in landfills, or at least the methane emissions from these products, are included in LCA studies more often than products in use. Methods for characterizing the fate of carbon in landfills are usually based on methods developed for estimating landfill gas generation but the specific parameter values and assumptions vary greatly from one LCA study to the next. Especially needed, however, are methods for characterizing carbon sequestration in products as this aspect of the forest products value chain is almost universally ignored in the LCA studies currently underway.

This work was funded, in part, by the International Council of Forest and Paper Associations (ICFPA) under a project intended to identify methods for characterizing carbon sequestration along the post-manufacturing portion of the value chain. The results of the ICFPA project have been released by NCASI[1]. Included in the ICFPA project report is a recommended method for characterizing carbon sequestration in products in use that could be used in future LCA studies.

Ronald A. Yeske

August 2004

[1] See *Characterizing Carbon Sequestration in Forest Products along the Value Chain*. NCASI report to ICFPA. December 26, 2003. http://www.ncasi.org/publications/Detail.aspx?id=2625

MOT DU PRÉSIDENT

En matière de gaz à effet de serre, de nombreux outils ont servi à évaluer les conséquences possibles des politiques gouvernementales et des décisions relatives à l'achat de produits forestiers. Parmi tous les outils disponibles, l'analyse du cycle de vie (ACV) est probablement celui qui convient le mieux à un examen global des effets sur toute la chaîne de valeur.

De récentes études effectuées par NCASI démontrent que la séquestration du carbone joue un rôle majeur dans la détermination du profil des gaz à effet de serre de la chaîne de valeur de l'industrie des produits forestiers. Les conclusions portant sur les énormes quantités de carbone séquestrées dans les produits forestiers en cours d'utilisation et enfouis sont particulièrement intéressantes. L'importance de la séquestration du carbone pour cette industrie et le rôle croissant de l'ACV comme outil d'évaluation des enjeux liés aux gaz à effet de serre ont conduit NCASI à documenter les méthodes d'ACV utilisées pour caractériser la séquestration du carbone, notamment dans les produits forestiers en cours d'utilisation ou enfouis.

NCASI a retenu les services de Franklin Associates, Ltd. pour recueillir et examiner les documents récents en matière d'ACV dans le but d'identifier les méthodes servant à caractériser la séquestration du carbone et de déterminer s'il existe des méthodes communes à l'ensemble des études d'ACV. NCASI a demandé au consultant de réaliser une revue globale de la littérature publiée depuis 1990. Le consultant a trouvé peu d'ACV traitant de séquestration du carbone dans les produits, en particulier dans les produits en cours d'utilisation ou ceux dans les sites d'enfouissement. Treize études ont fait l'objet d'une évaluation détaillée parce qu'elles traitaient de séquestration du carbone ou d'émissions liées à des sites d'enfouissement attribuables aux produits forestiers.

La présente étude confirme qu'il n'existe pas de méthodes couramment utilisées ou généralement reconnues pour caractériser la séquestration du carbone dans les études d'ACV. Habituellement, chaque étude fait appel à sa propre méthode élaborée par l'organisation qui effectue l'étude. Dans les études d'ACV, on traite plus souvent du carbone dans les produits enfouis (ou au moins des émissions de méthane liées à ces produits) que du carbone dans les produits en cours d'utilisation. Les méthodes de caractérisation du devenir du carbone dans les sites d'enfouissement découlent habituellement des méthodes d'estimation des gaz émis par ces sites. Toutefois, la valeur des paramètres et les hypothèses de départ varient beaucoup d'une étude d'ACV à l'autre. Il existe un besoin évident pour des méthodes pouvant caractériser la séquestration du carbone dans les produits car cet aspect est presque entièrement négligé dans les études d'ACV présentement en cours.

L'International Council of Forest and Paper Associations (ICFPA) a financé une partie de cette étude dans le cadre d'un projet ayant pour objectif l'identification de méthodes de caractérisation de la séquestration du carbone dans le segment postfabrication de la chaîne de valeur. NCASI a publié les résultats du projet de l'ICFPA[1]. Dans le rapport, on y décrit une méthode de caractérisation de la séquestration du carbone dans les produits en cours d'utilisation pouvant servir dans de futures d'études sur l'ACV.

Ronald A. Yeske

Août 2004

[1] Voir *Characterizing Carbon Sequestration in Forest Products along the Value Chain*. Rapport de NCASI soumis à l'ICFPA. 2 décembre 2003. http://www.ncasi.org/publications/Detail.aspx?id=2625

AN ANALYSIS OF THE METHODS USED TO ADDRESS THE CARBON CYCLE IN WOOD AND PAPER PRODUCT LCA STUDIES

SPECIAL REPORT NO. 04-03
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ABSTRACT

An extensive worldwide literature search was conducted to find Life Cycle Inventory (LCI) and Life Cycle Assessment (LCA) studies that considered the carbon cycle for wood or paper products in the use and end of life stages. The principal issues of interest were how the fate of carbon was evaluated during the product use phase and end of life in landfills, including methane emissions from landfills.

Sixty-six LCAs have been identified on wood and paper products. Most of these do not address carbon flow issues throughout the entire life cycle, but focus instead on other environmental parameters usually included in life cycle studies. Where biomass carbon is addressed, it is usually only in the context of carbon taken from the atmosphere and fixed into trees. Carbon sequestered in products and methane emissions from landfills are ignored in most studies, although many more studies address methane emissions than address carbon sequestration in products and landfills. Where biomass carbon is included it is usually, but not always, considered “global warming neutral.”

Of the 66 LCA studies, 13 were selected for in-depth review. Many of these presented clear statements on how product use and end-of-life carbon storage and carbon dioxide and methane releases were handled, but most of these lacked good data support. Many of the authors used very simple assumptions and cited the lack of good data or methodology. Typical assumptions for landfills were that all organic products decay in landfills, or no organic products decay in landfills, or some fraction decays in landfills. There was little uniformity in assumptions on methane emissions and recovery, with only studies for the United States Environmental Protection Agency (EPA) and a German company—IFEU—citing actual measurements.

Carbon sequestration in products in use or in landfills was usually not addressed, or was addressed via simplifying assumptions, e.g., that wood products permanently sequester carbon. Data from EPA, Dr. Morton Barlaz at North Carolina State University, and the German company IFEU were cited in several cases. Even where the reports were comprehensive, the methodologies for carbon flows and sequestration varied significantly.

The report cites 11 references (at the end of Appendix A) that provide useful background on how to develop carbon cycle data for LCAs. In addition, ISO/TR 14047 –published in the fall of 2003 –gives in “Example 3” a number of ideas for carbon cycle LCA methods for harvested wood products. Although carbon sequestration is receiving significant attention as an option for controlling atmospheric CO_2 levels, there is no uniform peer-reviewed methodology for characterizing sequestration in the ISO standards, nor has one been adopted by LCA practitioners.

KEYWORDS

carbon, climate change, greenhouse gases, landfills, life cycle assessment, life cycle inventories, methane, paper products, wood products

RELATED NCASI PUBLICATIONS

Technical Bulletin No. 872 (March 2004). *Critical Review of Forest Products Decomposition in Municipal Solid Waste Landfills*

Characterizing Carbon Sequestration in Forest Products along the Value Chain. NCASI report to the International Council of Forest and Paper Associations. December 26, 2003. http://www.ncasi.org/publications/Detail.aspx?id=2625

UNE ANALYSE DES MÉTHODES UTILISÉES POUR EXAMINER LE CYCLE DU CARBONE DANS LES ÉTUDES D'ACV SUR LES PRODUITS DU BOIS ET DU PAPIER

RAPPORT SPÉCIAL NO. 04-03
AOÛT 2004

RÉSUMÉ

On a effectué à l'échelle internationale une recherche exhaustive de la littérature dans le but de trouver des études d'inventaire du cycle de vie (ICV) et d'analyse du cycle de vie (ACV) qui tiennent compte du cycle du carbone lors de l'utilisation des produits du bois ou du papier ou à la fin de leur vie utile. On s'est particulièrement intéressé à la façon d'évaluer le devenir du carbone durant le stade d'utilisation du produit et celui où sa vie utile se termine dans un site d'enfouissement. On a aussi examiné les émissions de méthane de ces sites.

La recherche a mis en lumière soixante-six études d'ACV portant sur les produits du bois et du papier. La plupart d'entre elles ne se préoccupent pas des questions liées au flux du carbone au cours de son cycle de vie complet. Elles se concentrent surtout sur les autres paramètres environnementaux habituellement inclus dans les études du cycle de vie. Lorsqu'elles traitent du carbone contenu dans la biomasse, ces études évaluent habituellement la quantité de carbone éliminée de l'atmosphère et la quantité fixée par les arbres. Dans la plupart des études, on néglige la quantité de carbone séquestrée dans les produits de même que les émissions de méthane provenant des sites d'enfouissement, bien qu'il y ait plus d'études sur les émissions de méthane que d'études sur la séquestration du carbone dans les produits et dans les sites d'enfouissement. Lorsqu'on tient compte du carbone contenu dans la biomasse, il est généralement considéré comme une quantité neutre en matière de réchauffement global.

Parmi les 66 études d'ACV, treize ont fait l'objet d'une analyse plus poussée. Bon nombre d'entre elles présentaient des explications précises sur leur façon d'aborder la question du stockage du carbone dans les produits en cours d'utilisation et en fin de vie utile et la manière de déterminer les émissions de dioxyde de carbone et de méthane, mais la plupart ne contenaient pas bonnes données pour appuyer leurs énoncés. Plusieurs auteurs ont fait appel à des hypothèses très simples et ont souligné le manque de bonnes données ou de méthodes sur ce sujet. Dans le cas des sites d'enfouissement, on a habituellement présumé que toute la matière organique se décomposait, ou bien qu'aucune matière organique ne se décomposait, ou bien qu'une partie seulement se décomposait. Il n'y avait aucune cohérence dans les hypothèses sur les émissions de méthane et leur récupération. Seules des études de l'Agence américaine de protection de l'environnement (EPA) et d'une société allemande (IFEU) ont rapporté avoir fait appel à de vrais mesures.

Les études n'ont généralement pas traité de la séquestration du carbone dans les produits en cours d'utilisation ou enfouis, ou l'ont fait en usant d'hypothèses simples (par exemple, en supposant que les produits du bois séquestrent le carbone d'une manière permanente). On a souvent cité les données de l'EPA, celles du Dr. Morton Barlaz du *North Carolina State University* et celles de la société allemande IFEU. Même dans les cas où il existait une description détaillée de l'étude, les méthodes de caractérisation des flux et de la séquestration du carbone différaient de façon significative.

Le présent rapport présente 11 références bibliographiques (à la fin de l'Annexe A) qui apporte de l'information utile sur la façon d'obtenir des données sur le cycle du carbone en vue de réaliser une ACV. De plus, l'exemple 3 dans la norme ISO/TR 14047, publiée à l'automne 2003, fournit des idées sur des méthodes de caractérisation du cycle du carbone dans le cadre d'une ACV des produits

du bois. Bien que la séquestration du carbone soit sérieusement considérée comme une option de contrôle des niveaux de CO_2 dans l'atmosphère, les méthodes citées dans les normes ISO pour caractériser la séquestration ne sont pas uniformes et n'ont fait l'objet d'aucune revue par des pairs. Qui plus est, les praticiens d'ACV n'ont pas encore adopté de méthode standard.

MOTS CLÉS

analyse du cycle de vie, carbone, changement climatique, gaz à effet de serre, inventaires du cycle de vie, méthane, produits du bois, produits du papier, sites d'enfouissement

AUTRES PUBLICATIONS DE NCASI DANS CE DOMAINE

Bulletin technique No. 872 (mars 2004). *Critical Review of Forest Products Decomposition in Municipal Solid Waste Landfills*

Characterizing Carbon Sequestration in Forest Products along the Value Chain, Rapport de NCASI soumis à l'*International Council of Forest and Paper Associations,* 26 décembre 2003. http://www.ncasi.org/publications/Detail.aspx?id=2625

CONTENTS

AN ANALYSIS OF THE METHODS USED TO ADDRESS THE CARBON CYCLE IN WOOD AND PAPER PRODUCT LCA STUDIES

1.0 INTRODUCTION

This is a report on the findings of a review of harvested wood product (HWP) life cycle assessment (LCA) studies in North America, Europe, Japan, Australasia, and India. (In this report, the term life cycle assessment is used to include LCI—life cycle inventories—which are the first requirement to an LCA.) The study was commissioned by the National Council for Air and Stream Improvement (NCASI). The primary focus was to determine the methods used to address the carbon cycle, with special emphasis on the product use and end of life (disposal or reuse) phases, including how methane emissions from landfills and carbon sequestration are addressed. The time frame is 1990 to the present. (LCA was first defined in 1990.) Wood products include any product derived from wood, including building materials, paper, and paperboard products. The search was restricted to publicly available LCIs or LCAs.

For each study obtained, the review addressed the following information and issues:

- General information describing the study (including boundaries)
- Grade(s)of paper and paperboard or type(s) of wood product(s) covered
- Time-in-use (i.e., elapsed time between final production and end of life) assumed for each grade or product type
- Method used (if any) to adjust time-in-use to reflect the effects of recycling
- Method used to address the removal of carbon from the atmosphere by trees
- Method and parameter values used to estimate the amount and duration of carbon storage in landfills attributable to paper, paperboard, and wood products
- Method and parameter values used to estimate the amount and timing of methane generated from landfills by wood and paper products
- The source(s) of the parameter values used to estimate the fate of paper, paperboard, or wood products in landfills (carbon storage and degradation to landfill gas)
- Method and parameter values used to address the emissions of carbon dioxide and methane generated from paper, paperboard, or wood products in landfills, including emissions from burning of methane
- Assumptions made about the use and efficiency of landfill cover and gas collection systems in collecting and destroying methane
- Other carbon sinks included in the life cycle study—e.g., permanent storage in archives, carbon in ash from waste-to-energy units, etc.
- Conclusions about the effects of paper, paperboard, or wood products use, reuse, and disposal on carbon storage, and more generally, on net greenhouse gas emissions

2.0 METHODOLOGY

To identify environmental life cycle studies (LCA) of harvested wood products, a comprehensive search of various information sources was carried out. The information sources included electronic databases; using direct Internet search engines for articles, people, and journals; physical searches of relevant journals; contacting known experts in the field by phone and email; studying abstracts; and obtaining hard copies of possibly relevant documents.

Examples of electronic databases include ScienceDirect, in which abstracts of articles from hundreds of technical journals can be found, and EBSCO, which searches several thousand professional journals. Assistance was also obtained from the reference librarians at the Linda Hall Library, an internationally respected library of science and technology located in Kansas City, Missouri. The reference librarians at Johnson County Community College (Overland Park, Kansas) obtained copies of dozens of possibly relevant articles through their interlibrary loan capabilities. More than a dozen articles were downloaded from Internet sites for examination.

2.1 Development of Comprehensive List

The first task was to obtain a comprehensive list of wood and paper product LCAs. The earliest reference found was a discussion of the issue of carbon storage and emissions from landfills as an appropriate inclusion in studies of harvested wood products (C. Row and R.B. Phelps, in *Forests in a Changing Climate*, Climate Institute, 1990). Specific reference to its inclusion in LCA studies first appears in a discussion in a 1994 article by Reid A. Miner and Alan A. Lucier, "Considerations in Performing Life-Cycle Assessments on Forest Products" (*Environmental Toxicology and Chemistry*, vol. 13, no. 8, pp.1375-1380, 1994). Also that same year, a paper by Yaros and Boustead (discussed in detail later) provided the first specific guidance for inclusion of carbon storage in wood products and effects of disposal in LCA.

In examining the available LCA studies, it appeared that a wide variety of specific methods were used, which seems to be permitted under the umbrella of the ISO 14040 standards for LCA. However, some of the studies used terminology unfamiliar to the LCA community of practitioners, and some lacked the comprehensiveness in coverage usually expected in an LCA. One class of studies in particular is called "carbon balance" studies. These studies meet most of the requirements for an LCA, and would result in a significant omission if not included.

One study states that it is not an LCA, but rather a carbon balance assessment. However, it is a product-specific life cycle study of the carbon flows from growing trees through disposal and subsequent emissions and includes fossil fuel use in production, etc. It appears that this is very similar to an LCI, even though the authors say it is not. There are also numerous carbon balance studies that look at many aspects of the life cycle of wood and paper products. Some of them are for the U.S., or North America, or Europe. Some have very detailed methods for carbon calculations, especially carbon stored in the forest. Some do not spell out specific methodologies or data, but reference other documents as data sources. They do not focus on specific products, but on wood or paper products generally. Some include fossil fuel use, some do not. Some of these documents provide basic methodologies for calculations that are necessary for others to carry out LCAs.

A comprehensive list including all studies that appear to be harvested wood or paper product LCAs was developed. For studies authored prior to 1995, the title was sufficient for inclusion. In other words, if the title or abstract indicated it was a wood or paper product LCA, it is included in the comprehensive list without further need for evaluation. Prior to 1995, the research team concluded that carbon flows were not a part of LCAs.

Papers authored in 1995 and in subsequent years were evaluated more carefully. Abstracts, and often full copies of the papers, were obtained. The reason for this was to obtain information as to how carbon was addressed, with emphasis on the use and end of life stages. However, if a study appeared to be a harvested wood product LCA, it was included in the comprehensive list whether carbon was addressed or not.

Appendix A provides the comprehensive list of 67 studies. Fifteen of those appear to describe conditions in North America, with the remaining studies describing conditions in Europe, Asia, and Australia. The studies listed include a focus on a number of different products, including wood products used in dwelling construction and a wide variety of paper and paperboard products.

Most of the studies in the comprehensive list do not address carbon flow issues.

2.2 Selection of Studies for Detailed Analysis of Carbon Cycle Methodologies

In the scope of work for this project, thirteen reports that are analyzed for LCAs address carbon flows. To produce a “short list” from the comprehensive list, a decision was made to use four criteria as guidelines for selecting a study for further analysis. Studies had to meet three of the following four criteria to be selected for further study:

- Life cycle studies that include most life cycle aspects, starting with trees, and that include the important production, use and disposal steps, including emissions resulting from disposal
- Studies that focus on specific products
- Studies that include carbon emission aspects of fossil fuel use
- Studies that consider methane and CO_2 emissions from landfills and carbon sequestration in landfills

For three studies of construction products, the authors assumed that there was no disposal of wood products, and that the recovery for recycling or reuse was 100%. They state that this is common in urban areas where landfill tipping fees are high. This means that the carbon is stored permanently in the products and eliminates the relevance of the final criterion with regard to methane and CO_2 emissions from disposal practices. Other studies focused on use and disposal, but were selected because they provide details on how carbon can be addressed for post-production phases of products.

2.3 General Background Studies

Although not the focus of this report, in our search for LCA studies, we found a number of basic studies and reports that are relevant to the subject of this report, but are not LCAs. These documents can be used by practitioners to develop methods of addressing carbon cycle calculations, and many of them provide useful data. These studies are listed at the end of Appendix A.

