Corrugated Packaging Life Cycle Assessment Summary Report

Prepared for:

CORRUGATED PACKAGING ALLIANCE

Fibre Box Association | TAPPI
American Forest & Paper Association |
Association of Independent Corrugated Converters

The Corrugated Packaging Alliance is a corrugated industry initiative jointly sponsored by the American Forest & Paper Association (AF&PA), the Association of Independent Corrugated Converters (AICC), the Fibre Box Association (FBA) and TAPPI. For more information, visit *www.corrugated.org*, *www.afandpa.org*, *www.aiccbox.org*, *www.fibrebox.org* **and** *www.tappi.org*.

CORRUGATED PACKAGING LIFE CYCLE ASSESSMENT SUMMARY REPORT

The Corrugated Packaging Alliance (CPA) commissioned NCASI to conduct a Life Cycle Assessment (LCA) of corrugated products. An LCA is a standardized, scientific tool to assess environmental impacts associated with all stages of a product's life from cradle to grave.

By commissioning this type of study, CPA can communicate to customers and stakeholders the environmental performance of corrugated products. At the same time, this study helps describe the environmental impacts of corrugated's different life-cycle stages in relation to overall environmental performance and the potential environmental benefits of process improvements.

The study evaluates the environmental performance of U.S. industry-average corrugated products manufactured in 2010 throughout their entire life cycle and subsequently contrasts environmental impacts of the industry-average corrugated products manufactured in 2010 with those made in 2006. The study also presents the relative impacts of both U.S. industry-average and 100 percent recycled content corrugated products made in 2010.

Objectives

There were three main objectives to the study:

1. To educate customers and stakeholders about the environmental attributes of the industry's corrugated products produced in 2010;
2. To contrast these updated results with the 2006 data published in 2009; and
3. To present the relative environmental performance of a 2010 corrugated product made of 100 percent recycled fiber with that of the industry-average recycled content (approximately 46 percent recycled fiber).

This study was performed following the principles described in the ISO 14040/14044 standards for study disclosed publically. An external peer review panel has reviewed the LCA study.

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Products Studied

Three different products were evaluated in this study:

1. The 2010 U.S. industry-average 1 kg corrugated product (main focus of this study);
2. The 2006 U.S. industry-average 1 kg corrugated product; and
3. The 2010 U.S. 1 kg corrugated product made from 100 percent recycled fiber (often referred to in this study as the 100 percent recycled product).

Corrugated products (e.g., corrugated boxes, sometimes called "cardboard boxes") are made of corrugated board (combined board). Corrugated board is the structure formed by bonding one or more sheets of fluted corrugating medium to one or more flat facings of linerboard.

The 2010 U.S.-average corrugated product studied consists of 70.1 percent linerboard and 29.9 percent corrugated medium with an average basis weight of 131.9 lb./thousand square feet (msf, 0.644 kg/m^2). In 2010, on average 46 percent of the fiber used to make new containerboard was from old corrugated containers (OCC), with the balance supplied mostly by Kraft and semi-chemical pulp. More information regarding the 2006 product can be found in the LCA report of the original study (**http://www.corrugated.org/upload/CPALCAfinalreport08-25-10.pdf**). It was assumed that the 2010 100 percent recycled product was made of the same ratio of linerboard to corrugating medium and had the same basis weight.

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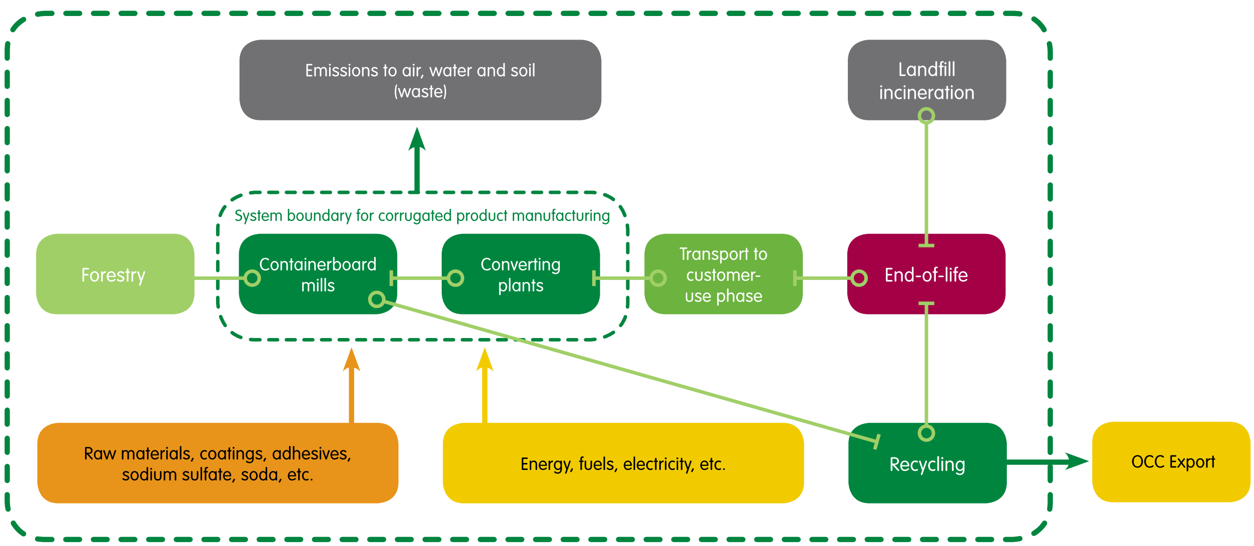
System Boundaries (Life Cycle)

The functional unit for the study was "***the domestic use of 1 kg of an average corrugated product produced in the U.S. in 2010.***" The system boundary included the entire life cycle of the corrugated product. The product system was separated into four life-cycle stages:

1. **Pulp and papermaking operations** include forest operations (planting, growing and harvesting of trees), transportation of forest products and production of containerboard, conversion into rolls, and supporting activities (on-site steam and power production, on-site chemical production, effluent treatment, on-site waste management, etc.).
2. **Converting** includes the activities involved in converting the linerboard and corrugating medium into corrugated packaging.
3. **Use** includes transportation to the use phase.
4. **End-of-Life** includes end-of-life management of the packaging product (landfilling, burning with energy recovery).

Figure 1.

System Scope and Life-cycle Phases for U.S. Average Corrugated Product
Summary of System Boundaries



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The study assessed corrugated life-cycle effects on the following seven environmental impact indicators:

1. Global warming potential
2. Ozone depletion
3. Photo-chemical oxidation (smog)
4. Acidification
5. Eutrophication
6. Respiratory effects (particulates)
7. Fossil fuel depletion

and four inventory indicators:

8. Non-renewable energy demand
9. Renewable energy demand
10. Water use
11. Water consumption

Definitions and information about each indicator are included in **Appendix D**.