3.0 SUMMARY OF STUDIES SELECTED FOR DETAILED ANALYSIS

Appendix B of this report contains the completed templates for the thirteen referenced documents that address the carbon cycle issues for the studies selected for further analysis. While the reader is directed to that appendix for further study of the details, an abbreviated overview of the thirteen studies is given here. (Only eleven entries are listed because of grouping of related studies.)

Yaros and Boustead, 1994

This is the earliest study found that addresses specific LCA issues for harvested wood products with reference to the carbon cycle. While it is not an LCA of a specific product, it addresses the carbon cycle issues from cradle to grave. The authors assume that all methane released from landfills is recovered and combusted, and point out that this returns the carbon to the natural cycle.

Paper Task Force Report, White paper no. 3, 1995, with some tables updated to 2002

This paper is authored by the Environmental Defense Fund. They assume that all paper products decay in a landfill, producing methane and carbon dioxide. They also assume that no methane is recovered and combusted. They conclude that recycling (avoidance of disposal) is the best choice for reducing the greenhouse gas (GHG) emissions.

W.A. Young, W. Coté and others at International Paper, several papers and reports, 1999 and 2000

Staff at International Paper have conducted studies, which they refer to as carbon balance studies, that appear to at least closely approximate LCI studies, although only GHG and carbon issues are addressed. Three paper mills have been included. These are very detailed studies primarily devoted to the development of carbon issues in the forest, but they address the entire life cycle of paper products. They cite the lack of a good model for what happens to paper and paperboard products in landfills, but cite work by EPA and Barlaz and assume that half of the paper is sequestered in the landfill, and half decays to CO_2 and methane. They assume that 53% of methane is combusted.

Borjesson and Gustavsson, 2000

This LCA study is a comparison of framing for building construction using wood or concrete in Sweden. It is included because it uses a very comprehensive methodology for including the carbon cycle issues at every stage. For example, while they assume that 20% of lumber eventually decays in landfills, they make extensive use of sensitivity analyses so that the implications of the uncertainties in values can be seen clearly. This is a well referenced and documented paper.

Forintek (Athena) and CORRIM, 2000 and 2002

These are comprehensive LCA databases that carefully address the carbon cycle for building products. They are cradle to gate in scope, meaning that the scope of coverage stops with the manufactured product ready to ship to customers. The authors point out that this may be sufficient for construction products in urban areas with high landfill tipping fees, and thus assume that the lumber will be reused or recycled in some fashion. Therefore, the carbon is permanently stored in products, or is combusted and returned to the atmosphere. However, carbon from fuel use in the recovery and recycling operations would need to be included for a complete picture.

ISO/TR 14047:2003(E). 2003

This technical report has become part of the ISO 14040 series of LCA standards. Example 3 is a rich source of ideas for carbon cycle LCA methods for harvested wood products. Example values are given for a variety of generic paper, paperboard, and lumber products, and numerous models are suggested for various calculations, such as how to calculate the life time of paper, paperboard, and lumber products.

Tiedemann, A. et al. 2000

This study encompasses the whole printing paper market of Germany and includes some important countries (in Scandinavia) that export paper to Germany. The emphasis of the study is on different recycling and waste management systems. Biomass carbon is not considered a contributor to global warming. The studies use models developed by IFEU (a German consulting firm) for disposal issues.

The IFEU landfill model is based upon data from all German landfills in the mid-1990s. It describes a 50-year time horizon for products in the landfill, and does not include any carbon sequestration for organic carbon. During the 50 years, 50% of organic carbon is degraded. There do not appear to be any specific data for wood or paper products; rather, they are included in the general category of organic carbon.

Suter, P. et al. (1996) and Frischknect, R. (1996)

These studies report data for life cycle inventories of waste management processes in Switzerland. Combustion (municipal and hazardous waste), different types of landfills (sanitary, residual and inert material), and wastewater treatment (different classes) are included. The goal is to integrate waste treatment in LCA studies. The results can be used as an input to the life cycle inventory database ECOINVENT to calculate LCIs for waste-specific treatment processes. Carbon from trees is included as a negative CO_2 value. Emissions from landfills are addressed in detail.

Grant, T. (2001)

The study refers to solid waste management in the state of Victoria, Australia. It considers landfilling followed by recycling or electricity generation. Carbon sequestration and GHG emissions are considered, but forest-related carbon flows are beyond the scope of this study.

Axel Springer Verlag AG, et al., A Life Cycle Assessment of the production of a daily newspaper and a weekly magazine (1998)

This study addresses the production and use of newspapers and weekly magazines in Sweden, Canada, and Germany. Carbon in trees and in recycled paper is considered to be a carbon sink, and negative CO_2 values are calculated. Burning wood or wood products for fuel is considered GHG-neutral, and no CO_2 emissions from those sources are included. Landfilled paper is assumed to decay completely to CO_2, but there is no mention of methane emissions in the report.

U.S. EPA, "Solid Waste Management and Greenhouse Gases – A Life-Cycle Assessment of Emissions and Sinks, 2nd Edition", May 2002, EPA530-R-02-006

This is a greenhouse gas- and carbon-focused life cycle study of alternative management methods for materials in the municipal solid waste stream in the United States. It includes a variety of types of paper products and a few wood products. The report addresses the greenhouse gas and carbon implications of source reduction, recycling, burning for energy, composting, and landfilling. The analytical framework attempts to quantify carbon sequestered in forests and in landfills as well as methane emissions from landfills, but carbon in products in use is not considered. Carbon in biomass-derived CO_2 is considered climate-neutral. The examination of the fate of carbon in landfills is based on laboratory data developed for EPA by Barlaz at North Carolina State University. Forest carbon is examined via a family of models developed by the U.S. Forest Service.

4.0 SUMMARY OF STUDY TREATMENTS OF TWELVE KEY ISSUES

Each of the reports summarized in the previous section was analyzed using a set of twelve key issues dealing primarily with the treatment of carbon cycle issues. In this section, the treatment of each of those key issues in the thirteen reports is summarized in order to provide an indication of any common features among the thirteen studies.

4.1 General Information Describing the Study (including boundaries)

Eleven of the thirteen studies were LCIs utilizing data of variable quality. Some studies used data from specific primary sources that represented actual operations, while others used generic data and hypothetical calculations. Some used a combination of two or more types of data. Two of the studies were not LCIs, but were included because they addressed the methods of carbon cycle LCIs and included many valuable suggestions for data sources.

The life cycle for forest products is defined by boundary conditions that start with the planting of trees and extraction by the trees of carbon from the environment, and all operations through disposal or recycling. Most of the study boundaries started with the planting of trees, although two (Paper Task Force 1995; Borjesson and Gustavsson 2000) started with the harvesting of trees. However, there was a wide variation of the placement of the end boundary. In most cases, reports stated (or implied) that the data for disposal and post disposal were not considered to be of acceptable quality. Forintek stops at the plant gate, while CORRIM (2002) stops at the construction of a building shell. Some studies focused on recycling alternatives and identified disposal as the end boundary.

4.2 Grade(s) of Paper and Paperboard or Type of Wood Product(s) Covered in the Study

Only one study (Yaros and Boustead 1994) did not specify specific products. Three studies focused on lumber and plywood products, while two more included lumber as well as paper and paperboard. The remaining seven studies covered a wide variety of bleached and unbleached kraft paper and paperboard products, such as printing papers and packaging paperboard. Three studies identified newsprint as one product, but no studies specified tissue products. Although recycled products were not identified specifically, some studies consider end-of-life options, including recycling.

4.3. Time-in-Use (i.e., elapsed time between final production and discard) Assumed for Each Grade or Product Type

Most studies were for products assumed to be produced and discarded in the same year. Some did not specify a lifetime or made no assumptions about product life. One study assumed 50 to 100 years for buildings, while another assumed 30 years for lumber. Two studies were cradle-to-gate, so they made no assumptions about product lifetime. The ISO TR 14047 suggested use of half-life models such as those proposed by USDA or IRS.

4.4 Method Used (if any) to Adjust Time-in-Use to Reflect the Effects of Recycling

None of the studies directly addressed this issue, although the use of the half-life models (ISO TR 14047 2003) would appear to incorporate time in use.

4.5 Method Used to Address the Removal of Carbon from the Atmosphere by Trees

The life cycle studies examined in detail generally did not address carbon sequestration in the forest. The few studies that explicitly address carbon sequestration in the forest used stock accounting approaches; i.e., sequestration was defined as the change in forest carbon stocks over time.

In several cases, even though forest carbon sequestration was not explicitly addressed, the carbon contained in wood products was considered as a negative emission going into the value chain. The most common framework for following biomass carbon in the value chain was flow accounting, wherein biomass-derived CO_2 emissions are defined as actual physical transfers of biomass-CO_2 to the atmosphere. In most cases, however, biomass-derived CO_2 was tracked separately from fossil fuel-derived CO_2.

4.6 Method and Parameter Values Used to Estimate the Amount and Duration of Carbon Storage in Landfills Attributable to Paper, Paperboard, and Wood Products

The majority of studies did not address carbon storage in landfills, and there was no common method used by the ones that did address carbon storage. Three studies state there are no reliable models. Borjesson and Gustavsson (2000) assumed that 80% of carbon from building materials was stored in landfills; Tiedemann (2000) did not include sequestration of organic carbon; Suter et al. (1996) assumed 100% degradation in landfills, and Grant et al. (2002) assumed that 34% of newspapers and 23% of paperboard does not degrade. EPA (2002) used laboratory-generated data from Barlaz to model the amounts of carbon that remain sequestered in landfills. (These data are summarized in NCASI Technical Bulletin No. 872, *Critical Review of Forest Products Decomposition in Municipal Solid Waste Landfills*.)

4.7 Method and Parameter Values Used to Estimate the Amount and Timing of Methane Generated from Landfills

Half of the studies did not address this issue. The other studies all addressed it differently, using decomposition equations and various time horizons to arrive at different answers. All studies that address the issue cite different references, so there is no uniformity in the results.

4.8 The Source(s) of the Parameter Values Used to Estimate the Fate of Paper, Paperboard, or Wood Products in Landfills (carbon storage and degradation to landfill gas)

See above discussions.

4.9 Method and Parameter Values Used to Address the Emission of Carbon Dioxide Generated from Paper, Paperboard, or Wood Products in Landfills, Including Emissions from Burning of Methane

No two studies used the same methods. Two studies assumed that all paper that decomposes ends up as CO_2. Three studies mention that biogenic carbon is "carbon neutral." In many of the studies, CO_2 from landfills was not addressed although it was not clear whether this was due to the scope of the study or a decision that biomass-derived CO_2 need not be included due to its climate-neutrality. The studies that do cover the topic cite different literature sources for values, including two studies that use landfill emission data adjusted by "paper factors."

4.10 Assumptions Made about the Use and Efficiency of Landfill Cover and Gas Collection Systems in Collecting and Destroying Methane

Five studies do not mention this issue. Only two describe the issue of landfill covers explicitly (Grant et al. 2001; EPA 2002). Grant et al. indicate that the range of recovery is 30% to 85%. EPA uses extensive data from other EPA studies to support an assumption that landfill gas collection systems are 75% efficient and that 10% of the methane that is not collected is oxidized as it migrates through the landfill cover. The remaining studies come to different conclusions based upon literature or landfill emission data, with recovery percentages ranging from 32% to 70%. One study assumes no recovery and another assumes 100% recovery.

4.11 Other Carbon Sinks Included in the Life Cycle Study (e.g., permanent storage in archives, carbon in ash from waste-to-energy units, etc.)

None of the studies respond to this issue. They either did not address the issue, or specifically excluded it. One possible exception is the ISO/TR 14047 (2003), in which half-life models for products are proposed.

4.12 Conclusions about the Effects of Paper, Paperboard, or Wood Products Use, Reuse, and Disposal on Carbon Storage, and More Generally, on Net Greenhouse Gas Emissions

Four studies either did not address this issue or reached no specific conclusions. Given the range of assumptions, boundary conditions, and data sources used in the remaining studies, it is not unexpected that they reached a variety of conclusions. No attempt was made to determine the extent to which the studies' conclusions were attributable to specific assumptions, boundary conditions, or data sets.

The majority of studies acknowledged that landfill emissions increase GHG concerns because of the production of methane, but did not address the more complex issues of carbon storage. It was concluded by most that recycling is the best alternative for reducing GHG emissions, followed by combustion of paper or methane, with energy recovery. Landfilling was acknowledged as the least desirable alternative because of methane generation and emissions to the atmosphere (although it must be recognized that most of these studies did not consider carbon sequestration in landfills). The studies did not distinguish between reuse (of wood products), in which carbon is sequestered, and recycling, such as mulch and fuel production. In addition, several studies noted that recycling of paper products leads to increased use of fossil fuel compared to virgin materials.

5.0 DETAILED SUMMARIES OF CARBON BALANCE METHODS FOR SELECTED STUDIES (BY ISSUE)

This section presents detailed summaries of carbon balance methods for selected studies sorted by issue, so that the approach taken by each author or authors can be reviewed. Detailed summaries of the approaches taken, sorted by author(s), are in Appendix B.

5.1 General Information Describing the Study (including boundaries)

Yaros and Boustead, Carbon and energy balances in paper production

This paper contains no data, but outlines an LCI methodology of tracking carbon and energy from absorption in growing trees, through all subsequent processing, and addresses the emissions of CO_2 and methane from landfills. The authors recommend that the initial boundary of LCA studies be the planting of trees.

Paper Task Force, White Paper No. 3, 1995 with some tables updated to 2002

The boundaries of the study are from harvesting trees to final disposal emissions.

Young, Tonelli, Coté, and others at International Paper Company, Net carbon sequestration at pulp and paper mills (two papers)

These papers appear to follow the same basic methodology as the paper by Coté, et al. (2002), which describes a study of the Texarkana, Texas International Paper mill. This study is a carbon balance study of three International Paper mills located at Mobile, Alabama; Madison, Louisiana; and Texarkana, Texas. Data are presented for the three mills as a total, without giving details for the specific mills.

The paper obtained directly from Dr. Young has substantially greater amounts of methodological details than does the *Journal of Forestry* article.

The scope begins with the fixing of carbon by trees and ends with disposal of products. Fossil fuel inputs are included. Carbon in the soil in forests is excluded. Many aspects of forest dynamics are included, such as slash and root decay, which comprise the largest contributing category to carbon emissions.

Forintek Canada Corp. (Athena)

The original LCI study followed Canadian wood product production from cradle-to-gate (circa early 1990s and average technology). While some of the data were regional in scope, the LCI profiles for each product were generalized to a national level. The latter update report on softwood lumber was also a cradle-to-gate study (mid- to late 1990s, average technology). The update report replaced the resource extraction profile for all wood products derived from a softwood resource (e.g., excludes oriented strand board, or OSB).

The study boundary includes all forest management activities (nursery operations, planting and thinning), harvesting and transportation of raw fiber, production of solid wood products at the mill gate. Final product transportation by mode and distance is also indicated, but is not factored into the LCI profile. Data were developed from literature, proprietary studies conducted by Forintek Canada Corporation (1993) and mill surveys.

Borjesson and Gustavsson, Greenhouse gas balances, 2000

This is an LCI comparison of a Swedish apartment building with wood or concrete framing. Only GHG flows (CO_2 and methane) are considered. The scope begins with the extraction of raw materials and ends with the disposition of demolition waste. Fossil fuel used to produce the framing as well as other structural components are considered.

Coté, Young, et al., Carbon balance method for paper and wood products

This paper describes a carbon balance analysis, and is not an LCI. However, it has most elements of an LCI, although it examines only carbon flows.

This paper describes calculations for a paper mill in Texarkana, Texas. The scope begins with the growing of trees and ends with final disposal, including emissions subsequent to disposal, and sequestration in landfills. However, data were collected only on the portion of the system that begins with the wood arriving at the mill, and ends with the product ready for shipment to customers. Values for carbon flows both upstream and downstream from the product(s) were calculated using a variety of methodologies.

CORRIM, Inc., Life cycle environmental performance of renewable building materials. Also summarized with updates in Lippke, Garcia, et al.

This is a regional U.S. LCI of solid wood products from cradle to completion of a residential building shell inclusive of transportation effects. The study boundary includes all forest management activities (nursery operations, planting and thinning), harvesting and transportation of raw fiber, production of solid wood products, product transportation to designated building sites and on-site construction effects of erecting residential building shells. The wood product residential structural shells are compared against alternative material shell designs (steel and concrete masonry). Two distinct timber and wood product-producing regions are covered in the study—Pacific Northwest (PNW) and the U.S. Southeast (SE). Production technologies are stated to be average or typical for the late 1990s. Data have been developed from literature and mill surveys.

Note: This is an interim report. A new updated report was due to be released during the summer of 2003. The expansion is to include additional products such as glulam beams, laminated veneer lumber, and wood “I” joists. In a personal communication with Dr. Bruce Lippke, professor and director of the Rural Technology Initiative, he stated that the new report will look at direct emissions only, and will not include the indirect effects of CO and N_2O, which are included in the interim report.

ISO/TR 14047:2003(E), Environmental Management – Life Cycle Assessment

This document is not an LCA of a specific product, but addresses the carbon balance issues for all stages of an LCA, from the forest through disposal. References are given for specific data sources and formulas are suggested for calculations.

Tiedemann

This study encompasses the whole graphical paper (printing paper) market of Germany and includes some important export countries (Scandinavia). The functional unit is the yearly amount of these paper types in Germany. The emphasis of the study is different recycling and waste management systems. The geographical system boundary is Germany plus the Scandinavian countries (Sweden, Norway, and Finland) for the early phases of the life cycle only. Excluded is North America due to lack of data. The reference year for the standard scenario is 1995.

Suter, Zimmermann, Frischknecht, et al.

Suter: This study contains basic considerations for life cycle inventories of waste management processes in Switzerland. Incineration (municipal and hazardous waste), different types of landfill (sanitary, residual, and inert material) and wastewater treatment (different classes) are included. The goal is to integrate waste treatment in LCA studies. Status of technology refers to the year 1995. Infrastructure is included. There is a software tool (in Microsoft Excel) to calculate LCIs for waste treatment processes for individual waste compositions. The results can be used as an input to the life cycle inventory data base ECOINVENT to calculate LCIs for waste specific treatment processes.

Frischknecht: This study contains life cycle inventories of energy systems relevant for Switzerland. Wood is included mainly for use as fuel, but also as construction material in infrastructure. Paper and corrugated are used as packaging materials and not examined in detail.

Both studies deliver generic data sets to be used for upstream chains and downstream processes in LCA studies. The system boundaries are more like “cradle to gate” than “cradle to grave.” The two studies use results from each other. Processes covered in these studies are now included and updated in the Swiss life cycle assessment data base Ecoinvent 2000 (http://www.ecoinvent.ch/en/index.htm).

Grant, James, et al.

The study refers to the waste management in the state of Victoria, Australia. It contains a complex model of the real system used in this state and can therefore not directly be transferred to other states of Australia or other continents. The principal question to be answered is:

> *"Does the current recycling system result in a net reduction in environmental impacts and if so what is the magnitude of this saving?"*

Two alternatives are studied: landfill with electricity production and recycling. Avoided virgin material, avoided fossil fuels etc. are quantified in the inventories.

Axel Springer Verlag AG et al.

The authors conclude that the major environmental impact resulting from carbon emissions comes from the burning of fossil fuels. Burning wood or storing it in recycled paper helps lessen the impact.

EPA 2002

This study is called a “streamlined” LCA because it includes only greenhouse gases. However, it is life cycle in scope as it starts with the growing of trees, and carries through to the final disposal of materials including fate of landfill emissions. It includes a careful consideration of many carbon cycle issues, including the carbon sequestered in the forest. Included are the effects on the carbon balance from source reduction, recycling, composting, combustion of fuels, landfilling, and subsequent treatment (or non-treatment) of landfill emissions. (While composting results in carbon storage in soils, the EPA study excludes forest products from composting because of practical limits on the scope of the study.)

5.2 Grade(s) of Paper and Paperboard or Type of Wood Product(s) Covered in the Study

Yaros and Boustead, Carbon and energy balances in paper production

Forest products were addressed only generally. No specific grades or products were addressed.

Paper Task Force, White Paper No. 3, 1995 with some tables updated to 2002

This study included newsprint, corrugated, office paper, CUK (coated unbleached kraft) paperboard, and SBS (solid bleached sulfate) paperboard.

Young, Tonelli, Coté, and others at International Paper Company, Net carbon sequestration at pulp and paper mills, two papers

A wide variety of products are produced at the three mills, including bleached kraft and unbleached kraft. Recovered paper is a material input.

Forintek Canada Corp. (Athena)

This work is focused on

- forest management, harvesting, and transportation to processing plants,
- regional small and large dimension softwood lumber production on both a green and dry basis,
- softwood plywood production,
- oriented strand board (OSB) production, and
- engineered wood products—glulam, laminated veneer lumber, parallel strand lumber and wood “I” joists

Borjesson and Gustavsson, Greenhouse gas balances, 2000

This is a study of lumber used for framing.

Coté, Young, et al., Carbon balance method for paper and wood products

The products addressed in this study include bleached paperboard and bleached cup stock paper.

CORRIM, Inc., Life cycle environmental performance of renewable building materials. Also summarized with updates in Lippke, Garcia, et al.

The CORRIM report examines the performance of alternate building systems. Among the issues and product types examined are

- regional forest management of varying intensities, harvesting, and transportation to processing plants,
- softwood lumber production on both a green and dry basis for the Pacific Northwest (PNW) and a dry basis only for the Southeast (SE),
- softwood plywood production for both the SE and PNW, and
- oriented strand board production for the SE region only.

ISO/TR 14047:2003(E), Environmental Management – Life Cycle Assessment

Example values are given for a variety of generic paper, paperboard and lumber products.

Tiedemann

The study addresses important grades of paper used for graphical papers (newspaper, journals) and copy paper.

Suter, Zimmermann, Frischknecht, et al.

Suter: In principle all types are addressed generically. Results for paper in sanitary landfill are included as an example.

Frischknecht: This work focuses on paper and corrugated, mainly for packaging purposes, and wood as fuel and construction material.

Grant, James, et al.

The study object is the actual waste collected within the waste management system of Victoria. Specifically, the following materials are considered: paper and paperboard packaging; liquid paperboard (LPB); high density polyethylene (HDPE); polyvinyl chloride (PVC) polyethylene terephthalate (PET); other; mixed packaging plastic; glass (bottles and jars); steel cans; and aluminum cans.

Axel Springer Verlag AG et al.

This is a study of newspaper and printing paper used in weekly magazines.

EPA 2002

This life cycle study examines a number of forest products from a waste management perspective. The study includes the study of 16 specific products or materials found in solid waste. The forest products include corrugated, magazines/third class mail, newspaper, phonebooks, textbooks, dimension lumber (as listed in the category of “wood containers and packaging”), and medium-density fiberboard. Construction lumber does not appear to be covered in the estimates of quantities of materials discarded.

5.3 Time-in-Use (i.e., elapsed time between final production and discard) Assumed for Each Grade or Product Type

Yaros and Boustead, Carbon and energy balances in paper production

Not given.

Paper Task Force, White Paper No. 3, 1995 with some tables updated to 2002

Unspecified average or typical values used.

Young, Tonelli, Coté, and others at International Paper Company, Net carbon sequestration at pulp and paper mills, two papers

Production, consumption, and disposal are assumed to occur in the same year.

Forintek Canada Corp. (Athena)

Not applicable—the LCI gate was defined as a cradle to manufacturing gate analysis, specifically undertaken to support software dealing with the use of wood and other products in a whole building context.

Borjesson and Gustavsson, Greenhouse gas balances, 2000

The life of the building was assumed to be 50 or 100 years.

Coté, Young, et al., Carbon balance method for paper and wood products

All occurrences in this study were assumed to happen in the same year.

CORRIM, Inc., Life cycle environmental performance of renewable building materials. Also summarized with updates in Lippke, Garcia, et al.

Not applicable for the interim report—the LCI gate was the completion of the residential shell on the building site. Dr. Bruce Lippke, the lead investigator, reports that the new report considers landscape management systems which include storage of carbon in products. There are also some data on this in the Rural Technology Report cited above.

ISO/TR 14047:2002(E), Environmental Management – Life Cycle Assessment

This example suggests use of a “half life model” developed by USDA and the IRS.

Tiedemann

This study focuses on short-lived products with a lifetime of typically less than one year.

Suter, Zimmermann, Frischknecht, et al.

Wood used in construction is assumed to remain in use for 30 years.

Grant, James, et al.

This work examines paper and packaging waste derived from short-lived products. The LCA may be characterized as an “end-of-life” LCA and starts with collection of waste. The substitution processes are, however, “cradle to grave” (e.g., electricity from coal). The time of methane production is described as “decades” with the time scenario appearing to be nearer to the 100 year assumption than to indefinite time horizon preferred in recent Scandinavian and Swiss studies (except perhaps for scenario 1 (full degradation); see Section 5.6).

Axel Springer Verlag AG et al.

Not given.

EPA 2000

Time-in-use is not addressed in this study.

5.4 Method Used (if any) to Adjust Time-in-Use to Reflect the Effects of Recycling

Yaros and Boustead, Carbon and energy balances in paper production

Not given.

Paper Task Force, White Paper No. 3, 1995 with some tables updated to 2002

Not given.

Young, Tonelli, Coté, and others at International Paper Company, Net carbon sequestration at pulp and paper mills, two papers

Not given.

Forintek Canada Corp. (Athena)

Not applicable.

Borjesson and Gustavsson, Greenhouse gas balances, 2000

Not given.

Coté, Young, et al., Carbon balance method for paper and wood products

Not given, but excludes virgin fiber that goes into material recovered for recycling.

CORRIM, Inc., Life cycle environmental performance of renewable building materials. Also summarized with updates in Lippke, Garcia, et al.

Not applicable.

ISO/TR 14047:2002(E), Environmental Management – Life Cycle Assessment

Method given to incorporate recycling as part of the "half life model" discussed in Section 5.3 above.

Tiedemann

The products of recycling are similar with regard to lifetime (e.g., paper used for newspapers have a high amount of recycled paper).

Suter, Zimmermann, Frischknecht, et al.

Not modeled.

Grant, James, et al.

See 5.3 above.

Axel Springer Verlag AG et al.

Time-in-use is not discussed, but recycled paper is considered a carbon sink.

EPA 2002

This study does not address time-in-use.

5.5 Method Used to Address the Removal of Carbon from the Atmosphere by Trees

Yaros and Boustead, Carbon and energy balances in paper production

The authors suggest a framework for carbon accounting that does not address carbon sequestration in forests or products. It does include, however, "carbon dioxide absorption during tree growing…" and "carbon dioxide emissions when wood products are burned…." This can be characterized as a flow accounting approach; i.e., it defines biomass carbon emissions as flows of biomass carbon to the atmosphere (as opposed to stock accounting which defines biomass carbon emissions as reductions in biomass carbon stocks).

Paper Task Force, White Paper No. 3, 1995 with some tables updated to 2002

This paper does not address carbon sequestration in forests or products. It tracks biomass CO_2 emissions separately from fossil fuel CO_2 emissions. A parameter called "total GHG emissions" is used; this includes both biomass- and fossil fuel-derived CO_2. The comparisons between scenarios, however, are performed using “net GHG emissions,” a term that excludes biomass-derived CO_2 emissions. The exclusion of biomass-derived CO_2 from net GHG emissions is based on the recognition that the carbon in biomass-derived CO_2 was once in the atmosphere and therefore, when it is returned to the atmosphere, it results in no net increase in atmospheric carbon.

Young, Tonelli, Coté, and others at International Paper Company, Net carbon sequestration at pulp and paper mills, two papers

The authors follow carbon flows from the atmosphere into trees, through the value chain, and then either back into the atmosphere or into permanent sequestration in the landfill. Forest carbon sequestration is estimated as the net carbon flows into and out of the forest rather than as a stock change in the forest. In addition, releases of biomass-derived carbon are assigned to the points where the transfer of carbon into the atmosphere physically takes place and are added to fossil fuel-derived CO_2 emissions. Thus, this study can be judged to be using a flow accounting framework for biomass carbon.

Forintek Canada Corp. (Athena)

The CORRIM project calculates forest carbon sequestration by calculating forest carbon stocks over time. Specifically, the report indicates that “carbon removed is calculated as the difference between carbon in the year before activity and carbon after the activity plus any accumulation during the year of activity.” The study focuses on two specific forest systems, one in the Pacific Northwest (PNW) U.S. and the other in the Southeast (SE) U.S. Different models are used to calculate carbon stock changes in the two regions. In both cases, “carbon information…includes the standing carbon inventory just prior to harvest at the rotation age and an estimate of removed carbon through forest management activities, both intermediate thinning and the final harvest.” The final report will explain the details on how the forest carbon stocks and stock changes are integrated into the life cycle analysis by following forest cohorts over time, which implicitly acknowledges carbon uptake without specific calculations.

Borjesson and Gustavsson, Greenhouse gas balances, 2000

This study is a comparison of different building systems (i.e., wood vs. concrete) and examines forest carbon sequestration only tangentially. For those scenarios that used less wood than the wood-framed house, one of the options considered for the unused trees is allowing them to remain in the forest, storing carbon. The only forest carbon sequestration considered is equal to the carbon in the wood that otherwise would have been used in a wood-framed house. The report, therefore, cannot be said to have examined forest carbon sequestration.

Coté, Young, et al., Carbon balance method for paper and wood products

See discussion above under “Young, Tonelli, Coté, et al.”

CORRIM, Inc., Life cycle environmental performance of renewable building materials. Also summarized with updates in Lippke, Garcia, et al

See discussion above under “Forintek Canada Corp. (Athena).”

ISO/TR 14047:2002(E), Environmental Management – Life Cycle Assessment

In this example of the application of impact assessment to a forest products system, sequestered forest carbon is considered to be “the net growth in biomass carbon [in the forest], after discounting for harvesting.” This is essentially a stock change calculation; i.e., forest carbon sequestration is equal to the increases in stocks of forest carbon. The increase in carbon stocks in the forest over a period of time reflects the net effect of a number of factors including growth, harvest, litter accumulation and decomposition, and other factors.

Tiedemann

No specific model is used; the biogenic CO_2 is not counted for global warming potential (GWP). The ecosystem forest was quantified in the category “land use” using the hemerobic level concept proposed by Isa Renner (Klöpffer, W. and Renner, I. 1995. Methodik der Wirkungsbilanz im Rahmen von Produkt-Ökobilanzen unter Berücksichtigung nicht oder nur schwer quantifizierbarer Umwelt-Kategorien. UFO-Plan Nr.: 100 01 102. Bericht der C.A.U. GmbH an das Umweltbundesamt, Berlin Mai 1994. UBA Texte 23/95 Methodik der produktbezogenen Ökobilanzen - Wirkungsbilanz und Bewertung Berlin). In that way it was possible to distinguish a forestry “near to nature” (extensive cultivation) from intensive cultivation, as in plantations.

Suter, Zimmermann, Frischknecht, et al.

The study appears to carry a negative balance of atmospheric carbon into the value chain, with the life cycle giving a balance of -1,810 kg CO_2/t wood.

Grant, James, et al.

Although this study acknowledges that there are potential effects on forest carbon sequestration related to recycling, it includes only a brief evaluation of forest carbon. The evaluation, based on national carbon accounting data, causes the authors to conclude that the changes in forest carbon are small enough to be ignored and a “neutral carbon balance” is assumed.

Axel Springer Verlag AG et al.

The boundaries of this life cycle assessment do not include the forest. The carbon in harvested wood entering the value chain, however, is treated as a removal of carbon from the atmosphere. If this carbon reenters the atmosphere, for instance by decay or burning, this is treated as an emission at the point where the transfer to the atmosphere occurs and is considered the same as CO_2 from fossil fuel burning. Therefore, although the study does not directly address forest carbon stock accounting, the methods used downstream suggest that a flow accounting framework is being used for biomass carbon.

EPA 2002

Changes in forest carbon stocks are modeled using a family of models developed by the U.S. Forest Service.

5.6 Method and Parameter Values Used to Estimate the Amount and Duration of Carbon Storage in Landfills Attributable to Paper, Paperboard, and Wood Products

Yaros and Boustead, Carbon and energy balances in paper production

Sequestration in landfills is not addressed.

Paper Task Force, White Paper No. 3, 1995 with some tables updated to 2002

No specific values for carbon storage in landfills were assumed.

Young, Tonelli, Coté, and others at International Paper Company, Net carbon sequestration at pulp and paper mills, two papers

The authors state that a reliable model has not been developed. They assume that half of paper will not decompose by anaerobic methods and half will decompose in accordance with “flask studies” by Eleazer et al., 1997 and described in NCASI Technical Bulletin No. 872. The study used “weighted average decomposition rates for all products.”

Forintek Canada Corp. (Athena)

Sequestration in landfills is not covered.

Borjesson and Gustavsson, Greenhouse gas balances, 2000

Based upon a literature search, it was assumed that 20% of wood is converted to landfill gas. Calculations are also provided for a range of 10% to 40% of wood being converted to gas. The remainder is stored.

Coté, Young, et al., Carbon balance method for paper and wood products

Specific values not given nor are there any methodology details, but the paper indicates that “this analysis employs rates of landfill decomposition of paper products such that half are in conditions that will not allow anaerobic decomposition and the other half decompose at rates indicated by the flask studies [conducted by Barlaz and described in NCASI Technical Bulletin No. 872].” The study used “weighted average decomposition rates for all products.”

CORRIM, Inc., Life cycle environmental performance of renewable building materials. Also summarized with updates in Lippke, Garcia, et al.

Carbon sequestration in landfills is not covered.

ISO/TR 14047:2003(E), Environmental Management – Life Cycle Assessment

This example calculation references EPA landfill models and the need for better factors, mentions the importance of developing methane emission factors.

Tiedemann

The IFEU landfill model is based upon data from all German landfills in the mid-1990s. It describes a 50-year time horizon for products in the landfill, and does not include any carbon sequestration for organic carbon.

Suter, Zimmermann, Frischknecht, et al.

Complete degradation is assumed within the controlled phase (150 years).

Grant, James, et al

Three scenarios were used, No. 2 being the baseline scenario: (1) full degradation of all organic compounds; (2) carbon sequestration based on U.S. EPA data (34% of newspaper not degraded, 23% of paperboard not degraded); and (3) lignin content taken into account (78% of newspaper not degraded, 53% of paperboard not degraded).

Axel Springer Verlag AG et al.

Not given.

EPA 2002

EPA relied solely on the experimental work of Barlaz for these data. (See NCASI Technical Bulletin No. 872 for a summary of these data.)

5.7 Method and Parameter Values Used to Estimate the Amount and Timing of Methane Generated from Landfills

Yaros and Boustead, Carbon and energy balances in paper production

Chemical mass balances around the landfill were developed assuming anaerobic decomposition.

Paper Task Force, White Paper No. 3, 1995 with some tables updated to 2002

The method used was to take MSW carbon emission values from the following reference: Franklin Associates, Ltd., *The Role of Recycling in Integrated Solid Waste Management to the Year 2000*, prepared for Keep America Beautiful, Stamford, CT, 1994, (Chapter 6 and Appendix I). The authors assumed that paper products have one-third more carbon than MSW, so CO_2 and methane emission numbers for MSW were adjusted upward. CO_2 from landfills was not included in the calculations because it comes from biomass. Methane emissions from landfills were multiplied by 20 to reflect the GHG CO_2 equivalency. (Note: In earlier versions of this report, the authors used a factor of 69, but this was corrected in the 2002 updates.) No recovery of methane from landfills was assumed.

Young, Tonelli, Coté, and others at International Paper Company, Net carbon sequestration at pulp and paper mills, two papers

Fifty-three percent of methane is considered to be collected and burned (EPA estimates, no specific citation). The 1999 report by Young, et al. indicates that "this analysis employs rates of landfill decomposition of paper products such that half are in conditions that will not allow anaerobic decomposition and the other half decompose at rates indicated by the flask studies [conducted by Barlaz and described in NCASI Technical Bulletin No. 872]." The study used "weighted average decomposition rates for all products."

Forintek Canada Corp. (Athena)

This issue is not covered.

Borjesson and Gustavsson, Greenhouse gas balances, 2000

Sixty percent of the landfill gas is assumed to be methane with the remainder being CO_2. A multiplier of 21 was used to convert methane emissions to CO_2 equivalents. It was assumed that 70% of landfill gas is collected and burned. Calculations were carried out for three time intervals: 0-100 years, 50-100 years, and 50-200 years. Landfill gas is shown only for the 50-200 year calculations.

Coté, Young, et al, Carbon balance method for paper and wood products

See discussion of *Young, et al.* above

CORRIM, Inc., Life cycle environmental performance of renewable building materials. Also summarized with updates in Lippke, Garcia, et al.

This issue is not covered.

ISO/TR 14047:2003(E), Environmental Management – Life Cycle Assessment

EPA landfill models were used to estimate methane releases as well as carbon sequestration in landfills.

Tiedemann

During the 50 years, 50% of organic carbon is degraded.

Suter, Zimmermann, Frischknecht, et al.

The duration of methane generation is assumed to be 30 years. If carbon content of landfilled waste is 281g/kg, (carbon content of paper = 406 g/ kg), then theoretical amount of produced gas is 525 l/kg landfilled waste. A realistic amount of produced gas is estimated to be 200 l/kg landfilled waste. The composition of landfill gas is assumed to be 47% (by volume) CH_4 (335.7 g/m3), 37%CO_2 (726.8 g/m3), 13%N_2 (163 g/m3), 2.5%O_2 (36 g/m3).

Grant, James, et al.

55% of the methane formed (calculated in Section 5.6 above) is assumed to be captured and used for flaring or electricity production. 50% of the remaining 45% non-captured methane is assumed to be oxidized within the landfill.

Axel Springer Verlag AG et al.

Methane is not mentioned in the report.

EPA 2002

See discussion in Section 5.6 above. Timing of methane release was not addressed. Instead, the study examined ultimate methane generation and release.