In accordance with accepted greenhouse gas accounting practices, biomass-derived CO_2 (or "biogenic CO_2") was tracked separately from fossil fuel-derived CO_2 and other greenhouse gases in the life-cycle inventory. The net emissions of biogenic CO_2 were determined by taking the difference between biogenic CO_2 emissions from the system and CO_2 removals from the atmosphere by trees as they grow within system boundaries. The net emissions of biogenic CO_2 were added to other greenhouse gas (GHG) emissions to determine the global warming results. This approach was also used in the previous LCA study.

Results

Part 1. Industry-Average 2010 Product

Table 1 shows the relative life-cycle inventory results per functional unit for the 2010 industry-average corrugated product, including:

- Pulp and papermaking operations (mainly containerboard production) are the main contributors to all impact categories except for the global warming indicator. More detail on the global warming indicator is provided in the next section.
- Pulp and papermaking and converting contribute equally to water consumption results.
- Converting is also a contributor to most other indicators due to purchased electricity and natural gas.
- End-of-life contributes significantly to the global warming indicator results.
- Finally, the use phase (which primarily reflects the impacts of transportation) does not contribute significantly to impact categories.

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Table 1.

LCIA Results per Functional Unit

Impact category	Unit/FU	Total	Life Cycle Stage Contribution: 1. Pulp and Papermaking Operations	2. Converting	3. Use	4. End of Life (EOL)
Impact Assessment Indicators						
Global Warming, flow accounting*	kg CO_2 eq.	0.554	-0.0525 (-9.5%)	0.268 (48.4%)	0.0239 (4.3%)	0.315 (56.8%)
Ozone Depletion	kg CFC-11 eq.	1.28E-07	1.21E-07 (94.5%)	6.35E-09 (5.0%)	4.06E-10 (0.3%)	7.86E-11 (0.1%)
Photo-chemical oxidation (smog)	kg O_3 eq.	0.147	0.110 (74.8%)	0.0310 (21.1%)	0.0043 (3.0%)	0.0022 (1.5%)
Acidification	kg SO_2 eq. †	0.0130	0.0105 (80.8%)	0.0024 (18.1%)	0.0001 (1.0%)	7.50E-05 0.6%
Eutrophication	kg N eq.†	9.83E-04	8.18E-04 (83.2%)	1.26E-04 (12.8%)	8.68E-06 (0.9%)	3.11E-05 (3.2%)
Respiratory effects (particulates)	kg PM2.5 eq.	1.67E-03	1.47E-03 (88.0%)	1.43E-04 (8.6%)	5.32E-06 (0.3%)	4.86E-05 (2.9%)
Fossil fuel depletion	MJ surplus	1.96	1.34 (68.4%)	0.556 (28.4%)	0.0441 (2.3%)	0.0232 (1.2%)
Additional Inventory Indicators						
Non-renewable energy demand	MJ	21.8	16.1 (73.9%)	5.19 (23.8%)	0.326 (1.5%)	0.197 (0.9%)
Renewable energy demand ‡	MJ	14.4	13.7 (95.2%)	0.7 (4.8%)	≈ 0 (≈ 0%)	≈ 0 (≈ 0%)
Water use	kg	47.5	40.0 (84.2%)	7.26 (15.3%)	0.00 (0.0%)	0.00 (0.0%)
Water consumption	kg	13.6	6.68 (49.1%)	6.82 (50.1%)	0.00 (0.0%)	0.00 (0.0%)

**The flow accounting approach was also used in the previous LCA study. †Total of air and water. ‡Excluding energy of raw material inputs that are not used as an energy source to a product system (e.g., wood into pulp).*

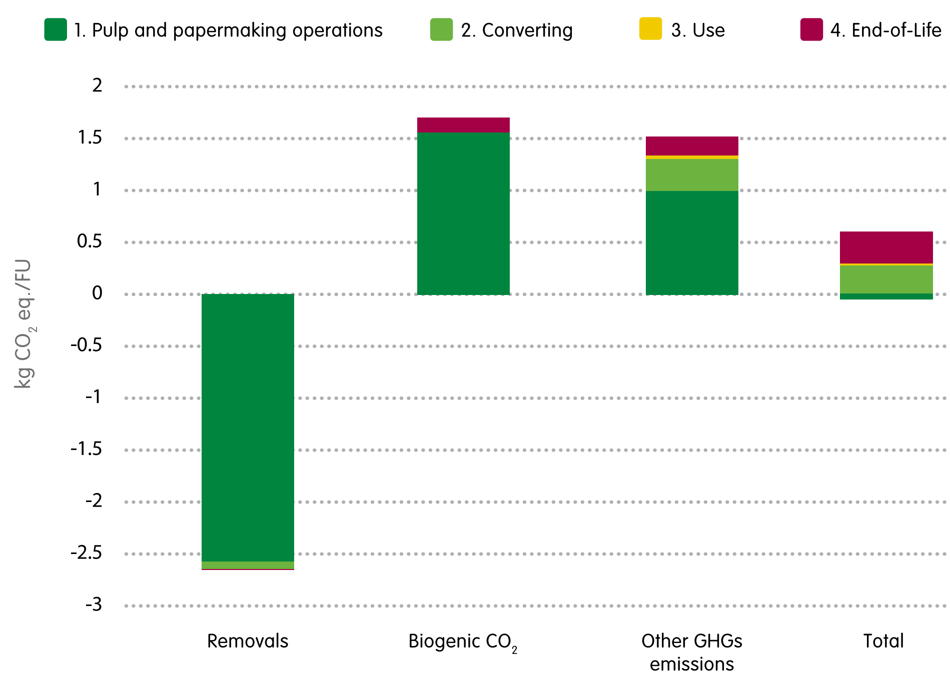
Details on Global Warming

This section presents additional details on the global warming indicator. Figure 2 below illustrates how each life-cycle stage contributes to the individual GHG emissions. From this figure, the following can be observed:

- **Removals** (primarily due to biomass – trees grown to produce containerboard) offset a large proportion of all GHGs (biogenic CO_2 and other GHGs). Live trees absorb and capture carbon from the atmosphere. That carbon remains trapped in the harvested wood fiber and manufactured corrugated product through its entire life cycle, right up to End-of-Life (EOL). The captured carbon, having been removed from the atmosphere, offsets that which is emitted at EOL.
- Emissions of biogenic CO_2 occur mainly at pulp and paper mills. (A portion of the sequestered carbon is released through combustion of biomass fuels at pulp and paper mills.)
- Emissions of other GHGs are spread out across pulp and papermaking operations, converting and EOL stages.
- Overall, the main contributors to the total global warming indicator are (in this order):
  1. End-of-Life
  2. Converting
  3. Pulp and papermaking operations

Figure 2.

Contribution of the Life-Cycle Stages to Individual GHGs



Within the **Pulp and Papermaking Operations** life-cycle stage, fiber production is responsible for removals of biogenic CO_2 from the atmosphere (carbon absorption and sequestration) while energy production is the main process responsible for biogenic CO_2 return to the atmosphere and other GHG emissions. The rest (for instance, chemical production and residuals management) does not contribute significantly to the global warming indicator.