5.8 The Source(s) of the Parameter Values Used to Estimate the Fate of Paper, Paperboard or Wood Products in Landfills (carbon storage and degradation to landfill gas)

Yaros and Boustead, Carbon and energy balances in paper production

Landfill analyses involved chemical mass balances, assuming anaerobic decomposition.

Paper Task Force, White Paper No. 3, 1995 with some tables updated to 2002

See Section 5.7 above for this source.

Young, Tonelli, Coté, and others at International Paper Company, Net carbon sequestration at pulp and paper mills, two papers

EPA estimates are mentioned but the citation is missing. Barlaz et al. 1997, is cited, but complete citation is not in either paper. The correct reference is probably Eleazer et al. 1997. See Section 5.7 above for more information.

Forintek Canada Corp. (Athena)

This is a cradle to gate study so landfill issues were not covered.

Borjesson and Gustavsson, Greenhouse gas balances, 2000

Biogass production information was taken from Manna et al., *"Modeling biogas production at landfill site. Resources,"* Conservation and Recycling, 26, 1-14 (1999).

Coté, Young, et al., Carbon balance method for paper and wood products

Values not given, but cites work by Row, Skog, Micales and U.S. EPA. See Section 5.7 above.

CORRIM, Inc., Life cycle environmental performance of renewable building materials. Also summarized with updates in Lippke, Garcia, et al.

Not covered.

ISO/TR 14047:2003(E), Environmental Management – Life Cycle Assessment

See discussion in Sections 5.6 and 5.7 above.

Tiedemann

There do not appear to be any specific data for different wood or paper products; rather, they are included in the general category of organic carbon.

Suter, Zimmermann, Frischknecht, et al.

Derived by project team.

Grant, James, et al.

The information was from U.S. EPA and publications from EU and Australia.

Axel Springer Verlag AG et al.

Not given.

EPA 2002

EPA used data generated by Barlaz (see NCASI Technical Bulletin No. 872) and national information on landfill use and design and MSW disposal rates.

5.9 Method and Parameter Values Used to Address the Emission of Carbon Dioxide Generated from Paper, Paperboard or Wood Products in Landfills, Including Emissions from Burning of Methane

Yaros and Boustead, Carbon and energy balances in paper production

The authors state that the methane generated in landfills is usually collected and used as a fuel. No distinction is made between carbon dioxide with origins from biomass or non-biomass sources.

Paper Task Force, White Paper No. 3, 1995 with some tables updated to 2002

See Section 5.7 above for this source (assumed no methane was recovered from landfills). Carbon dioxide derived from biomass origins was assumed to be climate-neutral.

Young, Tonelli, Coté, and others at International Paper Company, Net carbon sequestration at pulp and paper mills, two papers

Thirty percent of paper in a landfill is eventually emitted as a gas, with about half being methane. CO_2 emissions originating from biomass were reported separately from non-biomass sources of CO_2.

Forintek Canada Corp. (Athena)

This study did not address landfill issues.

Borjesson and Gustavsson, Greenhouse gas balances, 2000

The emissions of burning methane are not described, but the response in Section 5.7 above describes the assumptions stated.

Coté, Young, et al., Carbon balance method for paper and wood products

No details are given, but cites work by Row, Skog, Micales and U.S. EPA. Biomass and fossil emissions are reported separately.

CORRIM, Inc., Life cycle environmental performance of renewable building materials. Also summarized with updates in Lippke, Garcia, et al.

Not covered.

ISO/TR 14047:2002(E), Environmental Management – Life Cycle Assessment

Carbon dioxide releases from biomass decomposition are considered to be “net zero” CO_2 equivalents with respect to global warming potential and are tracked separately from fossil fuel-related carbon dioxide releases.

Tiedemann

The carbon is released as a gas, which is 55% methane (by volume). Of the gas released, 62.5% is uncontrolled. Of the 32.5% that is collected, 47% is burned and 53% is used in internal combustion engines. No mention is made of the emissions from the burned or combusted methane. Biomass-derived CO_2 is not included in estimates of global warming potential.

Suter, Zimmermann, Frischknecht, et al.

In these studies, the wood enters the value chain with a negative CO_2 emission (related to CO_2 uptake in the forest) and downstream releases are then counted as emissions. Resulting emissions to atmosphere (not including upstream chains) are

- 1,070 + 21.7g CO_2/ kg paper in sanitary landfill during controlled phase (0-150 a)
- 138 g CH_4/ kg paper in sanitary landfill during controlled phase (0-150a)
- 1,062 g CO_2/ kg untreated wood in sanitary landfill during controlled phase (0-150 a)
- 135 g CH_4/ kg untreated wood in sanitary landfill during controlled phase (0-150a)

Grant, James, et al.

Methane is assumed to be completely transformed to CO_2 when combusted. Additional information on methane flaring is given above. The report assigns zero impact from biomass-derived CO_2. The report indicates that “if all the methane is captured, there is no greenhouse impact from landfilling of the organic fractions.”

Axel Springer Verlag AG et al.

It is assumed that 30% of paper goes to post consumer waste and 10% of paper used by deinking mills is also going to waste. All paper that goes to waste ends up as carbon emitted to the atmosphere from landfills or from incinerators. Carbon from landfills and from paper incineration is considered to be climate-neutral. The emissions are subtracted to the original CO_2 “bonus” given to wood from which paper is made.

EPA 2002

The report states that "CO_2 [from decomposition of biomass in landfills] is not counted as a greenhouse gas…" The amounts generated are estimated using the same methods as described above for methane.

5.10 Assumptions Made about the Use and Efficiency of Landfill Cover and Gas Collection Systems in Collecting and Destroying Methane

Yaros and Boustead, Carbon and energy balances in paper production

The authors state that the methane generated is usually collected and used as a fuel.

Paper Task Force, White Paper No. 3, 1995 with some tables updated to 2002

Carbon dioxide from landfills was not included as a greenhouse gas. For additional information see Section 5.7 above.

Young, Tonelli, Coté, and others at International Paper Company, Net carbon sequestration at pulp and paper mills, two papers

Landfill cover is not mentioned, but it is assumed (based on EPA data) that 53% of methane is collected and burned.

Forintek Canada Corp. (Athena)

Landfill issues are not covered.

Borjesson and Gustavsson, Greenhouse gas balances, 2000

This study indicates that 70% of methane is recovered.

Coté, Young, et al., Carbon balance method for paper and wood products

Not given, but cites work by Row, Skog, Micales and U.S. EPA. Also, see *Young, et al*. above for more information.

CORRIM, Inc., Life cycle environmental performance of renewable building materials. Also summarized with updates in Lippke, Garcia, et al.

Landfill gas issues are not addressed in this study.

ISO/TR 14047:2002(E), Environmental Management – Life Cycle Assessment

See discussion in Section 5.6 above.

Tiedemann

See discussion in Sections 5.7 and 5.9 above.

Suter, Zimmermann, Frischknecht, et al.

This study assumes that 47% of landfill gas released uncontrolled to the atmosphere and 53% is collected for burning (18% flared, 35% for energy use).

Grant, James, et al.

The permeability of the landfill covers (clay or HDPE liner) amounts to 1-3% (cited: Grant et al. 1999); see also Section 5.7 above. All landfills dispose of a landfill gas capturing system; 55% is used as a default value, the total range of reported values (EU and Australia) being 30 to 85%. The range of CH_4- oxidation within the landfill is 10 to 90%. The default value used is 50%.

Axel Springer Verlag AG et al.

Not given.

EPA 2002

EPA used their extensive data base and background in calculations to estimate the amount of methane that entered the atmosphere, as well as the amounts recovered and flared or burned for energy recovery. Methane that was burned to CO_2 was not included as it was considered to be part of the biogenic cycle. Methane burned with energy recovery received a carbon credit because of replacing utility generation from fossil fuels. For these electricity-generating landfills, a 15% downtime (flaring) was assumed. For landfills with gas collection systems, EPA assumed that these systems were 75% efficient. Of the uncollected methane, 10% was assumed to be oxidized in landfill covers before escaping to the atmosphere.

5.11 Other Carbon Sinks Included in the Life Cycle Study (e.g., permanent storage in archives, carbon in ash from waste-to-energy units, etc.)

Yaros and Boustead, Carbon and energy balances in paper production

Not given.

Paper Task Force, White Paper No. 3, 1995 with some tables updated to 2002

Not given.

Young, Tonelli, Coté, and others at International Paper Company, Net carbon sequestration at pulp and paper mills, two papers

Not given.

Forintek Canada Corp. (Athena)

Not covered in boundaries of study.

Borjesson and Gustavsson, Greenhouse gas balances, 2000

Not given.

Coté, Young, et al., Carbon balance method for paper and wood products

Not given.

CORRIM, Inc., Life cycle environmental performance of renewable building materials. Also summarized with updates in Lippke, Garcia, et al.

Not covered.

ISO/TR 14047:2002(E), Environmental Management – Life Cycle Assessment

The decay curves used for time-in-use allowed some carbon to remain in archives.

Tiedemann

No permanent storage assumed.

Suter, Zimmermann, Frischknecht, et al.

None.

Grant, James, et al.

No archives; incineration of waste is not used in Victoria; thus, no ash has to be considered.

Axel Springer Verlag AG et al.

Not given.

EPA 2000

Carbon in incinerator ash was excluded, but was mentioned as likely very small. Other miscellaneous sinks not included.

5.12 Conclusions about the Effects of Paper Paperboard or Wood Products Use, Reuse, and Disposal on Carbon Storage, and More Generally, on Net Greenhouse Gas emissions

Yaros and Boustead, Carbon and energy balances in paper production

Net GHG emissions are minimized by incinerating paper due to the multiplier effect of methane from landfills on net GHG emissions.

Paper Task Force, White Paper No. 3, 1995 with some tables updated to 2002

The authors concluded that recycling reduces net GHG as compared to virgin systems.

Young, Tonelli, Coté, and others at International Paper Company, Net carbon sequestration at pulp and paper mills, two papers

The effect of carbon storage in products is not addressed, and the carbon stored in landfills is thought to be very small compared to other carbon sequestration. It is 9% of total carbon emissions (although this value is not for emitted carbon). On a life cycle basis, the sequestration associated with the product systems for these mills is estimated to exceed the mills' emissions.

Forintek Canada Corp. (Athena)

The interim report from CORRIM, which is related to the Forintek work, indicates that, for the two settings examined, wood-based building structures have better life cycle greenhouse gas profiles than comparable steel- and concrete-based systems.

Borjesson and Gustavsson, Greenhouse gas balances, 2000

Under a variety of assumptions concerning reuse of wood, burning of demolition waste and collection and burning of methane, the use of wood framing results in about the same or more or less GHG emissions than does concrete framing. GHG emissions for wood exceeds that for concrete if all of the demolition waste goes to landfill.

Coté, Young, et al., Carbon balance method for paper and wood products

Concludes that the Texarkana plant results in net sequestration of carbon.

CORRIM, Inc., Life cycle environmental performance of renewable building materials. Also summarized with updates in Lippke, Garcia, et al.

The interim report from CORRIM indicates that, for the two settings examined, wood-based building structures have better life cycle greenhouse gas profiles than comparable steel- and concrete-based systems.

ISO/TR 14047:2002(E), Environmental Management – Life Cycle Assessment

The study provides an example of how to characterize carbon sequestration in forest products but does not reach specific conclusions beyond those related to estimation methods.

Tiedemann

The general conclusion of the study was that material recycling is the best solution, followed by incineration/energy production. Landfill is the “worst” solution. The total global warming potential (GWP) due to graphical paper in Germany corresponds to 800,000 to 900,000 inhabitants (out of ca. 80,000,000) despite a 69% collection rate (1995) and high material recycling (ca. 80%) and despite a “renewable” raw material.

Suter, Zimmermann, Frischknecht, et al.

None.

Grant, James, et al

Recycling leads to net savings, expressed for one average household in Melbourne per week, of 3.2 kg CO_2-equivalents (base scenario). Further net savings are 32.2 MJ embodied energy, 1.3 g ethene-equivalents (smog precursors) 92.5 litres water and 3.6 kg of solid waste.

Axel Springer Verlag AG et al.

Landfilling produces CO_2 emissions.

EPA 2002

EPA’s study is intended to allow local decision makers to arrive at their own conclusions regarding the preferred method for managing components of the municipal solid waste stream. In general, however, source reduction and recycling were found to reduce carbon emissions. Storage of carbon in forests and landfills reduced the carbon emissions of forest products examined in the study.

6.0 SUMMARY AND RECOMMENDATIONS

An extensive worldwide literature search was conducted to find Life Cycle Inventory (LCI) and Life Cycle Assessment (LCA) studies that considered the carbon cycle for wood or paper products in the use and end-of-life stages. The principal issues of interest were how the fate of carbon was evaluated during the product use phase and end of life in landfills, including methane emissions from landfills.

Thirteen studies were selected for more intense scrutiny. The results of this review can be summarized as follows.

- *Products Studied:* There was little consistency among the studies. A variety of packaging paper and paperboard grades were included, as well as printing papers. Three studies were on wood products.
- *Time in Use:* Product life was not a significant issue in the studies. Most paper and paperboard grades were assumed to be produced and discarded in the same year, while studies of wood products assumed 30 to 100 years of life with minimal disposal in landfills. Some studies stopped at the production of products and did not even consider life times. There was no evidence that time in use was adjusted for recycling.
- *Characterization of Carbon Removal by Trees:* The life cycle studies examined in detail generally did not address carbon sequestration in the forest. The few studies that explicitly address carbon sequestration in the forest used stock accounting approaches; i.e., sequestration was defined as the change in forest carbon stocks over time.

  In several cases, even though forest carbon sequestration was not explicitly addressed, the carbon contained in wood products was considered as a negative emission going into the value chain. The most common framework for following biomass carbon in the value chain was flow accounting, wherein biomass-derived CO_2 emissions are defined as actual physical transfers of biomass-CO_2 to the atmosphere. In most cases, however, biomass-derived CO_2 was tracked separately from fossil CO_2.
- *Carbon in Landfilled Products:* There was no common method for addressing this issue. Some studies did not include it. Several mentioned that there were no generally accepted models. Two assumed 100% degradation in landfills, while others assumed somewhere between zero to 66% degradation. When decomposition was considered, the most common approach was to use theoretical anaerobic decomposition equations using different time horizons and reaching different results. Two studies assumed that the degradation resulted in CO_2 only, and two studies considered forest product carbon degradation "carbon neutral," apparently ignoring the different greenhouse gas (GHG) effects of methane and CO_2. Many different assumptions were also used with regard to the fate of landfill gases, including different recovery assumptions and amount of recovered methane which is burned. In some instances, there was also a lack of detail provided on the emissions resulting from burning methane.

The areas that require the most emphasis from an LCA standpoint are the use cycle of the wood or paper products, and the sequestration of carbon in landfills plus the methane releases and capture from landfills. The background studies cited in Appendix A, while they are not LCAs in themselves, provide an important set of references for developing a protocol for LCAs for wood and paper products, especially with respect to landfilling. ISO 14047 provides further carbon cycle LCA methods to evaluate.

It is clear that much work remains to be done to establish a uniform recognition of the carbon balance for sequestration of carbon in wood and paper products and end of life releases of methane. LCA protocol also requires that scope and boundaries be established for each LCA. This process may influence the outcome of a study to the benefit or detriment of one product in a comparative analysis. Thus, a uniform protocol for addressing carbon in the use and end of life phase is very important.

APPENDIX A

COMPREHENSIVE LIST OF WOOD AND PAPER PRODUCT LCA STUDIES AVAILABLE TO THE PUBLIC: 1990—PRESENT

INTRODUCTION

This appendix includes the following sections:

- Citations for studies selected for further analysis of carbon flow methods, with some brief discussion of each
- Studies not selected for further analysis, with notes as to why they were not selected
- Studies dated 1994 and earlier
- General background studies, which may be useful for practitioners seeking to develop forest product LCAs.

CITATIONS FOR STUDIES SELECTED FOR FURTHER ANALYSIS OF CARBON FLOW METHODS

Yaros, B.R., and Boustead, I, Carbon and energy balances in paper production. In *Proceedings of the International Conference on Ecobalance*, Tsukuba, Japan, 1994 pp. 155-160.

Paper Task Force Report, *White paper no. 3, Lifecycle environmental comparison: virgin paper and recycled paper-based systems*. 1995 with some tables updated 2002, Environmental Defense Fund (may be downloaded from www.edf.org) also summarized in the following reference: **Blum, L., Dennison, R.A., and Ruston, J.F.** A life-cycle approach to purchasing and using environmentally preferable paper. *Journal of Industrial Ecology*, Vol 1, No. 3 (1998), pp. 15-46.

Young, R.J., Tonelli, J.P., Coté, W.A. and Row, C., A study of net carbon sequestration at integrated pulp and paper mills, International Paper, 1999. (copy obtained from Randolph Young, email:randolph.young@ipaper.com) summarized in:

Young, R.J., Row, C., Tonelli, J.P., Coté, W.A. and Lenocker, C. Carbon sequestration and paper: a carbon balance assessment**.** *Journal of Forestry*, 98(9): 38-43 (2000).

Forintek Canada Corp. *Raw material balances, energy profiles and environmental unit factor estimates for structural wood products*. Mar./93 Updated Apr./00: *Summary report: A life cycle analysis of Canadian softwood lumber production*. Prepared by Jamie K. Meil, ATHENA™ Sustainable Materials Institute. [Updated softwood lumber profile (green and dry lumber) is available from Canadian Raw Materials Database Initiative website (http://crmd.uwaterloo.ca/)].

Borjesson, P. and Gustavsson, L., Greenhouse gas balances in building construction: wood versus concrete from life-cycle and forest land-use perspectives. *Energy Policy* 28 (2000) 575-588.

Coté, W.A., R.A. Young, K.B. Risse, A.F. Costanza, J.P. Tonelli, and C. Lenocker. A carbon balance method for paper and wood products. *Environmental Pollution* 116 (2002) S1-S6.

CORRIM, Inc. *Life cycle environmental performance of renewable building materials in the context of residential building construction – Phase I interim research report on the research plan to develop environmental-performance measures for renewable building materials with alternatives for improved performance*. March, 2002. 255 pages.

International Standards Organization (ISO). 2003. *Environmental management - Life cycle assessment - Examples of application of ISO 1404*. Technical Report TR 14047:2003(E). Switzerland: International Standards Organization.

Tiedemann, A. et al.: *Ökobilanzen für graphische Papiere* (FKZ 103 501 20). UBA Texte 22/00. Berlin 2000 (+ CD rom). Including: Klöpffer, W.; Grahl, B.; Hamm, U.: Schlußbericht (Critical review) an das Umweltbundesamt Berlin (pp 1-16).

Plinke, E.; Schonert, M.; Meckel, H.; Detzel, A.; Giegrich, J.; Fehrenbach, H.; Ostermayer, A.; Schorb, A.; Heinisch, J.; Luxenhofer, K.; Schmitz, S.:

Schonert, M.; Metz, G.; Detzel, A.; Giegrich, J.; Ostermayer, A.; Schorb, A.; Schmitz, S. *Ökobilanz für Getränkeverpackungen II, Phase 2*. These studies are the most extensive packaging studies ever performed in Germany. They have been used in the political decision process and continue to be important factors. In addition to the UBA-LCAs, companies perform their own LCAs, including critical review according to ISO 14040 for submission to the federal ministry of the environment. Wood is used in the palettes (transport), paper cardboard, etc. as secondary packaging and as part of Tetrapak-type cartons. The basic methodology is the one developed by IFEU, Heidelberg (Umberto software) and not much different from the graphical paper study reviewed in detail by Tiedemann.