In the **Converting** stage, while some removals are associated with chemical usage (starch, which is bio-based), there are very few emissions of biogenic CO_2 because converting facilities do not typically use biomass fuels. A fraction of the biogenic carbon associated with starch is released at End-of-Life. Other GHGs in this stage are distributed across energy (mainly purchased electricity and natural gas), transportation of the containerboard to converting facilities, and chemicals (mainly starch and ink).

At **End-of-Life**, methane from landfills is the main contributor to the global warming indicator. The previous study showed that results for the global warming indicator were sensitive to assumptions regarding landfill gas recovery and burning. The sensitivity analysis was not repeated in this study, but the effect is expected to be less important because less corrugated product was landfilled (more was recovered for recycling) in 2010 than in 2006.

Sensitivity Analyses

Sensitivity analyses were performed on various aspects to determine how certain assumptions, calculation methods and values would affect impact indicator results. Some observations from these are:

- The global warming indicator results are also affected by the corrugated recovery rate, due to the resulting impact on landfill disposal, and somewhat affected by the allocation method (See Appendix B).
- The global warming indicator results are sensitive to the approach used to calculate emissions of biogenic CO_2 (See Appendix C).
- Somewhat different results are obtained when using the CML and TRACI methods for the eutrophication indicator, mainly because these two methods give priority to different substances released to the environment (See Appendix C).
- The transportation distance of containerboard to converting facilities has a moderate effect on global warming, smog, fossil fuel depletion and non-renewable primary energy demand.

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Part 2. Industry-Average 2006 Product

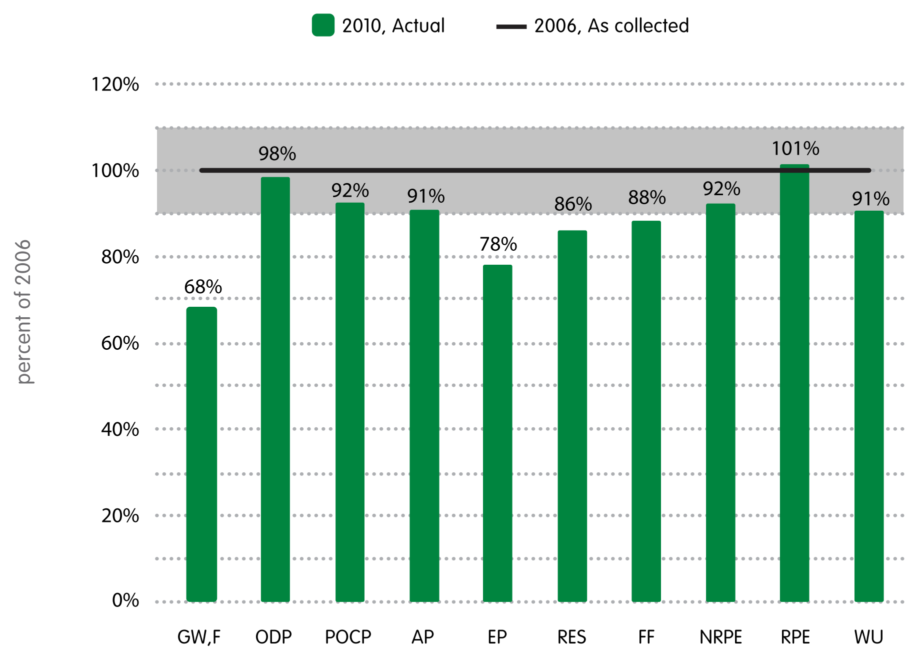
One objective of this study was to compare the environmental performance of the 2006 industry-average corrugated product to the 2010 industry-average corrugated product, and to document any changes. The 2006 report is publically available and can be found at http://www.corrugated.org/upload/CPALCAfinalreport08-25-10.pdf.

The system structure in 2010 was essentially the same as in 2006. However, the recovery rate[1] for old corrugated containers (OCC) increased from 72 percent to 85 percent between 2006 and 2010.

Figure 3 compares the impact scores obtained for 2010 with those obtained for 2006. It can be seen that from 2006 to 2010, the environmental performance of the industry-average corrugated product generally improved. Each indicator is discussed below.

Figure 3.

Comparing the Life-Cycle Environmental Performance of 2010 with that of 2006



- Between 2006 and 2010, the **global warming** indicator results were **reduced by 32 percent**, primarily because:
  - In 2010, the recovery rate for OCC was higher than in 2006, causing less corrugated to end up in landfills, where it could decompose and result in methane emissions.
  - Direct emissions of fossil fuel-related CO_2, methane and nitrous oxide from containerboard mills were reduced in 2010 compared to 2006. This was due to a decrease in total fossil fuel used and a switch from coal to less carbon-intensive fuels, mainly natural gas.

[1] Recovery rate: fraction of the OCC that is not disposed at its End-of-Life but rather is recovered to be recycled.

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    - The net biogenic CO_2 emissions (emissions minus removals) were lower in 2010 than in 2006, again mostly due to the increased recovery rate for OCC. (Carbon in recovered fiber remains sequestered through reuse, and increased recovery translates to reduced landfill emissions.)
    - Fiber and fuel production emissions were reduced.

- The indicator results for **eutrophication** were **reduced by 22 percent** between 2006 and 2010. This reduction is mainly due to a reduction in pulp and paper mill effluent phosphorus and to reduced atmospheric emissions of NO_x and SO_x from pulp and paper mills.
- Consumption of **fossil fuels** was reduced from 2006 to 2010. The fossil fuel depletion indicator went **down by 12 percent**, mainly due to reduced fossil fuel usage at containerboard mills. **Non-renewable energy** use also went down but the reduction was less significant.
- The result of the **respiratory effects** indicator **decreased by 14 percent** between 2006 and 2010, mainly due to reduction of SO_x emissions and particulates from pulp and paper mills.
- There were no significant changes in the **ozone depletion**, **smog**, **acidification**, **water use** and **renewable energy demand** indicator results between 2006 and 2010.

Industry-Average 2006 Product: Sensitivity Analyses

Several sensitivity analyses were undertaken to test the impacts of key variables on the comparison results. The sensitivity analysis found that the changes in the environmental performance of the industry-average corrugated product between 2006 and 2010 calculated in the study were affected in magnitude by the parameters examined in the sensitivity analysis but not in direction, indicating that the results are consistent.

Part 3. 100 Percent Recycled and Industry-Average 2010 Product

This section presents the results for the relative impacts of the 100 percent recycled and industry-average products (which include 46 percent recovered and 54 percent new fiber). The results are affected by the allocation method used. The study used two allocation methods for the environmental impacts of fiber production to calculate results. The method used for allocating those loads and benefits affects the calculation of results differently for each type of product, as explained below.

- The **Cut-Off Method** assigns all environmental burdens and benefits of producing new fiber (including forestry operations) to production of that new fiber only. This means that all the burdens of forestry operations are allocated to production of the new fiber, and none of those burdens are allocated to the 100 percent recycled product.
- The alternate, **Number-of-Uses allocation method** assigns the burdens and benefits of producing new fiber to both products (industry-average and 100 percent recycled) based on an average number of times the fiber is used.