Suter, P. (responsible professor); Zimmermann, P. (project leader) et al. *Ökoinventare von Entsorgungsprozessen***,** 1996. and **Frischknecht, R., Bollens, U., Bosshart, S., Ciot, M., Ciseri, L., Doka, G., Dones, R., Gantner, U., Hischier, R., Martin, A. 1996** These Swiss studies are LCAs of wood and paper products, and contain information to integrate waste treatment scenarios into life cycle studies. The results are part of the Swiss LCA (Ecoinvent) database. A wide variety of wood and paper products are included.

Grant, T.; James, K.L.; Lundie, S.; Sonneveld, K.: January 2001, with additional information in: **James, K.L.; Grant, T.; Sonneveld, K.: (2002).** This study addresses waste management alternatives in Victoria, Australia. A number of materials are evaluated, including paper and paperboard packaging.

Axel Springer Verlag, STORA and CANFOR, **with a scientific consultant: INFRAS, Zurich**, *A life cycle assessment of the production of a daily newspaper and a weekly magazine (1998)***.** This study addresses carbon flows for newspapers and weekly magazines in Sweden, Canada and Germany.

STUDIES NOT SELECTED FOR FURTHER ANALYSIS

Following each reference is a brief explanatory note as to why the study was not selected, and in some instances, additional discussion of the study.

Glover, J., D.O. White and T.A.G. Langrish. Wood versus Concrete and Steel in House Construction – A life cycle assessment. *Journal of Forestry*, December 2002.

Energy only.

Bystrom, S. and L. Lonnstedt. Paper recycling: environmental and economic impact. *Resources Conservation and Recycling* 21 (1997) 109-127.

Carbon cycle not included.

Aylesford Newsprint. *Newsprint: A lifecycle study*. Work done by Ecobalance UK, available at http://www.aylesford-newsprint.co.uk/pdf/lcs.pdf.

Carbon cycle not included.

Denison, R. Environmental life-cycle comparisons of recycling, landfilling, and incineration: A review of recent studies. *Annual Review of Energy and the Environment* 1996 21:191-237, published by Annual Reviews Inc.

Carbon cycle not included.

Case Study -- Life Cycle Inventory of WWPA Western Lumber. LCA Symposium: Methods & Applications for the Forest Products Industry. In *TAPPI 1996 Life Cycle Assessment Symposium Proceedings* Atlanta, GA: Tappi Press.

Carbon storage and related issues specifically excluded (application of Scientific Certification Systems methods).

LCA of Distribution in Sacks. In *TAPPI 1996 Life Cycle Assessment Symposium Proceedings*. Atlanta, GA: Tappi Press.

Carbon cycle not included.

Smith, Matthew; Whitelegg, John. Life cycle analysis of housing. *Housing Studies*, Apr 97, Vol. 12 Issue 2, p215, 15p.

Does not address carbon balances (uses built-in Ecoindicators of SimaPro).

Scharai-Rad, M. and Welling, J. Environmental and energy balances of wood products and substitutes. FAO, Rome (2002) downloaded from http://www.fao.org/DOCREP/004/Y3609E/Y3609E00.HTM#Contents.

Discusses "CO_2 neutrality" of wood, but does not consider specific carbon storage calculations for forests, or carbon storage effects of use or disposal. All discarded wood products are assumed to be recycled or burned.

IEA Bioenergy, Task 25. Schlamadinger, B. (Task leader): *Greenhouse gas balances of bioenergy systems*. An international research collaboration under the auspices of the International Energy Agency. Homepage: http://www.joanneum.ac.atr/iea-bioenergy-task25.

> *Wood products not addressed specifically. Project description, no details. Important points are carbon storage dynamics; trade-offs (e.g., afforestations vs. fossil fuel substitution); emission factors; efficiency; upstream energy inputs; by-products; "leakage" (biofuel often provides an additional fuel without actually replacing fossil fuel); other greenhouse gases (CH_4 and N_2O explicitly mentioned). Planted forests in New Zealand are mentioned as carbon sinks (J.P. Maclaren 1996 cited).*

> *Remark: The group at Joanneum Graz/Austria seems to be especially active in the field LCA/bioenergy/forests. Graz is the capital of "green" Styria (60% covered by forests).*

Langowski, H.-C. (ed.) *Life cycle assessment study on resilient floor coverings.* For ERFMI. Fraunhofer IRB Verlag, ISBN 3-8167-5210-1, Stuttgart 1998. **Including: Klöpffer, W.; Tukker, A.; Richter, K.** *Life cycle inventory with impact assessment. Expert review, final report* August 1997, 11 pp. Short version published in journal as **Albrecht, G.; Langowski, H.-C.:** Life Cycle Assessment Study on Resilient Floor Coverings. *International Journal of Life Cycle Assessment* 2(2) 73-80. Related papers (describing the end-of-life models developed by Fraunhofer):

Kremer, M.; Goldhan, G.; Heyde, M.: Waste treatment in product specific life cycle inventories - An approach of material-related modeling. Part I: Incineration. *International Journal of Life Cycle Assessment* 3(1) 47-55 (1988) and **Bez, J.; Heyde, M.; Goldhan, G.** Waste treatment in product specific life cycle inventories - An approach of material-related modeling. Part II: Sanitary landfill. *International Journal of Life Cycle Assessment* 3(2) 100-105 (1988).

> *A comparative LCA of many floor coverings based on PVC, polyolefins, linoleum, rubber, textiles and wood (parquet). A reference lifetime of 20 years was chosen for all coverings, irrespective of their technical lifetimes or use times. f.u. = 20 m^2/20 yr. The most remarkable result of this study refers to parquet (one sample only for comparison with the resilient coverings). Parquet showed the highest GWP of all systems, since landfill was assumed as a major removal path. See also the Fraunhofer landfill model by Bez, Heyde and Goldhan (Part II).*

> *Bez assumed (possibly incorrectly) that a sanitary landfill is essentially terminated after 100 years (time horizon). It is argued that the leachate of a modern landfill can be collected near-quantitatively, but the biogas only incompletely "Only a small part of the landfill gas can be vacuumed off, cleaned and used as an energy carrier". A "reactor landfill model" is presented, based on average German landfills. The gas formed is used - in the average - for fueling a gas motor (13%), being flared (13%) or diffuses out of the landfill (74%). Wood and paper are not treated separately, but clearly belong to a broad category called the waste group "non inert."*

Heyde, M.; Kremer, M.: *Recycling and recovery of plastics from packaging in domestic waste. LCA-type analysis of different strategies*. LCA Documents Vol 5 (1999). ISBN 3-928379-57-7. Ecoinforma Press Bayreuth Including (Chapter 10): Bontoux, L.; Papameletiou, D. (Eds.): Critical Review (performed by Boustead I. et al.).

Appendix A4-4.1.2.

> *This is a comprehensive LCA which includes landfilling (Germany) and global warming. but focuses on plastics.*

Frühwald, A.; Hasch, J. Life cycle assessment of particleboards and fibreboards. (undated manuscript, 16 pp).

Cradle-to-mill gate, i.e. by definition no end of life included. Full LCAs are supposed to follow, using the generic data collected.

Jungmeier, G. Greenhouse gas balances of bioenergy systems. Short description of project (July 1997-June 1999).

This project aims at a full life-cycle balancing of different bioenergy systems for Austria 2000 and projected for 2020. The greenhouse emissions are quantified over the full life cycles and given in CO_2*-equivalents per kWh heat and/or electricity. No report is available. There is no attention to carbon sequestration in wood products.*

TU München, Holzforschung München (HFM) Ökobilanzierung Holzfußböden (LCA of wooden floor coverings) Ph.D. thesis by Barbara Nebel, ISBN 3-8316-0136-4, Herbert Utz Verlag, München (www.utzverlag.de). Short version (in German, August 2002) based on the Ph.D. thesis at http://www.oekobilanzen-holz.org . Related presentation (SETAC-Europe annual meeting, Hamburg 2003): Nebel, B.; Cowell, S. (University of Surrey, UK): Global Warming Reduction Potential of biomass based products: An example of wood products. (Abstract and PowerPoint slides available).

LCAs of several wooden floor coverings, functional unit: 1 m^2 *floor installed, including lacquer (coating), 50 years, renovation every 15 years, no cleaning. Reference time 1998-2001. There is only one end-of-life scenario: incineration + substitution of fossil fuels. Furthermore, the relatively long lived wooden products are considered as carbon sequestration.*

Strömberg, L.; Haglind, I.; Jacobson, B.; Ekvall, T.; Eriksson, E.; Kärnä, A.; Pajula, T. *Guidelines on life cycle inventory analysis of pulp and paper*. NORDPAP DP 2/30 SCAN FORSK-RAPPORT 669, February 1997.

Global warming and the carbon cycle are not treated in this guideline. Although it is mentioned in Section 4.3 (System Boundaries) that the life cycle extends to "final disposal", there is no further consideration of this important step.

Anna Rydberg et al. (CIT Ekologik, Chalmers Industriteknik) (2000) *LCA of the distribution in paper sacks. Executive summary*.

The landfill scenario gives the highest contribution to global warming of the paper sack scenarios, because of the methane emissions at the landfill. The fate of carbon is considered for several end-of-life scenarios but carbon sequestration is not considered. (Full report ordered from commissioner, but not received.)

Birgit Brunklaus; Henrikke Baumann. *Vad innebär ett ökat träbyggande i Sverige för miljön?* 20 pp. ESA-rapport 2002:6. Göteborg 2002.

Translation of title and summarizing paragraph asked for - not yet provided.

Nielsen, Per H.; Hauschild, Michael. Product specific emissions from municipal solid waste landfills. Part I: Landfill model. *International Journal of Life Cycle Assessment* 3(3) 158-168 (1998). Part II: Presentation and verification of the computer tool LCA-Land. *International Journal of Life Cycle Assessment* 3(4) 225-236 (1998).

Waste in landfill LCI-model, time frame 100 years (the oldest "modern" municipal landfills in Europe date back to the early 1970's). The assumption is made that 50% of the biogas is recovered for energy production (quantified as heat) and 50% is emitted to the atmosphere; no detailed information was available from literature. Wood and paper belong to the waste fraction "General Organic Matter," which is supposed to be easily degradable. All forest products are assumed to degrade at the same rate.

Finnveden, G.; Huppes, G. (eds.). *Life cycle assessment and treatment of solid waste.* ISSN 1102-6944. AFR-Report 98, Stockholm, November 1995 *Proceedings of a conference.*

This report is a summary comparison of twelve other studies. Carbon storage due to wood products is discussed in qualitative terms (p. 6).

Especially interesting for modeling landfills is the paper by Jan-Olov Sundquist: "LCA and Solid Waste: Organic materials in municipal solid waste landfill" pp. 138-148. It is argued that landfills will generate emissions for thousands of years, but we cannot measure these emissions today; hence the need for models and treating potential emissions rather than actual ones. A "surveyable time period" is suggested, consisting of the first four landfill phases (high internal activity) until the later part of the methane phase. After the methane phase, a kind of steady state is reached. The model includes microbial oxidation of CH_4 *during diffuse emission in the top soil layer (ca. 15%). During the surveyable time period, lignin and humus are not degraded, cellulose and hemicellulose 70% degraded, other carbohydrates, fats and proteins 100% degraded. Estimate: 67 g* CH_4*/kg paper product, if landfill gas collection is 50% efficient; 130 g* CH_4*/kg (GWP: 2,7 kg* CO_2 *equivalents) if no gas collection is installed (time horizon: surveyable time; order of magnitude: 100 years).*

Eriksson, P.-E. *Comparative LCAs for wood construction and other construction methods - Energy use and GHG emissions*. January 2003, 15 pp. (Source ?)

This report is a summary comparison of twelve other studies. Carbon storage due to wood products is discussed in qualitative terms (p. 6).

Finnveden, G.; Johansson, J.; Lind, P.; Moberg, Å. *Life cycle assessments of energy from solid waste*. Report fms 137, FOA-B-00-00622-222-SE. ISBN 91-7056-103-6; ISSN 1404-6520, fms report 2000:2. August 2000.

In the base scenario, emissions from landfills are considered for a hypothetical infinite time period. Wood products are not addressed specifically.

Quotations from the summary: "To summarize some of the overall conclusions it can be noted that recycling of paper and plastic materials are in general favourable according to our study with regard to overall energy use, emissions of greenhouse gases and the total weighted results . . . In the base scenario, emissions from landfills are considered for a hypothetical infinite time period. . . . The modeling of landfills can also have a decisive influence. If shorter periods are used, in the order of a century, landfilling is favoured and may become a preferable option over incineration."

Analisi del Ciclo di Vita di Prodotti in Legno. *Sintesi (Summary)*. 10 pp. Torino, Marzo 2001. Summary report in Italian. Related paper: **Nicoletti, G.M.; Notarnicola, B.; Tassielli, G.** LCA of beech manufactured products. Abstract of paper presented at the International Conference on Ecobalance, Mumbai (India), February 13-15, 2002 In *International Journal of Life Cycle Assessment* 7(3) 189 (2002).

No details given for wood products. Summary report in Italian. CO_2 assimilated to give wood is treated as a credit with negative sign; in that way, the carbon dioxide ("carbonio") emissions are fully counted in GWP calculations (fossil + biogenic). Burning of wood products (assumed "ciclo di vita" 1 year) with production of energy is considered as recycling (riciclo). At the end of the summary, however, three scenarios are considered: recycling, burning/energy reclaim, and landfill ("discarica"), since only 50% of wood (or all wood products?) are actually recycled in Italy today. A very high GWP is attributed to landfill and biogas is said to be the reason due to its methane ("metano") content - in the last sentence of the text.

Frühwald, A.; Solberg, B. (eds.). *Proceedings of the international workshop "Life-Cycle Analysis - a Challenge for Forestry and Forest Industry"***.** 3-5 May 1995, Hamburg, Germany.

This is a general overview of national carbon accounting issues and related activities for Europe. There is insufficient detail to support the analysis in this review.

European Forest Institute, Joensuu (Finland): Carbon balance implications from wood production chain, manufacturing and use of wood products. 1998-99.

No details are available.

An Independent Analysis of the Policy Options for Sustainable Recovery of Used Newspapers in the UK. Summary Report. Westlea, Swindon (undated, after 1997).

Recycling is compared with incineration/energy production, reducing fossil fuel, especially natural gas consumption. Recycling nevertheless turns out to be better with respect to a large number of impact categories. Landfill seems not to have been considered as an alternative (due to coming EU-directive?) in this prospective study.

Pré Consultants B.V. (NL) Marc Goedkoop. Tutorial "The Wood Example" (included in LCA software; Methane formation in landfills calculated) November 2002. Downloaded from the demo version of Simapro 5.1 (2003)**.**

Important, since part of the most wide-spread LCA software, but not an LCA. The analytical framework allows carbon to be sequestered in landfills but not in products in use. The tutorial is based on the BUWAL 250 (Swiss packaging LCI data collection) library. It is assumed that 80% of wood is decomposed in the first 150 years, 56% of the biogas is methane. Collection: Swiss average, i.e., 53% of CH_4 is collected (31% used as fuel, 22% burnt). Due to the use of 31% as fuel, less natural gas is used (SimaPro subtracts the emissions of the avoided natural gas. This corresponds to systems expansion acc. to ISO 14041).

Rieradevall, J.; Domènech, X.; Fullana, P. Application of life cycle assessment to landfilling. *International Journal of Life Cycle Assessment* 2(3) 141-144 (1997).

LCA (case study) of household waste removal in a typical Spain landfill: 200 N m^3 biogas per metric ton of waste, 55% gas collection efficiency, 55% CH_4, 45% CO_2, Wood and paper are not considered separately but definitely belong to the household waste.

Abfälle (Waste). *Ökoinventare für Verpackungen, Bd. II.* (2nd ed.) Schriftenreihe Umwelt Nr. 250/II, Bern 1998.

This is Volume II of a very influential and much used Swiss inventory data bank for packaging. It goes back to the "BUS" (= BUWAL = Swiss EPA) study of 1984, fully revised 1991 (BUWAL, Habersatter and Widmer), again revised 1996 and 1998.

Biogenic CO_2 is not included in the inventories, since it is considered to be climate-neutral. Some data are given, however, in separate tables (p. 428). The following amounts of CH_4 formed in controlled landfills ("Reaktordeponie") per kg waste are given [g]: newspaper 138, paper used for packaging 129, cardboard 123, wood 135.

Plätzer, E.T. Papier versus Neue Medien: Eine Analyse der Umweltverträglichkeit von Presseinformation im Licht des technologischen Wandels. Ph.D. Thesis 1998. The environmental compatibility of (graphical) paper as a carrier for information is compared with the new electronic media.

The environmental compatibility of (graphical) paper as a carrier for information is compared with the new electronic media. End of life is treated according to the method developed by ETH Zürich (1996).

Virtanen, Y.; Nilsson, S. *Environmental impacts of waste paper recycling.* ISBN 1-85383-160-3. Earthscan Publ. Ltd., London 1993.

Not an LCA, but gives interesting - albeit somewhat outdated - background information about environmental impacts of the paper life cycle (not only recycling).

Grassl, H.; Hinrichsen, K.; Jahnen, W.; Englisch, G.; Hendel, S. *Methanquellen in der industrialisierten Gesellschaft*. Beispiel Bundesrepublik Deutschland. Meteorologisches Institut der Universität Hamburg und Max-Planck-Institut für Meteorologie. Hamburg, Mai 1991.

In this report, which is not an LCA, methane formed in landfills is considered under the aspect of its contribution to global warming (greenhouse effect); CH_4-formation rates are given.

Annual Report 2001, p.74: Tahara, K. et al. CO_2 balance of afforestation in Western Australia - Test site at Lenora. (International Conference on Desert Technology 6, September 2001).

No details given.

Madhu Verma; Sachin Dubey; Ritu Bharadwaj. Application of life cycle assessment to forestry products. Abstract of paper presented at the International Conference on Ecobalance, Mumbai, February 13-15, 2002 In *International Journal of Life Cycle Assessment* 7(3) 187-188 (2002).

Short summary only. The main emphasis seems to be on "Non-Timber Forest Products (NTFPs)". e.g. seeds and medical plants. Sustainability study rather than full-blown LCI/LCA.

Tak Hur: Advances of LCA activities in Korea. *International Journal of Life Cycle Assessment* 8(2) 63 (2003).

Summary progress report about LCA in (South) Korea.

A national LCI data collection project (including waste treatment) will be successfully finished in September 2003. Paper seems to be included in the 200 base modules, since a paper towel LCA is mentioned.

Hashimoto, S.; Nose, M.; Obara, T.; Moriguchi, Y. Wood products: Potential carbon sequestration and impact on net carbon emissions of industrialized countries**.** *Environmental Science & Policy* 5 (2002) 183-193.