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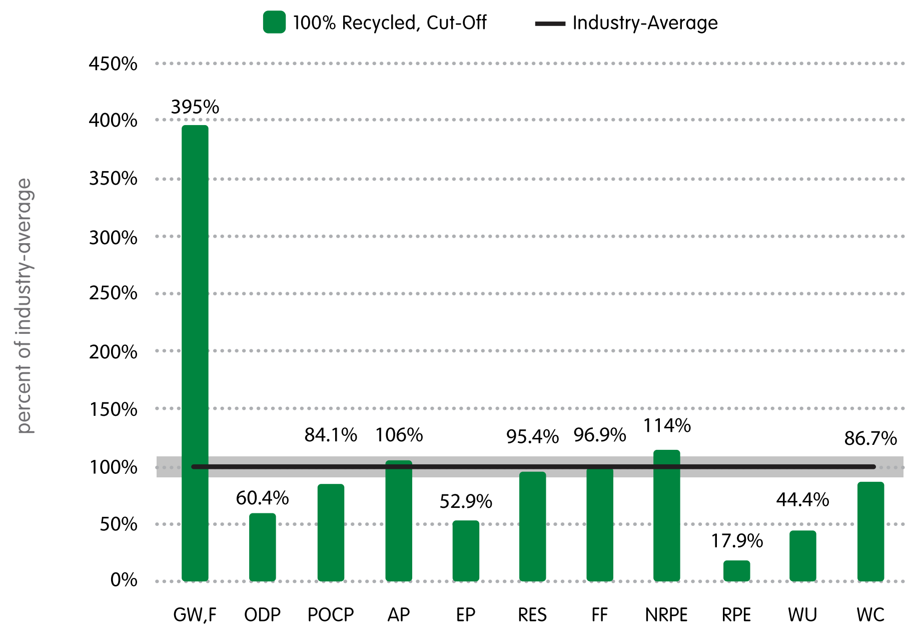
Cut-Off Method

Figure 4 presents the results for the comparison of the 100 percent recycled and industry-average recycled content products using the Cut-Off Method. From this figure, it can be observed that using the Cut-Off Method of allocation:

- Results in lower environmental impact in the global warming potential and non-renewable energy indicators for the industry-average product;
- Results in lower environmental impact in the ozone depletion, smog, eutrophication, renewable energy demand, water use and water consumption indicators for the 100 percent recycled product; and
- Results in no significant differences between the industry-average and 100 percent recycled products for the acidification, respiratory effects and fossil fuel depletion indicators.

Figure 4.

Comparison Impact Scores for 100 Percent Recycled and Industry-Average Corrugated Products (Cut-Off Method)



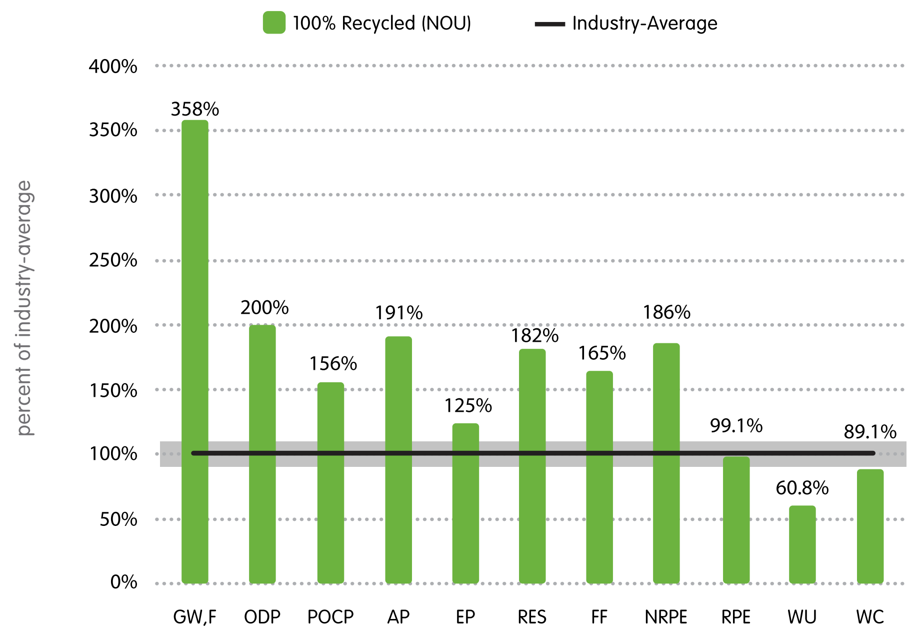
Number-of-Uses (NOU) Method

Figure 5 presents the results for the comparison of the 100 percent recycled and industry-average products using the Number-of-Uses method. From this figure, it can be observed that using the Number-of-Uses method for allocation:

- Results in lower environmental impacts in the global warming potential, ozone depletion, smog, acidification, eutrophication, respiratory effects, fossil fuel depletion and non-renewable energy demand indicators for the industry-average product;
- Results in lower environmental impacts in the water use and water consumption indicators for the 100 percent recycled product; and
- Results in no significant difference between the industry-average and 100 percent recycled products for the renewable energy demand indicator.

Figure 5.

Comparison Impact Scores for 100 Percent Recycled and Industry-Average Corrugated Products (Number-of-Uses Method)



100 Percent Recycled 2010 Product Results: Sensitivity Analyses

Several sensitivity analyses other than the allocation method for recycling were undertaken to test the robustness of the comparison results. The analyses indicated that the results presented are consistent.

Full Study Conclusions

This study represents a comprehensive LCA of 2010 U.S. industry-average corrugated product. The main conclusions that can be drawn from the study are discussed here.

1. The life-cycle environmental performance of the U.S. industry average corrugated product was significantly improved between 2006 and 2010. An improvement was observed for all indicators except ozone depletion, fossil-fuel depletion and non-renewable primary demand, for which the change was determined to be insignificant. Improvements in other impact categories were mainly due to:

    a. Increased recovery of corrugated products at their End-of-Life;

    b. Switch from coal to natural gas; and

    c. Reduction in pulp and paper mills' air releases of NO_x, SO_x and particulates.

2. Pulp and papermaking production (containerboard), including forestry, is the main driver of life-cycle environmental performance. For all impact categories, material and energy flows from pulp and paper mills dominate the results (positively or negatively). Environmental impacts are dominated by energy demands at the mill. Use of bio-based energy (e.g. hog-fuel, liquor, etc.) substantially reduces global warming contribution from mills.

3. Transportation of containerboard to converting facilities is important for some impact categories (e.g., fossil-fuel depletion, non-renewable energy demand).

4. End-of-Life only affects global warming indicator results. The global warming potential observed at End-of-Life is mainly due to methane generated in landfill operations, which is not captured and destroyed. Sensitivity analyses clearly showed that increasing the recovery rate has the potential to substantially reduce GHG emissions.

5. The global warming indicator results are affected by the approach used to calculate emissions of biogenic CO_2, highlighting the importance of understanding how biogenic CO_2 is accounted for in LCA studies.

6. The results of comparisons of a U.S. industry-average product to a 100 percent recycled product varied by indicator. Results show that one is not preferable over the other across all environmental indicators. The industry-average indicator results were lower for the global warming potential, acidification and non-renewable energy indicators regardless of the allocation method used. Results also suggest that the 100 percent recycled product uses and consumes less water, and consumes less renewable energy than the industry-average regardless of the allocation method used. The results for the other environmental indicators depend on the allocation method.

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APPENDIX

Appendix A. Data Sources

The data for the study were obtained from the following sources.

- Data on water inputs, environmental loads, solid waste management, and energy (quantity and types of fuels) for the relevant pulp and paper mills was drawn from responses to the 2010 AF&PA Environmental, Health, and Safety Survey.
- Information on quantity of energy used, fiber input, furnish production, and chemical consumption (quantity and type) at the department level were collected in a supplemental survey.
- Data regarding the emissions of toxic substances (as defined by the U.S. Toxic Release Inventory) were modeled using U.S. LCI and NCASI information.

Data on nutrient content of treated wastewater effluents from pulp and paper mills were derived from available information in the U.S. EPA Permit Compliance System database (**www.epa.gov/enviro/html/pcs/**); these data are insufficient to allow characterization of effluents from the specific mills in the database, but they do allow general characterization of effluents from U.S. pulp and paper mills.

- Data submitted by the industry in connection with the TSCA Inventory Update Rule (IUR, **www.epa.gov/iur/**) were used to estimate quantities of Kraft pulping co-products (e.g., turpentine and tall oil) produced; the IUR data were not sufficient to characterize every mill in the database, but were sufficient to characterize Kraft pulping processes in general.
- The converting facilities in the U.S. were surveyed to collect energy and material input information, production, and environmental release information.
- Data and models for other aspects of the life cycle (e.g., for landfills) were obtained from a number of government sources, public life-cycle databases (U.S. LCI, GaBi, *ecoinvent*), and published studies.

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Appendix B. Allocation Methods

Where allocation was needed to address co-products, the allocation was done using what was considered to be the most suitable available method with alternative methods being used in sensitivity analyses as appropriate.

The investigated product system is a hybrid of a closed-loop and open-loop product system because both closed-loop and open-loop recycling happen within the system. Recycling of converting wastes and old corrugated containers within containerboard production can be described as closed-loop recycling while imports and exports of recovered fiber to and from the investigated product system are cases of open-loop recycling. An *allocation method* is required to deal with open-loop recycling.

Two different recycling allocation methods were used in this study. One was used to characterize the environmental loads of the industry-average product. This and an additional method were used for comparing the 100 percent recycled product with the industry-average.

The allocation approach used in this study for the characterization of the industry-average product involved the assumption that the entire requirement for recovered fiber in containerboard production was fulfilled from converting wastes and old corrugated containers recovered at their End-of-Life (i.e., closed-loop recycling). In other words, no other recovered fiber sources (e.g., mixed papers) were considered for allocation purposes and hence no environmental load from other product systems was brought within the system boundary. In doing so, there was a net export of recovered fiber to other systems because more old corrugated containers are recovered than the containerboard production process actually needs.

It was assumed that this net export of recovered fiber leaves the system boundary without any environmental load associated with it (i.e., a Cut-Off Method was used). It is known that the choice of an allocation method for recycling is critical for comparing paper products with different recycled fiber contents. For this reason, two different methods were used to perform the comparison of the 100 percent recycled and industry-average products, each of which expresses a different perspective on how the environmental burden and benefits of new fiber production processes is shared across all uses of the fiber (i.e., first-use and recycled). The first method used is the *Cut-Off Method* described above.

The second method employed was the *Number-of-Uses Method* described in the ISO 14044 Standard and its accompanying technical report (ISO 14049). This second method was selected for several reasons. Among them is a recommendation from an international working group working on LCI issues, as included in a 1996 report by AF&PA (*Life Cycle Inventory Analysis User's Guide - Enhanced Methods and Applications for the Products Industry*), that this method be used in LCA studies of paper because it is the only one that reflects the complex interactions between new and recycled fiber. The main difference between the two methods is that the Cut-Off Method assigns the environmental burdens and benefits to new fiber only, while the Number-of-Uses Method shares the burdens and benefits across the new fiber and subsequent uses when being recycled.

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Appendix C. Methodology

The life-cycle modeling was done using the GaBiTM software package. Environmental impacts were characterized using the TRACI impact assessment method developed by U.S. EPA, using Intergovernmental Panel on Climate Change (IPCC) factors for global warming.

Biogenic CO_2 Calculations

In accordance with accepted greenhouse gas accounting practices, biomass-derived CO_2 was tracked separately from fossil fuel-derived CO_2 and other greenhouse gases in the life-cycle inventory. The effects of biomass carbon on the atmosphere were characterized by calculating the net emissions of biogenic CO_2 (emissions minus removals), which were then added to the global warming results. This approach, referred to as flow accounting, was also used in the previous LCA study.

Impact Indicator Calculations

In addition, impact indicator results were developed for the following indicators: ozone depletion, photochemical oxidation (smog), acidification, eutrophication, and fossil fuel depletion. The CML method was used to test the sensitivity of the acidification, eutrophication and smog indicators.

Results were also developed for the following additional inventory indicators: non-renewable primary energy demand and renewable primary energy demand, based on the method available in GaBi,™ as well as water use and water consumption based on life-cycle inventory data. Renewable primary energy demand excluded the intrinsic feedstock energy (which is the heat of combustion) of a raw material input not used as an energy source in the studied product systems.

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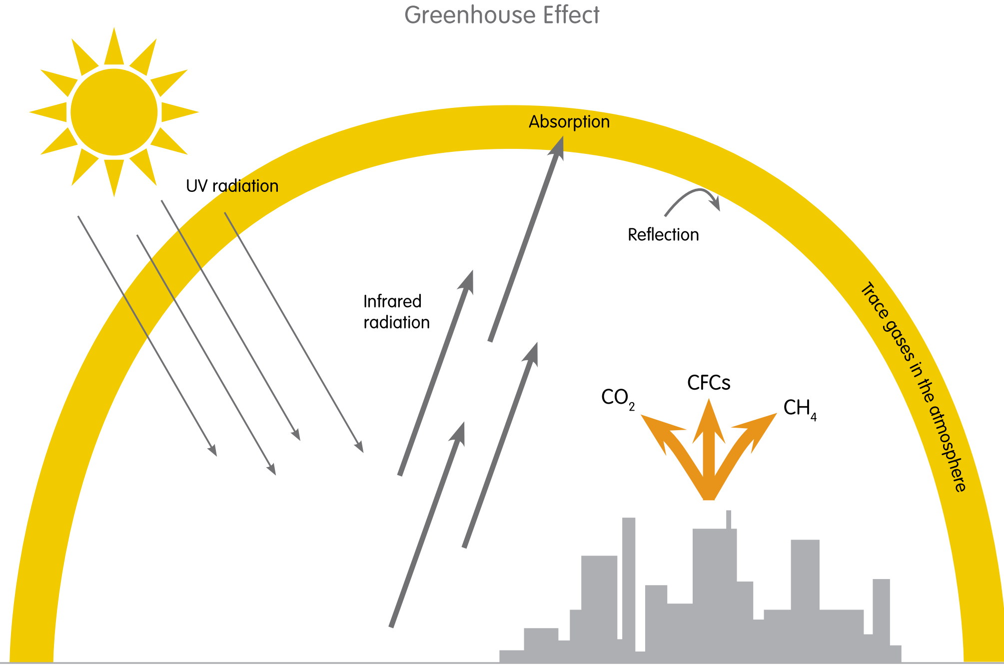
Appendix D. Impact Indicators