Not an LCA, but gives background information to the relationship between wood production, carbon sequestration and global warming; includes statistical data from many countries.

Hashimoto, S.; Moriguchi, Y.; Saito, A.; Ono, T. Six indicators of material cycles for describing society's metabolism: application to wood resources in Japan. *Environmental Science & Policy* (2003) 23 pp.

In press.

Werner, F. *Modelling of wood products in life cycle assessment with special emphasis on recycling and end-of-life*. Research and Work Report 115/48 EMPA Laboratory 115, Group Ecology. February 2002 (108 pp)

Short version (manuscript, 24 pp): **Werner, F.** *Recycling of used wood - Inclusion of end-of-life options in LCA***.**

Additional paper (manuscript, 19 pp): **Werner, F.; Künniger, T.; Richter, K.** *Holzprodukte in vergleichenden Ökobilanzen (Wood products in comparative LCAs)***,** in German.

*In this paper it is argued that 1 metric ton of dry wood (spruce) stores 1850 kg CO_2 which is given back to the atmosphere after natural biodegradation or incineration. The carbon dioxide stored in wood is therefore considered to be "CO_2-neutral." It is not mentioned, however, that this is only true for **aerobic** biodegradation and/or complete incineration. The energy stored (lower heating H_u) amounts to ca. 15 000 MJ (15 GJ) per ton dry wood. The manuscript is in its main part a meta-study, summarizing several wood LCAs.*

Werner, F.; Richter, K. *Parkett-Oekobilanz*. 1-page Summary by "Interessen-Gemeinschaft der Schweizerischen Parkett-Industrie /Communauté d´intérets de l´industrie Suisse du Parquet"

Advertisement. It is claimed that, based on Werner & Richter, 20-50% of the energy over the life cycle of parquet is renewable. The average use time is assumed to be 45 years; the UV-lacquers are based on water-soluble polymers.

Schweinle, J. About life cycle assessment of roundwood production in Germany. Accounting and managerial economics for an environmentally-friendly forestry. INRA Économie et sociologie rurales. *Actes et Communications* n° 15, 291-301 (1998)

*This study includes quantitatively the photosynthesis in the forests (softwood and hardwood), substances and energy. Only the growth of wood is considered. The LCA may therefore be designated as a "cradle-to-forest gate" LCA. Includes roundwood derived from the four major tree species in Germany: beech (*fagus sylvaticus*), oak (*quercus petraea*), Norway spruce (*picea abies*) and pine (*pinus sylvestris*).*

It is concluded that "as far as CO_2 is concerned, wood products have a great advantage in comparison to competing non-renewable materials. This should be stated out much more in future marketing strategies for wood products." However, "[t]he results shown above are only one facet of a whole LCA. Only a comparative LCA can show if forest products are more environmentally friendly than other products."

Finnveden, G.; Nielsen, P.H. Long-term emissions from landfills should not be disregarded. *International Journal of Life Cycle Assessment* 4(3) 125-126 (1999)

100 years are not enough. The landfills are expected to continue emitting pollutants both into the atmosphere and into the groundwater. The landfill site itself will remain a hazard for centuries.

Eggers, Thies; Karjalainen, T.; Pussinen, A. *Effects of the EU landfill directive on wood product carbon flows in Europe***.** (A 1-page summary of the EU-project: Long-term regional effects of climate change on European forests: impact assessment and consequences for carbon budgets (ENVA4-CT97-0577, DG 12-EHKN).

Not an LCA, but useful background information. A EU-Council directive, which is going to reduce biodegradable waste (including wood and paper) in landfilling to 75% (2006), 50% (2009) and 35% (2015) reference year = 1995, is modeled as a scenario. The changes in carbon stock and fluxes in the forest sector are calculated.

STUDIES DATED 1994 AND EARLIER

Vizcarra, A.T., K.V. Lao, and P.H. Lao. A life-cycle inventory of baby diapers subject to Canadian conditions, *Environmental Toxicology and Chemistry*, 13 (10):1707-1716, 1994.

Karna, A., J. Engstrom, and T. Kutinlahti. Recycling life cycle analysis of newsprint: a European view. *Pulp and Paper Canada*, 95: 11, 1994.

Life Cycle Inventory of a Corrugated Board Box. *1994 TAPPI Recycling Symposium Proceedings*. Atlanta, GA: Tappi Press.

A. Zabaniotou and E. Kassidi. Life cycle assessment applied to egg packaging made from polystyrene and recycled paper. *Journal of Cleaner Production*, 11 (2003) 549-559.

Pajula, T., and A. Karna. Life cycle scenarios of paper. In *Proceedings of the first Ecopapertech Conference*, Helsinki, June 1995. Paper may be available from the authors at the Finnish Pulp and Paper Research Institute, P.O. Box 70, FIN-02151 Espoo, Finland.

GENERAL BACKGROUND STUDIES

In the course of searching for LCA studies for this report, a number of basic documents were found that describe how to develop carbon cycle data for LCAs. These documents may be useful for practitioners seeking to develop forest product LCAs. The documents found are listed here for general information purposes.

Eleazer, W. E, Odle, W. S., Wang, Y.-S. and M. A. Barlaz. 1997. Biodegradability of municipal solid waste components in laboratory-scale landfills. *Environmental Science & Technology* 31 (3): 911-917.

Heath, L.S., Birdsey, R.A., Row, C., Plantinga, A.J. found in: Apps, M., Price, D. (eds.), Forest Ecosystems, Forest Management, and the Global Carbon Cycle, NATO Series Vol I 40. Springer-Verlag, Berlin, pp. 271-278.

Micales, J.A., Skog, K.E. 1997. The disposition of forest products in landfills. *International Biodeterioration and Degradation* 39 (1-3):145-158.

Row, C., Phelps, R.B. 1991. Carbon cycle Impacts if future forest products utilization and recycling trends. In *Agriculture in a world of change. Proceedings of Outlook 91*. U.S. Department of Agriculture, pp. 461-468.

Row, C., Phelps, R.B. 1996. Wood carbon flows and storage after timber harvest. In *Forests and Global Change, Vol. 2: Forest Management Opportunities for Mitigating Carbon Emissions*, ed. R.N. Sampson and D. Hair, 59-90. Washington, DC: American Forests.

Skog, K.E., Nicholson, G.A. 1996. Carbon cycling through wood products: the role of wood and paper products in carbon sequestration. *Forest Products Journal* 48, 75-83.

U.S. EPA. 2002. *Solid waste management and greenhouse gases – A life-cycle assessment of emissions and sinks*, 2nd Edition. EPA530-R-02-006. Washington, DC: U.S. Environmental Protection Agency.

Includes several references to the work of Morton Barlaz on landfill carbon issues. Provides descriptions of forest carbon models, sequestration in landfills and describes how HWP LCA calculations can be completed.

Life cycle inventory analysis user's guide: Enhanced methods and applications for the products of the forest industry. Prepared by The International Working Group, for the American Forest & Paper Association (1996).

Comprehensive guidance for conducting HWP LCA, but no data given.

Schwaiger, H.; Jäkel, U. (2000) Carbon balance of forest sectors in selected European countries under changing environmental conditions using a "stock change" accounting approach. *Mid-term Seminar Helsinki* 27-29. March 2000.

Not an LCI/LCA, but gives useful background information about carbon balances in several countries. Carbon storage in forests in four European countries: Austria, Germany, Finland and Portugal, and five species of trees: spruce, pine, beech, oak and birch. IPCC accounting approaches are included. Advantages of replacing non-wood products by wooden ones are discussed (emission factors). Predictions of the further development are made with a time horizon of 100 years.

Ekvall, Tomas. 1999. Key methodological issues for life cycle inventory analysis of paper recycling, *Journal of Cleaner Production*, 7:281-294.

Analyzes eight LCIs, but gives no details on disposal issues. Otherwise, it describes methods used to address carbon flows.

Finnveden, G.; Albertsson, A.-C.; Berendson, J.; Eriksson, E.; Höglund, L. O.; Karlsson, S.; Sundquist, J.-O. 1995. Solid waste treatment within the framework of life-cycle assessment. *Journal of Cleaner Production* 3(4) 189-199 (1995).

Methodological landmark paper, but no LCA/LCI. Incineration and landfilling are considered for inclusion into LCI (inputs and outputs), whereas formerly often only "solid waste" or several categories of such were listed and summed up in the inventory tables. Allocation and time frames are discussed. Data for landfill of corrugated cardboard in the surveyable time period (100 years): 130 g CH_4/kg waste (no gas extraction); 67 g CH_4/kg waste (with gas extraction). CO_2 is disregarded (neutral). Not collected methane is partly oxidized by soil bacteria on the way "up";

this fraction is estimated to 15%. Gas collection efficiency is estimated to be 50%. A method for calculating the CH_4-emission of paper and corrugated cardboard is given for 100 years time horizon, based on the cellulose and hemicellulose content (lignin is considered to be persistent in this time period).

APPENDIX B

DETAILED SUMMARIES OF CARBON BALANCE METHODS FOR SELECTED STUDIES (BY AUTHOR)

YAROS AND BOUSTEAD

Citation: Yaros, B.R., and Boustead, I. 1994.Carbon and energy balances in paper production. In *Proceedings of the International Conference on Ecobalance*, Tsukuba, Japan, pp. 155-160.

1. *General information describing the study (including boundaries).*

   This paper contains no data, but outlines an LCI methodology of tracking carbon and energy from absorption in growing trees, through all subsequent processing, and addresses the emissions of CO_2 and methane from landfills. The authors recommend that the initial boundary of LCA studies be the planting of trees.

2. *Grade(s) of paper and paperboard or type of wood product(s) covered in the study.*

   All (no specific grades or products were addressed).

3. *Time-in-use (i.e., elapsed time between final production and discard) assumed for each grade or product type.*

   Not given.

4. *Method used (if any) to adjust time-in-use to reflect the effects of recycling.*

   Not given.

5. *Method used to address the removal of carbon from the atmosphere by trees.*

   The authors suggest a framework for carbon accounting that does not address carbon sequestration in forests or products. It does include, however, "carbon dioxide absorption during tree growing…" and "carbon dioxide emissions when wood products are burned…." This can be characterized as a flow accounting approach; i.e., it defines biomass carbon emissions as flows of biomass carbon to the atmosphere (as opposed to stock accounting which defines biomass carbon emissions as reductions in biomass carbon stocks).

6. *Method and parameter values used to estimate the amount and duration of carbon storage in landfills attributable to paper, paperboard, and wood products.*

   Sequestration is not addressed.

7. *Method and parameter values used to estimate the amount and timing of methane generated from in landfills.*

   Chemical mass balances, assuming anaerobic decomposition.

8. *The source(s) of the parameter values used to estimate the fate of paper, paperboard or wood products in landfills (carbon storage and degradation to landfill gas).*

   Chemical mass balances, assuming anaerobic decomposition.

9. *Method and parameter values used to address the emission of carbon dioxide generated from paper, paperboard or wood products in landfills, including emissions from burning of methane.*

   The authors state that the methane generated in landfills is usually collected and used as a fuel. No distinction is made between GHG with origins from biomass or non-biomass sources.

10. *Assumptions made about the use and efficiency of landfill cover and gas collection systems in collecting and destroying methane.*

    The authors state that the methane generated is usually collected and used as a fuel.

11. *Other carbon sinks included in the life cycle study – e.g. permanent storage in archives, carbon in ash from waste-to-energy units, etc.*

    Not given.

12. *Conclusions about the effects of paper, paperboard or wood products use, reuse, and disposal on carbon storage, and more generally, on net greenhouse gas emissions.*

    Net GHG emissions are minimized by incinerating paper due the multiplier effect of methane from landfills on net GHG emissions.

PAPER TASK FORCE

Citation: Paper Task Force Report, White paper no. 3, Lifecycle environmental comparison: virgin paper and recycled paper-based systems, 1995 with some tables updated 2002, Environmental Defense Fund (may be downloaded from www.edf.org) also summarized in the following reference: **Blum, L., Dennison, R. A., and Ruston, J. F.** 1998. A life-cycle approach to purchasing and using environmentally preferable paper, *Journal of Industrial Ecology*, 1 (3):15-46.

1. *General information describing the study (including boundaries).*

   The boundaries of the study are from harvesting trees to final disposal emissions.

2. *Grade(s) of paper and paperboard or type of wood product(s) covered in the study.*

   Newsprint, corrugated, office paper, CUK (coated unbleached kraft) paperboard, SBS paperboard.

3. *Time-in-use (i.e., elapsed time between final production and discard) assumed for each grade or product type.*

   Unspecified average or typical values used.

4. *Method used (if any) to adjust time-in-use to reflect the effects of recycling.*

   Not given.

5. *Method used to address the removal of carbon from the atmosphere by trees.*

   This paper does not address carbon sequestration in forests or products. It tracks biomass CO_2 emissions separately from fossil fuel CO_2 emissions. A parameter called “total GHG emissions” is used that includes both biomass- and fossil fuel-derived CO_2. The comparisons between scenarios, however, are performed using “net GHG emissions”, a term that excludes biomass-derived CO_2 emissions. The exclusion of biomass-derived CO_2 from net GHG emissions is based on the recognition that the carbon in biomass-derived CO_2 was once in the atmosphere and therefore when it is returned to the atmosphere it results in no net increase in atmospheric carbon.

6. *Method and parameter values used to estimate the amount and duration of carbon storage in landfills attributable to paper, paperboard, and wood products.*

   No specific values for carbon sequestration were assumed.

7. *Method and parameter values used to estimate the amount and timing of methane generated from in landfills.*

   The method used was to take MSW carbon emission values from the following reference: Franklin Associates, Ltd., *The Role of Recycling in Integrated Solid Waste Management to the Year 2000*, prepared for Keep America Beautiful, Stamford, CT, 1994, Chapter 6 and Appendix I. The authors assumed that paper products have one-third more carbon than MSW, so CO_2 and methane emission numbers for MSW were adjusted upward. CO_2 from landfills was not included in the calculations because it comes from biomass. Methane emissions from landfills were multiplied by 20 to reflect the GHG CO_2 equivalency. (Note: In earlier versions of this report the authors used a factor of 69, but this was corrected in the 2002 updates.) Assumes that there is no recovery of methane from landfills.

8. *The source(s) of the parameter values used to estimate the fate of paper, paperboard or wood products in landfills (carbon storage and degradation to landfill gas).*

   See No. 7 above.

9. *Method and parameter values used to address the emission of carbon dioxide generated from paper, paperboard or wood products in landfills, including emissions from burning of methane.*

   See No. 7 above (*assumed* no methane was recovered from landfills). Carbon derived from biomass origins was *assumed* to be climate-neutral.

10. *Assumptions made about the use and efficiency of landfill cover and gas collection systems in collecting and destroying methane.*

    See No. 7 above.

11. *Other carbon sinks included in the life cycle study – e.g. permanent storage in archives, carbon in ash from waste-to-energy units, etc.*

    Not given.

12. *Conclusions about the effects of paper, paperboard or wood products use, reuse, and disposal on carbon storage, and more generally, on net greenhouse gas emissions.*

    The authors concluded that recycling reduces net GHG as compared to virgin systems.

YOUNG, TONELLI, COTÉ, ET AL.

Citation: Young, R. J., Tonelli, J. P., Coté, W. A. and Row, C. 1999. *A study of net carbon sequestration at integrated pulp and paper mills*. International Paper. (Copy obtained from Randolph Young, e-mail: randolph.young@ipaper.com.)

Summarized as: Young, R. J., Row, C., Tonelli, J. P., Coté, W. A. and Lenocker, C. 2000. Carbon sequestration and paper: a carbon balance assessment. *Journal of Forestry*, 98(9): 38-43.

1. *General information describing the study (including boundaries).*

   This paper appears to follow the same basic methodology as the paper by Coté et al., which describes a study of the Texarkana International Paper mill. This study is a carbon balance study of three International Paper mills located at Mobile, Alabama; Madison, Louisiana; and Texarkana, Texas. Data are presented for the three mills as a total, without giving details for the specific mills.

   The paper obtained directly from Dr. Young has substantially greater amounts of methodological details than does the *Journal of Forestry* article.

   The scope begins with the fixing of carbon by trees and ends with disposal of products. Fossil fuel inputs are included. Carbon in the soil in forests is excluded. Many aspects of forest dynamics are included, such as slash and root decay, which comprise the largest contributing category to carbon emissions.

2. *Grade(s) of paper and paperboard or type of wood product(s) covered in the study.*

   A wide variety of products are produced at the three mills, including bleached kraft and unbleached kraft, with recovered paper as a material input.

3. *Time-in-use (i.e., elapsed time between final production and discard) assumed for each grade or product type.*

   Production, consumption, and disposal are assumed to occur in the same year.

4. *Method used (if any) to adjust time-in-use to reflect the effects of recycling.*

   Not given.

5. *Method used to address the removal of carbon from the atmosphere by trees.*

   The authors follow carbon flows from the atmosphere into trees, through the value chain and then either back into the atmosphere or into permanent sequestration in the landfill. Forest carbon sequestration is estimated as the net carbon flows into and out of the forest rather than as a stock change in the forest. In addition, releases of biomass-derived carbon are assigned to the points where the transfer of carbon into the atmosphere physically takes place and are added to fossil fuel-derived CO_2 emissions. Thus, this study can be judged to be using a flow accounting framework for biomass carbon.

6. *Method and parameter values used to estimate the amount and duration of carbon storage in landfills attributable to paper, paperboard, and wood products.*

   The authors state that a reliable model has not been developed. They assume that half of paper will not decompose by anaerobic methods and half will decompose in accordance with "flask studies" by Eleazer et al. 1997.

7. *Method and parameter values used to estimate the amount and timing of methane generated from in landfills.*

   Fifty-three percent of methane is considered to be collected and burned (EPA estimates, no specific citation), but no timing information is given.

8. *The source(s) of the parameter values used to estimate the fate of paper, paperboard or wood products in landfills (carbon storage and degradation to landfill gas).*

   EPA estimates are mentioned but the citation is missing. Barlaz et al. 1997, is cited, but complete citation is not in either paper. The correct citation is probably Eleazer et al. 1997.

9. *Method and parameter values used to address the emission of carbon dioxide generated from paper, paperboard or wood products in landfills, including emissions from burning of methane.*

   Thirty percent of paper in a landfill is eventually emitted as a gas, with about half being methane. CO_2 emissions were reported two ways: from biomass origins and from all sources.

10. *Assumptions made about the use and efficiency of landfill cover and gas collection systems in collecting and destroying methane.*

    Landfill cover is not mentioned, and 53% of methane is collected and burned.

11. *Other carbon sinks included in the life cycle study – e.g. permanent storage in archives, carbon in ash from waste-to-energy units, etc.*

    Not given.

12. *Conclusions about the effects of paper, paperboard or wood products use, reuse, and disposal on carbon storage, and more generally, on net greenhouse gas emissions.*

    The effect of carbon storage in products is not addressed, and the carbon stored in landfills is thought to be very small compared to other carbon sequestration. It is 9% of total carbon emissions (although this value is not for emitted carbon).

FORINTEK CANADA CORP. (ATHENA)

Citation: Raw Material Balances, Energy Profiles and Environmental Unit Factor Estimates for Structural Wood Products. Mar./93 Prepared by Forintek Canada Corp. Updated Apr. 2000: Summary Report: *A Life Cycle Analysis of Canadian Softwood Lumber Production.* Prepared by Jamie K. Meil, ATHENA™ Sustainable Materials Institute. (Updated softwood lumber profile (green and dry lumber available from Canadian Raw Materials Database Initiative website (http://crmd.uwaterloo.ca/).

1. *General information describing the study (including boundaries).*

   The original LCI study followed Canadian wood product production from cradle to gate (circa early 1990s and average technology). While some of the data were regional in scope, the LCI profiles for each product were generalized to a national level. The latter update report on softwood lumber was also a cradle-to-gate study (mid to late 1990s, average technology). The update report replaced the resource extraction profile for all wood products derived from a softwood resource (e.g., excludes oriented strand board).

The study boundary includes all forest management activities (nursery operations, planting, and thinning), harvesting and transportation of raw fiber, production of solid wood products at the mill gate. Final product transportation by mode and distance is also indicated, but is not factored into the LCI profile. Data were developed from literature, proprietary studies conducted by Forintek Canada corp. and mill surveys.

2. *Grade(s) of paper and paperboard or type of wood product(s) covered in the study.*

   - Forest management, harvesting, and transportation to processing plants.
   - Regional small and large dimension softwood lumber production on both a green and dry basis.
   - Softwood plywood production.
   - Oriented strand board production.
   - Engineered wood products – glulam, laminated veneer lumber, parallel strand lumber and wood "I" joists.

3. *Time-in-use (i.e., elapsed time between final production and discard) assumed for each grade or product type.*

   Not applicable – the LCI gate was defined as a cradle-to-manufacturing gate analysis, specifically undertaken to support software dealing with the use of wood and other products in a whole building context.

4. *Method used (if any) to adjust time-in-use to reflect the effects of recycling.*

   Not applicable.

5. *Method used to address the removal of carbon from the atmosphere by trees.*

   The CORRIM project calculates forest carbon sequestration by calculating forest carbon stocks over time. Specifically, the report indicates that "carbon removed is calculated as the difference between carbon in the year before activity and carbon after the activity plus any accumulation during the year of activity." The study focuses on two specific forest systems, one in the Pacific Northwest (PNW) U.S. and the other in the Southeast (SE) U.S. Different models are used to calculate carbon stock changes in the two regions. In both cases, "carbon information…includes the standing carbon inventory just prior to harvest at the rotation age and an estimate of removed carbon through forest management activities, both intermediate thinning and the final harvest." The final report will explain the details on how the forest carbon stocks and stock changes are integrated into the life cycle analysis by following forest cohorts over time.

6. *Method and parameter values used to estimate the amount and duration of carbon storage in landfills attributable to paper, paperboard, and wood products.*

   Not covered as per point 3, above.

7. *Method and parameter values used to estimate the amount and timing of methane generated from in landfills.*

   Not covered as per point 3, above.

8. *The source(s) of the parameter values used to estimate the fate of paper, paperboard or wood products in landfills (carbon storage and degradation to landfill gas).*

Not covered as per point 3, above.

9. *Method and parameter values used to address the emission of carbon dioxide generated from paper, paperboard or wood products in landfills, including emissions from burning of methane.*

   Not covered as per point 3, above.

10. *Assumptions made about the use and efficiency of landfill cover and gas collection systems in collecting and destroying methane.*

    Not covered as per point 3, above.

11. *Other carbon sinks included in the life cycle study – e.g. permanent storage in archives, carbon in ash from waste-to-energy units, etc.*

    Not covered as per point 3, above.

12. *Conclusions about the effects of paper, paperboard or wood products use, reuse, and disposal on carbon storage, and more generally, on net greenhouse gas emissions.*

    Global warming potential based on CO_2, methane, and nitrous oxide. Carbon dioxide emissions associated with the burning of biomass was excluded from the GWP measure.

BORJESSON AND GUSTAVSSON

Citation: Borjesson, P. and Gustavsson, L. 2000. Greenhouse gas balances in building construction: wood versus concrete from life-cycle and forest land-use perspectives. *Energy Policy* 28 575-588.

1. *General information describing the study (including boundaries).*

   This is an LCI comparison of a Swedish apartment building with wood or concrete framing. Only GHG flows (CO_2 and methane) are considered. The scope begins with the extraction of raw materials and ends with the disposition of demolition waste. Fossil fuel uses to produce the framing as well as other structural components are considered.

2. *Grade(s) of paper and paperboard or type of wood product(s) covered in the study.*

   Lumber for framing.

3. *Time-in-use (i.e., elapsed time between final production and discard) assumed for each grade or product type.*

   The life of the building was assumed to be 50 or 100 years.

4. *Method used (if any) to adjust time-in-use to reflect the effects of recycling.*

   Not given.

5. *Method used to address the removal of carbon from the atmosphere by trees.*

   This study is a comparison of different building systems (i.e., wood vs. concrete) and examines forest carbon sequestration only tangentially. For those scenarios that used less wood that the wood-framed house, one of the options considered for the unused trees is allowing them to remain in the forest, storing carbon. The only forest carbon sequestration considered is equal to the carbon in the wood that otherwise would have been used in a wood-framed house. The report, therefore, cannot be said to have examined forest carbon sequestration.

6. *Method and parameter values used to estimate the amount and duration of carbon storage in landfills attributable to paper, paperboard, and wood products.*

   Based upon a literature search, it was assumed that 20% of wood is converted to landfill gas. Calculations are also provided for a range of 10% to 40% of wood being converted to gas. The remainder is stored.

7. *Method and parameter values used to estimate the amount and timing of methane generated from in landfills.*

   Sixty percent of the landfill gas is methane with the remainder being CO_2. A multiplier of 21 was used to convert methane emissions to CO_2 equivalents. It was assumed that 70% of landfill gas is collected and burned. Calculations were carried out for three time intervals: 0-100 years, 50-100 years, and 50-200 years. Landfill gas is shown only for the 50-200 year calculations.

8. *The source(s) of the parameter values used to estimate the fate of paper, paperboard or wood products in landfills (carbon storage and degradation to landfill gas).*

   Manna, et al. 1999. Modeling biogas production at landfill site. *Resources, Conservation and Recycling*, 26, 1-14.

   Pingoud, et al. 1996. Greenhouse impact of the Finnish sector including forest products and waste management, *Ambio* 25, 318-326.

   Swedish Environmental Protection Agency. 1996. *Deponering (Deposition)*. AFR-compendium 5, Stockholm, Sweden (in Swedish).

9. *Method and parameter values used to address the emission of carbon dioxide generated from paper, paperboard or wood products in landfills, including emissions from burning of methane Biomass and fossil emissions are treated separately.*

   The emissions of burning methane are not described, but No. 7 above describes the assumptions stated.

10. *Assumptions made about the use and efficiency of landfill cover and gas collection systems in collecting and destroying methane.*

    Seventy percent of methane was recovered.

11. Other *carbon sinks included in the life cycle study – e.g., permanent storage in archives, carbon in ash from waste-to-energy units, etc.*

    Not given.

12. *Conclusions about the effects of paper, paperboard or wood products use, reuse, and disposal on carbon storage, and more generally, on net greenhouse gas emissions.*

    Under a variety of assumptions concerning reuse of wood, burning of demolition waste and collection and burning of methane, the use of wood framing results in about the same or more or less GHG emissions than does concrete framing. GHG emissions for wood exceed those for concrete if all of the demolition waste goes to landfill.

COTÉ, YOUNG, ET AL.

Citation: Coté, W.A., R.A. Young, K.B. Risse, A.F. Costanza, J.P. Tonelli, and C. Lenocker. 2002. A carbon balance method for paper and wood products. *Environmental Pollution* 116:S1-S6.

1. *General information describing the study (including boundaries).*

   This paper describes a carbon balance analysis, and is not an LCI. However, it has most elements of an LCI, although it examines only carbon flows.

   This paper describes calculations for a paper mill in Texarkana, Texas. The scope begins with the growing of trees and ends with final disposal, including emissions subsequent to disposal, and sequestration in landfills. However, data were collected only on the portion of the system that begins with the wood arriving at the mill, and ends with the product ready for shipment to customers. Values for carbon flows both upstream and downstream from this were calculated using a variety of methodologies.

2. *Grade(s) of paper and paperboard or type of wood product(s) covered in the study.*

   Bleached board and bleached cupstock paper.

3. *Time-in-use (i.e., elapsed time between final production and discard) assumed for each grade or product type.*

   All occurrences in this study were assumed to happen in the same year.

4. *Method used (if any) to adjust time-in-use to reflect the effects of recycling.*

   Not given, but excludes virgin fiber that goes into material recovered for recycling.

5. *Method used to address the removal of carbon from the atmosphere by trees.*

   Values not given specifically, but cites work in the references given at the end of this report. Particularly, those by the following authors: Row, Hansen, Clark, Koch, and Young. They use the concept of a "drain area," the 70-county area from which wood is procured. They compare the carbon fixed by the growing trees to the carbon removed as harvested wood.

6. *Method and parameter values used to estimate the amount and duration of carbon storage in landfills attributable to paper, paperboard, and wood products.*

   Values not given nor are there any methodology details, but the paper cites work by Row, Skog, Micales and U.S. EPA (see references at the end).

7. *Method and parameter values used to estimate the amount and timing of methane generated from in landfills.*

   Values not given, but cites work by Row, Skog, Micales and U.S. EPA.

8. *The source(s) of the parameter values used to estimate the fate of paper, paperboard or wood products in landfills (carbon storage and degradation to landfill gas).*

   Values not given, but cites work by Row, Skog, Micales and U.S. EPA.

9. *Method and parameter values used to address the emission of carbon dioxide generated from paper, paperboard or wood products in landfills, including emissions from burning of methane.*

   No details are given, but cites work by Row, Skog, Micales and U.S. EPA. Biomass and fossil emissions are reported separately.

10. *Assumptions made about the use and efficiency of landfill cover and gas collection systems in collecting and destroying methane.*

    Not given, but cites work by Row, Skog, Micales and U.S. EPA.

11. *Other carbon sinks included in the life cycle study – e.g. permanent storage in archives, carbon in ash from waste-to-energy units, etc.*

    Not given.

12. *Conclusions about the effects of paper, paperboard or wood products use, reuse, and disposal on carbon storage, and more generally, on net greenhouse gas emissions.*

    Concludes that the Texarkana plant results in net sequestration of carbon.

Major References Cited in the Paper

Clark III, A. 1987. Summary of biomass equations available for softwood and hardwood species in the southern United States. In *Estimating tree biomass regressions and their error*. USDA Forest Service, Northeastern Forest Experiment Station.

Hansen, M.H., Frieswyk. T, Glover, J.F., Kelley, J.F. 1992. *The Eastwide Forest Inventory data base: Users manual*, USDA Forest Service, North Central Forest Experiment Station.

Heath, L.S., Birdsey, R.A., Row, C., Plantinga, A.J. found in: Apps, M., Price, D. (Eds.). *Forest ecosystems, forest management, and the global carbon cycle.* NATO Series Vol I 40. Springer-Verlag, Berlin, pp. 271-278.

Koch, P. 1989. *Estimates by species group and region in the USA*. USDA Forest Service, Northeast Forest Experiment Station.

Micales, J.A., Skog, K.E. 1997. The Disposition of forest products in landfills. *International Biodeterioration and Degradation* 39 (1-3), 145-158.

Row, C., Phelps, R.B. 1991. Carbon cycle impacts of future forest products utilization and recycling trends. In *Agriculture in a world of change. Proceedings of Outlook '91*. U.S. Department of Agriculture, pp. 461-468.

Row, C., Phelps, R.B. 1996. Wood carbon flows and storage after timber harvest. In *Forests and global change, Vol. 2: Forest management opportunities for mitigating carbon emissions,* ed. R.N. Sampson and D. Hair, 59-90. Washington, DC: American Forests.

Skog, K.E., Nicholson, G.A. 1996. Carbon cycling through wood products: the role of wood and paper products in carbon sequestration. *Forest Products Journal* 48, 75-83.

U.S. EPA, 1998. *Greenhouse gas emissions from management of selected materials in solid waste* (EPA 68-W6-0029). Washington, DC: U.S. EPA Office of Solid Waste and Policy.

Young, R.J., Row, C. Tonelli, J.P. Coté, W.A., Lenocker, C., 2000. Carbon sequestration and paper: a carbon balance assessment. *Journal of Forestry* 98(9):38-43.

CORRIM, INC.

CORRIM, Inc. 2002. *Life cycle environmental performance of renewable building materials in the context of residential building construction – Phase I interim research report on the research plan to develop environmental-performance measures for renewable building materials with alternatives for improved performance*. March, 2002. 255 pages.

Also summarized with updates in: **Lippke, Bruce, John Perez Garcia, and Carolina Manriquez.** 2003. *The Impact of forests and forest management on carbon storage*. Rural Technology Initiative, College of Forest Resources, University of Washington, June 2003.

1. *General information describing the study (including boundaries).*

   This is a regional U.S. LCI of solid wood products from cradle to completion of a residential building shell inclusive of transportation effects. The study boundary includes all forest management activities (nursery operations, planting and thinning), harvesting and transportation of raw fiber, production of solid wood products, product transportation to designated building sites and on-site construction effects of erecting residential building shells. The wood product residential structural shells are compared against alternative material shell designs (steel and concrete masonry). Two distinct timber and wood product producing regions are covered in the study—Pacific Northwest (PNW) and the U.S. Southeast (SE). Production technologies are stated to be average or typical for the late 1990s. Data have been developed from literature and mill surveys.

   Note: This is an interim report. A new updated report was due to be released during the summer of 2003. The expansion is to include additional products such as glulam beams, laminated veneer lumber and wood "I" joists. A personal communication with Dr. Bruce Lippke, professor and director of the Rural Technology Initiative, stated that the new report will look at direct emissions only, and will not include the indirect effects of CO and N_2O, which are included in the interim report.

2. *Grade(s) of paper and paperboard or type of wood product(s) covered in the study.*

   - Regional forest management of varying intensities, harvesting and transportation to processing plants.
   - Softwood lumber production on both a green and dry basis for the PNW and a dry basis only for SE.
   - Softwood plywood production for both the SE and PNW.
   - Oriented strand board production for the SE region only.

3. *Time-in-use (i.e., elapsed time between final production and discard) assumed for each grade or product type.*

   Not applicable for the interim report—the LCI gate was the completion of the residential shell on the building site. Dr. Bruce Lippke indicates that the new report (not yet completed) will consider landscape management systems which includes storage of carbon in products. There is also some data on this in the Rural Technology Report cited above.

4. *Method used (if any) to adjust time-in-use to reflect the effects of recycling.*

Not applicable.

5. M*ethod used to address the removal of carbon from the atmosphere by trees.*

   Carbon sequestration estimates were provided on the basis of scenario analysis which took into consideration regional location and species, management intensity (3 levels considered), rotation age and site class yield/growth projections. Carbon sequestration estimates considered standing carbon pools only (stem, branches, roots of the trees) and did not include any soil sequestration.

6. *Method and parameter values used to estimate the amount and duration of carbon storage in landfills attributable to paper, paperboard, and wood products.*

   Not covered.

7. *Method and parameter values used to estimate the amount and timing of methane generated from in landfills.*

   Not covered.

8. *The source(s) of the parameter values used to estimate the fate of paper, paperboard or wood products in landfills (carbon storage and degradation to landfill gas).*

   Not covered.

9. *Method and parameter values used to address the emission of carbon dioxide generated from paper, paperboard or wood products in landfills, including emissions from burning of methane.*

   Not covered.

10. *Assumptions made about the use and efficiency of landfill cover and gas collection systems in collecting and destroying methane.*

    Not applicable.

11. *Other carbon sinks included in the life cycle study – e.g., permanent storage in archives, carbon in ash from waste-to-energy units, etc.*

    Not covered.

12. *Conclusions about the effects of paper, paperboard or wood products use, reuse, and disposal on carbon storage, and more generally, on net greenhouse gas emissions.*

    Global warming potential based on CO_2, methane and nitrous oxide. Carbon dioxide emissions associated with the burning of biomass was excluded from the GWP measure.

ISO/TR 14047:2002(E)

Citation: International Standards Organization (ISO). 2003. *Environmental management - Life cycle assessment - Examples of application of ISO 1404*. Technical Report TR 14047:2003(E). Switzerland: International Standards Organization.

1. *General information describing the study (including boundaries).*

   This document is not an LCA of a specific product, but addresses the carbon balance issues for all stages of an LCA, from the forest through disposal. References are given for specific data sources and formulas are suggested for calculations.

2. *Grade(s) of paper and paperboard or type of wood product(s) covered in the study.*

   Example values are given for a variety of generic paper, paperboard, and lumber products.

3. *Time-in-use (i.e., elapsed time between final production and discard) assumed for each grade or product type.*

   Suggests use of a "half-life model" developed by USDA and the IRS.

4. *Method used (if any) to adjust time-in-use to reflect the effects of recycling.*

   Method given to incorporate recycling as part of the "half-life model" discussed in No. 3 above.

5. *Method used to address the removal of carbon from the atmosphere by trees.*

   In this example of the application of impact assessment to a forest products system, sequestered forest carbon is considered to be "the net growth in biomass carbon [in the forest], after discounting for harvesting." This is essentially a stock change calculation; i.e., forest carbon sequestration is equal to the increases in stocks of forest carbon. The increase in carbon stocks in the forest over a period of time reflects the net effect of a number of factors including growth, harvest, litter accumulation and decomposition, and other factors.

6. *Method and parameter values used to estimate the amount and duration of carbon storage in landfills attributable to paper, paperboard, and wood products.*

   References EPA models and the need for better factors, mentions the importance of developing methane emission factors.

7. *Method and parameter values used to estimate the amount and timing of methane generated from in landfills.*

   See No. 6 above.

8. *The source(s) of the parameter values used to estimate the fate of paper, paperboard or wood products in landfills (carbon storage and degradation to landfill gas).*

   See No. 6 above.

9. *Method and parameter values used to address the emission of carbon dioxide generated from paper, paperboard or wood products in landfills, including emissions from burning of methane.*

   See No. 6 above.

10. *Assumptions made about the use and efficiency of landfill cover and gas collection systems in collecting and destroying methane.*

See No. 6 above.

11. *Other carbon sinks included in the life cycle study – e.g. permanent storage in archives, carbon in ash from waste-to-energy units, etc.*

    See No. 3 above.

12. *Conclusions about the effects of paper, paperboard or wood products use, reuse, and disposal on carbon storage, and more generally, on net greenhouse gas emissions.*

    Not given.

TIEDEMANN

Citation: Tiedemann, A. et al. 2000. *Ökobilanzen für graphische Papiere* (FKZ 103 501 20). UBA Texte 22/00. Berlin 2000 (+ CD rom). Including: Klöpffer, W.; Grahl, B.; Hamm, U.: Schlußbericht (Critical review) an das Umweltbundesamt Berlin (pp 1-16).