Global Warming Potential (GW,F)

The mechanism of the greenhouse effect can be observed on a small scale, as the name suggests, in a greenhouse. These effects are also occurring on a global scale. The shortwave radiation from the sun comes into contact with the Earth's surface and is partly absorbed (leading to direct warming) and partly reflected as infrared radiation. The reflected part is absorbed by so-called greenhouse gases in the troposphere and is re-radiated in all directions, including back to Earth. This results in a warming effect at the Earth's surface. In addition to the natural mechanism, the greenhouse effect is enhanced by human activities. Greenhouse gases that are considered to be caused, or increased, anthropogenically are, for example, carbon dioxide, methane and CFCs. **Figure 1**, below, shows the main processes of the anthropogenic greenhouse effect. An analysis of the greenhouse effect should consider the possible long-term global effects. The global warming potential is calculated in carbon dioxide equivalents (CO_2 eq.). This means that the greenhouse potential of an emission is given in relation to CO_2. Since the residence time of the gases in the atmosphere is incorporated into the calculation, a time range for the assessment must also be specified. A period of 100 years is customary.

Figure 1.

Greenhouse Effect



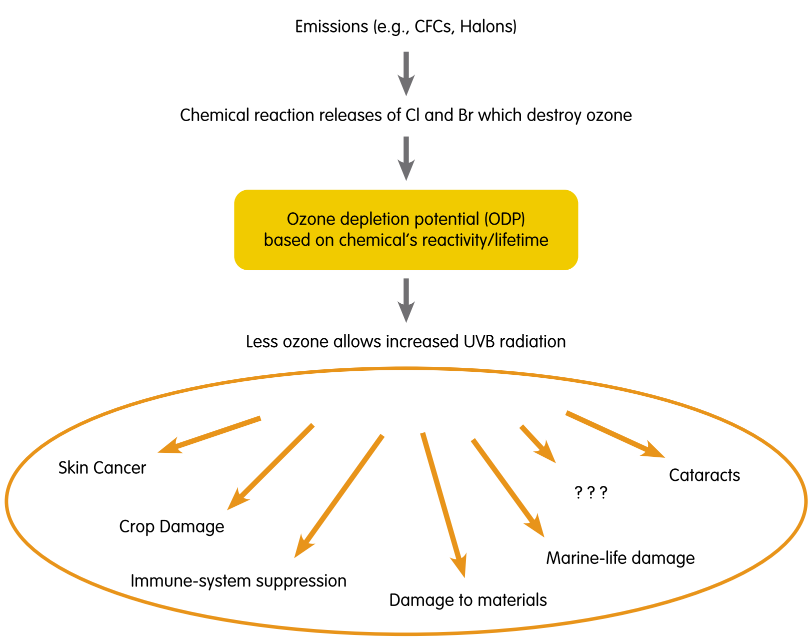
Ozone Depletion (ODP)

Text taken from Bare et al. (2003, p. 56)

Ozone (O_3) depletion is the reduction of the protective ozone within the stratosphere caused by emissions of ozone-depleting substances. Recent anthropogenic emissions of CFCs, halons, and other ozone-depleting substances are believed to be causing an acceleration of destructive chemical reactions, resulting in lower ozone levels and ozone "holes" in certain locations. These reductions in the level of ozone in the stratosphere lead to increasing ultraviolet-B (UVB) radiation reaching the Earth. As shown in **Figure 2**, below, increasing UVB radiation can cause additional cases of skin cancer and cataracts. UVB radiation can also have deleterious effects on crops, materials, and marine life. International consensus exists on the use of ozone depletion potentials, a metric proposed by the World Meteorological Organization for calculating the relative importance of CFCs, hydrochlorofluorocarbons (HFCs), and halons expected to contribute significantly to the breakdown of the ozone layer. The reference substance is CFC-11 (CFC-11 eq.).

Figure 2.

Ozone Depletion Impact Pathways
[Figure taken from Bare et al. (2003, p. 54)]

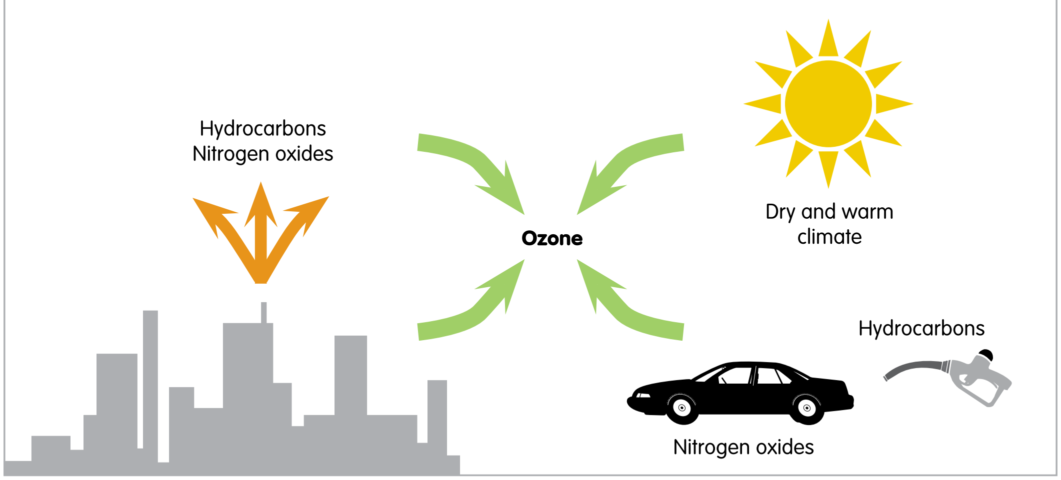


Photochemical Oxidation (Smog, POF)

Despite playing a protective role in the stratosphere, at ground level ozone is classified as a damaging trace gas. Photochemical ozone production in the troposphere, also known as summer smog, is suspected to damage vegetation and material. High concentrations of ozone are toxic to humans. Radiation from the sun in the presence of nitrogen oxides and hydrocarbons can result in complex chemical reactions, producing aggressive reaction products, one of which is ozone. Nitrogen oxides alone do not cause high ozone concentration levels. Hydrocarbon emissions occur from incomplete combustion, in conjunction with petrol (storage, turnover, refueling etc.) or from solvents. High concentrations of ozone arise when the temperature is high, humidity is low, when air is relatively static and when there are high concentrations of hydrocarbons. Because CO (carbon monoxide, mostly emitted from vehicles) reduces the accumulated ozone to CO_2 and O_2, high concentrations of ozone do not often occur near hydrocarbon emission sources. Higher ozone concentrations more commonly arise in areas of clean air, such as forests, where there is less CO. In TRACI, photochemical ozone formation is referred to in ozone equivalents (O_3 eq.). When analyzing, it's important to remember that the actual ozone concentration is strongly influenced by the weather and by the characteristics of the local conditions.

Figure 3.

Photochemical Oxidant Formation Impact Pathways



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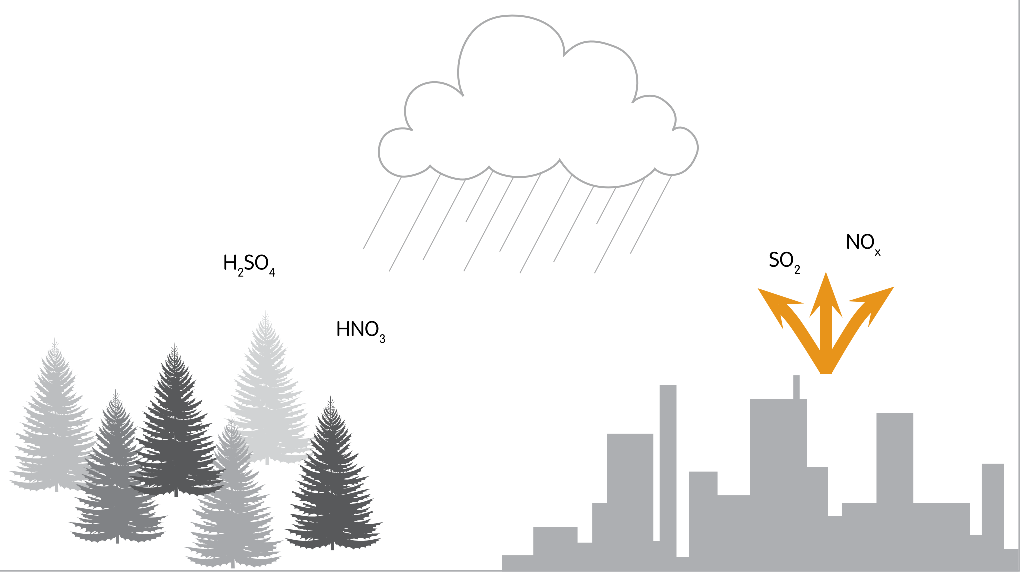
Acidification (AP)

The acidification of soils and waters occurs predominantly through transformation of air pollutants into acids. This leads to a decrease in the pH-value of rainwater and fog from 5.6 to 4 and below. Sulfur dioxide, nitrogen oxide and their respective acids (H_2SO_4 und HNO_3) produce relevant contributions. This damages ecosystems, whereby forest dieback is the most well-known impact. Acidification has direct and indirect damaging effects (such as nutrients being washed out of soils or an increased solubility of metals into soils). But even buildings and building materials can be damaged. Examples include metals and natural stones, which are corroded or disintegrated at an increased rate. When analyzing acidification, it should be considered that although it is a global problem, the regional effects of acidification could vary. **Figure 4**, below, displays the primary impact pathways of acidification. The acidification potential is given in sulfur dioxide equivalents (SO_2 eq.). The acidification potential is described as the ability of certain substances to build and release H+ ions. Certain emissions can also be considered to have an acidification potential, if the given S, N and halogen atoms are set in proportion to the molecular mass of the emission. The reference substance is sulfur dioxide.

Figure 4.

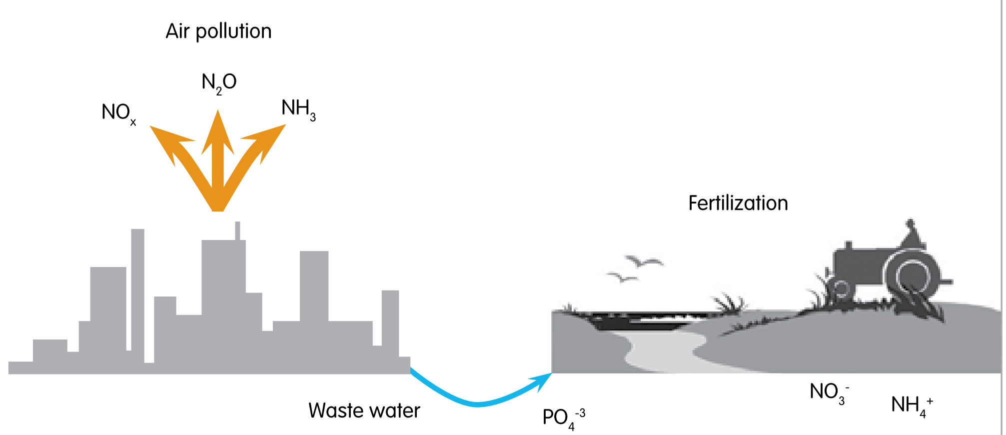
Acidification Impact Pathways



Eutrophication (EP)

Eutrophication is the enrichment of nutrients in a certain place. Eutrophication can be aquatic or terrestrial. Air pollutants, wastewater and fertilization in agriculture all contribute to eutrophication. The result in water is accelerated algae growth, which in turn prevents sunlight from reaching the lower depths. This leads to a decrease in photosynthesis and less oxygen production. In addition, oxygen is needed for decomposition of dead algae. Both effects cause a decreased oxygen concentration in the water, which can eventually lead to fish dying and to anaerobic decomposition (decomposition without the presence of oxygen). Hydrogen sulfide and methane are thereby produced. On eutrophicated soils, increased susceptibility of plants to diseases and pests is often observed, as is degradation of plant stability. If the eutrophication level exceeds the amounts of nitrogen necessary for a maximum harvest, it can lead to an enrichment of nitrate (NO_3). This can cause, by means of leaching, increased nitrate content in groundwater. Nitrate also can end up in drinking water. Nitrate at low levels is harmless from a toxicological point of view. However, nitrite, a reaction product of nitrate, can be toxic to humans at excessive doses. The causes of eutrophication are displayed in **Figure 5**.

Figure 5. Eutrophication Impact Pathways



The eutrophication potential is calculated in nitrate equivalents (N eq.). As with acidification potential, it's important to remember that the effects of eutrophication potential differ regionally and can vary significantly in different water bodies.

Respiratory Effects (Particulates, RES)

Text taken from Bare et al. (2003, p. 66).

Ambient concentrations of particulate matter (PM) are strongly associated with changes in background rates of chronic and acute respiratory symptoms, as well as mortality rates. Ambient particulate concentrations are elevated by emissions of primary particulates, measured variously as total suspended particulates, PM less than 10 µm in diameter (PM10), PM less than 2.5 µm in diameter (PM2.5), and by emissions of SO_2 and NO_x, which lead to the formation of the so-called secondary particulates sulfate and nitrate. In TRACI, respiratory effects are computed as PM2.5 equivalents (PM2.5 eq.).