1. *General information describing the study (including boundaries).*

   This study encompasses the whole graphical paper (printing paper) market of Germany and includes some important import countries (Scandinavia). The functional unit is the yearly amount of these paper types in Germany. The study emphasizes different recycling and waste management systems. The geographical system boundary is Germany plus the Scandinavian countries (Sweden, Norway, and Finland) for the early phases of the life cycle only. Excluded is North America due to lack of data. Reference year for the standard scenario: 1995.

2. *Grade(s) of paper and paperboard or type of wood product(s) covered in the study.*

   All important grades of paper used for graphical papers (newspaper, journals) and copy paper.

3. *Time-in-use (i.e., elapsed time between final production and discard) assumed for each grade or product type.*

   Short lived products, lifetime typically less than one year.

4. *Method used (if any) to adjust time-in-use to reflect the effects of recycling.*

   The products of recycling are similar with regard to lifetime (e.g., paper used for newspapers have a high amount of recycled paper).

5. *Method used to address the removal of carbon from the atmosphere by trees.*

   No specific model used; the biogenic CO_2 is not counted for GWP. The ecosystem forest was quantified in the category “land use” using the hemerobic level concept proposed by Isa Renner (Klöpffer & Renner 1995). In that way it was possible to distinguish a forestry “near to nature” (extensive cultivation) from intensive cultivation, as in plantations.

6. *Method and parameter values used to estimate the amount and duration of carbon storage in landfills attributable to paper, paperboard, and wood products.*

   The IFEU landfill model is based upon data from all German landfills in the mid-1990s. It describes a 50-year time horizon for products in the landfill, and does not include any carbon sequestration for organic carbon.

7. *Method and parameter values used to estimate the amount and timing of methane generated from in landfills.*

   During the 50 years, 50% of organic carbon is degraded.

8. *The source(s) of the parameter values used to estimate the fate of paper, paperboard or wood products in landfills (carbon storage and degradation to landfill gas).*

   There do not appear to be any specific data for different wood or paper products; rather, they are included in the general category of organic carbon.

9. *Method and parameter values used to address the emission of carbon dioxide generated from paper, paperboard or wood products in landfills, including emissions from burning of methane.*

   The carbon is released as a gas, which is 55% methane (by volume). Of the gas released, 62.5% is uncontrolled. Of the 32.5% that is collected, 47% is burned and 53% is used in internal combustion engines. No mention is made of the emissions from the burned or combusted methane.

10. *Assumptions made about the use and efficiency of landfill cover and gas collection systems in collecting and destroying methane.*

    See items 7 and 9 above.

11. *Other carbon sinks included in the life cycle study – e.g., permanent storage in archives, carbon in ash from waste-to-energy units, etc.*

    No permanent storage assumed.

12. *Conclusions about the effects of paper, paperboard or wood products use, reuse, and disposal on carbon storage, and more generally, on net greenhouse gas emissions.*

    The general conclusion of the study was that material recycling is the best solution, followed by incineration/energy production. Landfill is the “worst” solution. The total GWP due to graphical paper in Germany corresponds to 800,000 to 900,000 inhabitants (out of ca. 80,000,000) despite a 69% collection rate (1995) and high material recycling (ca. 80%) and despite a “renewable” raw material.

SUTER, ZIMMERMANN, FRISCHKNECHT, ET AL.

Citations:

a.) **Suter, P. (responsible professor); Zimmermann, P. (project leader) et al.** 1996. *Ökoinventare von Entsorgungsprozessen*, 1st Edition, ISBN No. 3-9520661-0-9 Zürich.

b.) **Frischknecht, R., Bollens, U., Bosshart, S., Ciot, M., Ciseri, L., Doka, G., Dones, R., Gantner, U., Hischier, R., Martin, A.** 1996: *Ökoinventare von Energiesystemen: Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz*. Edition No. 3, Gruppe Energie - Stoffe - Umwelt (ESU), Eidgenössische Technische Hochschule Zurich und Sektion Ganzheitliche Systemanalysen, Paul Scherrer Institut, Villigen, Bundesamt für Energie (ed.), Bern, CH.

1. *General information describing the studies (including boundaries).*

   a.) This study contains basic considerations for life cycle inventories of waste management processes in Switzerland. Incineration (municipal and hazardous waste), different types of landfill (sanitary, residual and inert material), and waste water treatment (different classes) are included. The goal is to integrate waste treatment in LCA studies. Status of technology refers to the year 1995. Infrastructure is included. There is a software tool (in Microsoft Excel) to calculate LCIs for waste treatment processes for individual waste compositions. The results can be used as an input to the life cycle inventory database ECOINVENT to calculate LCIs for waste specific treatment processes.

   b.) This study contains life cycle inventories of energy systems relevant for Switzerland. Wood is included mainly for use as fuel, but also as construction material in infrastructure. Paper and cardboard are used as packaging materials and not examined in detail.

   Both studies deliver generic data sets to be used for upstream chains and downstream processes in LCA studies, so the system boundaries are more like “cradle to gate” than “cradle to grave.” The two studies use results from each other. Processes covered in these studies are now included and updated in the Swiss life cycle assessment data base Ecoinvent 2000 (http://www.ecoinvent.ch/en/index.htm).

2. *Grade(s) of paper and paperboard or type of wood product(s) covered in the studies.*

   a.) In principle, all types; results for paper in sanitary landfill included as example.

   b.) Paper and paperboard, mainly for packaging purposes; wood as fuel and construction material.

3. *Time-in-use (i.e., elapsed time between final production and discard) assumed for each grade or product type.*

   30 years for construction wood.

4. *Method used (if any) to adjust time-in-use to reflect the effects of recycling.*

   Not modeled.

5. *Method used to address the removal of carbon from the atmosphere by trees.*

   Negative CO_2 emissions (-1,810 kg CO_2/t wood).

6. *Method and parameter values used to estimate the amount and duration of carbon storage in landfills attributable to paper, paperboard, and wood products.*

   100 % degradation within the controlled phase (150 years) is assumed.

7. *Method and parameter values used to estimate the amount and timing of methane generated from in landfills.*

   Duration of methane generation assumed to be 30 years.

   If carbon content of landfilled waste = 281g/kg, (carbon content of paper = 406 g/ kg), then theoretical amount of produced gas = 525 l/kg landfilled waste.

   Realistic amount of produced gas = 200 l/kg landfilled waste.

   Composition of landfill gas: 47Vol.-% CH_4 (335.7 g/m3), 37 Vol.-%CO_2 (726.8 g/m3), 13 Vol.-%N_2 (163 g/m3), 2.5Vol,-%O_2 (36 g/m3).

8. *The source(s) of the parameter values used to estimate the fate of paper, paperboard or wood products in landfills (carbon storage and degradation to landfill gas).*

   Derived by project team.

9. *Method and parameter values used to address the emission of carbon dioxide generated from paper, paperboard or wood products in landfills, including emissions from burning of methane.*

   Resulting emissions to atmosphere (not including upstream chains):

   1,070 + 21.7g CO_2/ kg paper in sanitary landfill during controlled phase (0-150 a)

   138 g CH_4/ kg paper in sanitary landfill during controlled phase (0-150a)

   1,062 g CO_2/ kg untreated wood in sanitary landfill during controlled phase (0-150 a)

   135 g CH_4/ kg untreated wood in sanitary landfill during controlled phase (0-150a)

10. *Assumptions made about the use and efficiency of landfill cover and gas collection systems in collecting and destroying methane.*

    47% of landfill gas released uncontrolled to the atmosphere.

    53% collected for burning (18% flared, 35% for energy use).

11. *Other carbon sinks included in the life cycle study – e.g., permanent storage in archives, carbon in ash from waste-to-energy units, etc.*

    None.

12. *Conclusions about the effects of paper, paperboard or wood products use, reuse, and disposal on carbon storage, and more generally, on net greenhouse gas emissions.*

    None.

GRANT, JAMES, ET AL.

Citation: Grant, T.; James, K.L.; Lundie, S.; Sonneveld, K. 2001. *Stage 2 Report for Life Cycle Assessment for Paper and Packaging Waste Management Scenarios in Victoria*. January 2001. Commissioned by EcoRecycle Victoria. Critical review performed in two stages by the Stakeholder Advisory Committee (SAC, data and presentation) and by CML Leiden (Technical peer review/LCA methodology). 140 pp (without attachments).

1. *General information describing the study (including boundaries).*

   The study refers to the waste management in the state of Victoria, Australia. It contains a complex model of the real system used in this state and can therefore not directly be transferred to other states of Australia or other continents. The principal question to be answered is

   > *"Does the current recycling system result in a net reduction in environmental impacts and if so what is the magnitude of this saving?"*

   Two alternatives are studied: landfill with electricity production and recycling. Avoided virgin material, avoided fossil fuels etc. are quantified in the inventories.

2. *Grade(s) of paper and paperboard or type of wood product(s) covered in the study.*

   The study object is the real waste collected within the waste management system of Victoria. Specifically, the following materials are considered:

   a.) Paper and paperboard packaging

   b.) Liquid paperboard (LPB)

   c.) High density polyethylene(HDPE)

   d.) Polyvinyl chloride (PVC)

   e.) Polyethylene terephthalate (PET)

   f.) Other, mixed packaging plastic

   g.) Glass (bottles and jars)

   h.) Steel cans

   i.) Aluminum cans

3. *Time-in-use (i.e., elapsed time between final production and discard) assumed for each grade or product type.*

   Paper and packaging waste is derived from short-lived products. The LCA may be characterized as an “end-of-life” LCA and starts with collection of waste. The substitution processes are, however, “cradle-to-grave” (e.g., electricity from coal). The time of methane production is described as “decades”; the time scenario seems to be nearer to the 100 year assumption than to indefinite time horizon preferred in recent Scandinavian and Swiss studies (except perhaps for scenario 1 – full degradation; see item 6).

4. *Method used (if any) to adjust time-in-use to reflect the effects of recycling.*

   See item 3.

5. *Method used to address the removal of carbon from the atmosphere by trees.*

   Although this study acknowledges that there are potential effects on forest carbon sequestration related to recycling, it includes only a brief evaluation of forest carbon. The evaluation, based on national carbon accounting data, causes the authors to conclude that the changes in forest carbon are small enough to be ignored and a "neutral carbon balance" is assumed.

6. *Method and parameter values used to estimate the amount and duration of carbon storage in landfills attributable to paper, paperboard, and wood products.*

   Three scenarios were used, No. 2 being the baseline scenario:

   a.) Full degradation of all organic compounds

   b.) Carbon sequestration (CS USEPA data): 34% of newspaper not degraded, 23% of paperboard not degraded)

   c.) Lignin content taken into account: 78% of newspaper not degraded, 53% of paperboard not degraded

7. *Method and parameter values used to estimate the amount and timing of methane generated from in landfills.*

   55% of the methane formed is assumed to be captured and used for flaring or electricity production; 50% of the remaining 45% non-captured methane is assumed to be oxidized within the landfill.

8. *The source(s) of the parameter values used to estimate the fate of paper, paperboard or wood products in landfills (carbon storage and degradation to landfill gas).*

   U.S. EPA, publications from EU and Australia.

9. *Method and parameter values used to address the emission of carbon dioxide generated from paper, paperboard or wood products in landfills, including emissions from burning of methane.*

   Full transformation of CH_4 to CO_2 during incineration (flaring or electricity production in three landfills).

   Oxidation within the landfill: see items 7 and 10.

10. *Assumptions made about the use and efficiency of landfill cover and gas collection systems in collecting and destroying methane.*

    The permeability of the landfill covers (clay or HDPE liner) amounts to 1-3% (cited: Grant et al. 1999); see also item 7. All landfills dispose of a landfill gas capturing system. 55% is used as a default value, the total range of reported values (EU and Australia) being 30 to 85%. The range of CH_4- oxidation within the landfill is 10 to 90%. The default value used is 50%.

11. *Other carbon sinks included in the life cycle study – e.g., permanent storage in archives, carbon in ash from waste-to-energy units, etc.*

    No archives; incineration of waste is not used in Victoria; thus, no ash has to be considered.

12. *Conclusions about the effects of paper, paperboard or wood products use, reuse, and disposal on carbon storage, and more generally, on net greenhouse gas emissions.*

Recycling leads to net savings, expressed for one average household in Melbourne per week, of 3.2 kg CO_2-equivalents (base scenario). Further net savings are 32.2 MJ embodied energy, 1.3 g ethene-equivalents (smog precursors) 92.5 litres water and 3.6 kg of solid waste.

AXEL SPRINGER VERLAG AG ET AL.

Citation: A life cycle assessment of the production of a daily newspaper and a weekly magazine. A study done for Axel Springer Verlag AG (in Germany), STORA (in Sweden) and CANFOR (in Canada).

1. *General information describing the study (including boundaries).*

The authors conclude that the major environmental impact resulting from carbon emissions comes from the burning of fossil fuels. Burning of wood or storing it in recycled paper helps lessen the impact.

2. *Grade(s) of paper and paperboard or type of wood product(s) covered in the study.*

Newspaper and printing paper used in weekly magazines.

3.*Time-in-use (i.e., elapsed time between final production and discard) assumed for each grade or product type.*

Not given.

4. *Method used (if any) to adjust time-in-use to reflect the effects of recycling.*

Time-in-use is not discussed, but recycled paper is considered a carbon sink.

5. *Method used to address the removal of carbon from the atmosphere by trees.*

The boundaries of this life cycle assessment do not include the forest. The carbon in harvested wood entering the value chain, however, is treated as a removal of carbon from the atmosphere. If this carbon reenters the atmosphere, for instance by decay or burning, this is treated as an emission at the point where the transfer to the atmosphere occurs and is considered the same as CO_2 from fossil fuel burning. Therefore, although the study does not directly address forest carbon stock accounting, the methods used downstream suggest that a flow accounting framework is being used for biomass carbon.

6. *Method and parameter values used to estimate the amount and duration of carbon storage.*

Not given.

7. *Method and parameter values used to estimate the amount and timing of methane generated from in landfills.*

Methane is not mentioned in the report.

8. *The source(s) of the parameter values used to estimate the fate of paper, paperboard or wood products in landfills (carbon storage and degradation to landfill gas).*

   Not given.

9. *Method and parameter values used to address the emission of carbon dioxide generated from paper, paperboard or wood products in landfills, including emissions from burning of methane.*

   It is assumed that 30% of paper goes to postconsumer waste and 10% of paper used by deinking mills also goes to waste. All paper that goes to waste ends up as carbon emitted to the atmosphere from landfills or from incinerators. Carbon from landfills and from paper incineration is considered to be climate-neutral. The emissions are subtracted to the original CO_2 “bonus” given to wood from which paper is made.

10. *Assumptions made about the use and efficiency of landfill cover and gas collection systems in collecting and destroying methane.*

    Not given.

11. *Other carbon sinks included in the life cycle study – e.g., permanent storage in archives, carbon in ash from waste-to-energy units, etc.*

    Not given.

12. *Conclusions about the effects of paper, paperboard or wood products use, reuse, and disposal on carbon storage, and more generally, on net greenhouse gas emissions.*

    Landfilling produces CO_2 emissions.

EPA 2002

Citation: EPA. 2002. *Solid waste management and greenhouse gases – A life cycle assessment of emissions and sinks*, 2nd ed. EPA report number EPA530-R-02-006. May 2002. http://www.epa.gov/epaoswer/non-hw/muncpl/ghg/greengas.pdf

1. *General information describing the study (including boundaries).*

   This study is called a “streamlined” LCA because it includes only greenhouse gases. However, it is life-cycle in scope as it starts with the growing of trees, and carries through to the final disposal of materials including fate of landfill emissions. It includes a careful consideration of many carbon cycle issues, including the carbon sequestered in the forest. Included are the effects on the carbon balance from source reduction, recycling, composting, combustion of fuels, landfilling, and subsequent treatment (or non-treatment) of landfill emissions. (While composting results in carbon storage in soils, the EPA study excludes forest products from composting because of practical limits on the scope of the study.)

2. *Grade(s) of paper and paperboard or type of wood product(s) covered in the study.*

   This life cycle study examines a number of forest products from a waste management perspective. The study includes the study of 16 specific products or materials found in solid waste. The forest products include corrugated, magazines/third class mail, newspaper, phonebooks, textbooks, dimension lumber (as listed in the category of “wood- containers and packaging”), and medium density fiberboard. Construction lumber does not appear to be covered in the estimates of quantities of materials discarded.

3. *Time-in-use (i.e., elapsed time between final production and discard) assumed for each grade or product type.*

   Time-in-use is not addressed in this study.

4. *Method used (if any) to adjust time-in-use to reflect the effects of recycling.*

   This study does not address time-in-use.

5. *Method used to address the removal of carbon from the atmosphere by trees.*

   Changes in forest carbon stocks are modeled using a family of models developed by the U.S. Forest Service.

6. *Method and parameter values used to estimate the amount and duration of carbon storage.*

   EPA relied solely on the experimental work of Barlaz for this data. (See NCASI Technical Bulletin No. 872 for a summary of these data.)

7. *Method and parameter values used to estimate the amount and timing of methane generated from in landfills.*

   See discussion in Section 5.6 above. Timing of methane release was not addressed. Instead, the study examined ultimate methane generation and release.

8. *The source(s) of the parameter values used to estimate the fate of paper, paperboard or wood products in landfills (carbon storage and degradation to landfill gas).*

   EPA used data generated by Barlaz (see NCASI Technical Bulletin No. 872) and national information on landfill use and design and MSW disposal rates.

9. *Method and parameter values used to address the emission of carbon dioxide generated from paper, paperboard or wood products in landfills, including emissions from burning of methane.*

   The report states that "CO_2 [from decomposition of biomass in landfills] is not counted as a greenhouse gas…" The amounts generated are estimated using the same methods as described above for methane.

10. *Assumptions made about the use and efficiency of landfill cover and gas collection systems in collecting and destroying methane.*

   EPA used their extensive database and background in calculations to estimate the amount of methane that entered the atmosphere, as well as the amounts recovered and flared or burned for energy recovery. Methane that was burned to CO_2 was not included as it was considered to be part of the biogenic cycle. Methane burned with energy recovery received a carbon credit because of replacing utility generation from fossil fuels. For these electricity-generating landfills, a 15% downtime (flaring) was assumed. For landfills with gas collection systems, EPA assumed that these systems were 75% efficient. Of the uncollected methane, 10% was assumed to be oxidized in landfill covers before escaping to the atmosphere.

11. *Other carbon sinks included in the life cycle study – e.g., permanent storage in archives, carbon in ash from waste-to-energy units, etc.*

    Carbon in incinerator ash was excluded, but was mentioned as likely very small. Other miscellaneous sinks not included.

12. *Conclusions about the effects of paper, paperboard or wood products use, reuse, and disposal on carbon storage, and more generally, on net greenhouse gas emissions.*

    EPA's study is intended to allow local decision makers to arrive at their own conclusions regarding the preferred method for managing components of the municipal solid waste stream. In general, however, source reduction and recycling were found to reduce carbon emissions. Storage of carbon in forests and landfills reduced the carbon emissions of forest products examined in the study.