Abiotic Resource Depletion, Fossil Fuel (FF, NRPE)

Several ways of analyzing fossil fuel and energy consumption exist (Bare et al. 2003). Many of these techniques acknowledge a preference for renewable energy sources as opposed to non-renewable energy sources.

GaBi proposes a non-renewable **Primary Energy Demand** (NRPE) indicator. Primary Energy Demand is often difficult to determine due to the various types of energy sources. Primary Energy Demand is the quantity of energy directly withdrawn from the hydrosphere, atmosphere or geosphere, or energy source without any anthropogenic change. For fossil fuels and uranium, this would be the amount of resource withdrawn expressed in its energy equivalent (i.e., the energy content of the raw material). For renewable resources, the energy-characterized amount of biomass consumed would be described. For hydropower, it would be based on the amount of energy that is gained from the change in the potential energy of the water (i.e., from the height difference). The total “Primary energy consumption non-renewable,” given in MJ, essentially characterizes the gain from the energy sources natural gas, crude oil, lignite, coal and uranium. Natural gas and crude oil are used both for energy production and as material constituents (e.g., in plastics). Coal is primarily used for energy production. Uranium is only used for electricity production in nuclear power stations.

TRACI (Bare et al. 2003, p. 68) argues that, although a useful measure, primary energy demand does not fully address potential depletion issues associated with energy consumption. For example, solid and liquid fuels are not perfect substitutes (i.e., solid fuels are not currently practical in personal transportation applications). For this reason, depletion of petroleum has different implications than depletion of coal, and so forth. TRACI quantifies **Fossil Fuel Depletion** (FF) by taking into account the fact that continued extraction and production of fossil fuels tends to consume the most economically recoverable reserves first, so that (assuming fixed technology) continued extraction will become more energy intensive in the future. This is especially true once economically recoverable reserves of conventional petroleum and natural gas are consumed, leading to the need to use non-conventional resources such as oil shale.

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Renewable Primary Energy Demand (RPE)

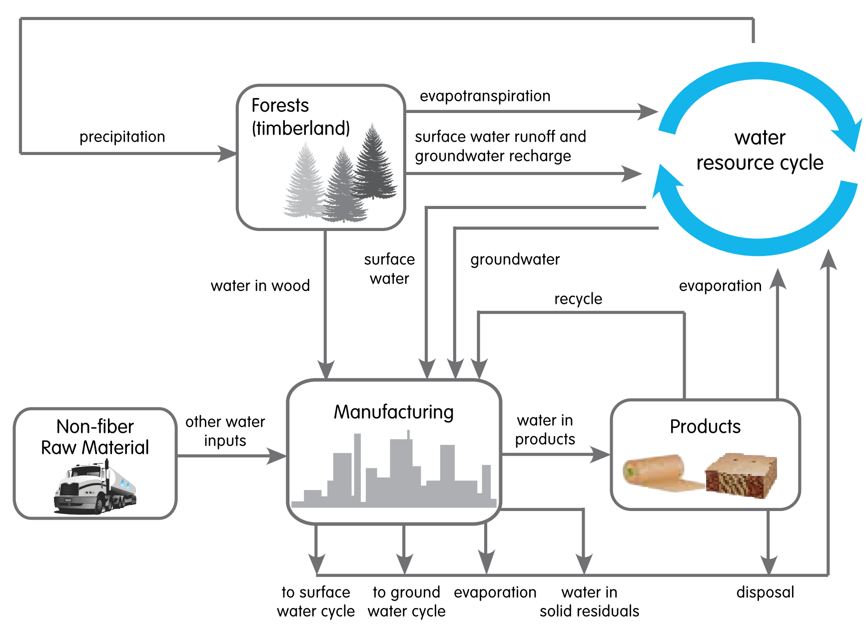
GaBi proposes renewable Primary Energy Demand indicator. Primary Energy Demand is often difficult to determine due to the various types of energy sources. Primary Energy Demand is the quantity of energy directly withdrawn from the hydrosphere, atmosphere or geosphere, or energy source without any anthropogenic change. For fossil fuels and uranium, this would be the amount of resource withdrawn expressed in its energy equivalent (i.e., the energy content of the raw material). For renewable resources, the energy-characterized amount of biomass consumed would be described. For hydropower, it would be based on the amount of energy that is gained from the change in the potential energy of the water (i.e., from the height difference). The total "Primary energy consumption renewable," given in MJ, is generally accounted separately and comprises hydropower, wind power, solar energy and biomass. Feedstock energy, that is the energy of raw material inputs that are not used as an energy source to a product system (e.g., wood into pulp), was not included.

Water Use and Consumption (WU, WC)

Water use is the water withdrawn from the environment. In this study, turbine water was not included in water use. Water consumption is that portion of water withdrawn from a source that is not directly returned after use. It is the water that is no longer available because it has been evaporated, transpired, incorporated into products, or otherwise removed from the water environment. **Figure 6** below presents the connection of the forest products industry to the water cycle.

Figure 6.

Connection of the Forest Products Industry to the Water Cycle



ADDENDUM

Critical Review by a Panel of Experts

The Corrugated Packaging Alliance (CPA) representing a joint venture of the American Forest and Paper Association, Fibre Box Association (FBA), the Association of Independent Corrugated Converters (AICC) and TAPPI commissioned a panel of life cycle assessment (LCA) experts to conduct a critical review of a study entitled: "Life Cycle Assessment of U.S. Average Corrugated Product" as conducted by the National Council for Air and Stream Improvement. The following is a review attestation for the updated Final Report, April 2014.

Review Panel Members

- Mr. Jamie Meil, Managing Director, Athena Sustainable Materials Institute - Chair
- Dr. Lindita Bushi, Senior Research Associate, Athena Sustainable Materials Institute
- Ms. Melissa Hamilton, Principal and Managing Director, EarthShift LCC

Review Objectives

Per International Organization of Standardization (ISO) 14044:2006 Environmental Management - Life cycle assessment - Requirements and guidelines, the critical review process included the following criteria to ensure conformance with applicable standard(s) performance requirements:

- Are the methods used to conduct the LCA consistent with ISO 14040/14044 standards?
- Are the methods used to conduct the LCA scientifically and technically valid?
- Are data underlying the study appropriate and reasonable in relation to the goal of the study?
- Do the interpretations reflect the limitations identified and the goal of the study?
- Is the study report transparent and consistent?

The review process entailed reviewing draft reports and providing technical and editorial comments, a meeting with the commissioner and LCA practitioner to clarify various issues and review of intermediate work products.

Review Results

Based on the review objectives, the review panel attests that the study conforms to the applicable ISO standards as a comprehensive study that may be disclosed to the public. This critical review in no way implies that the panel members endorse the results of the LCA study, nor that they endorse the assessed products. Rather, it ensures that the study, among other requirements, was carried out according to the provisions of the ISO standards.

Respectfully,

Jamie Meil, Panel Chair

April 25, 2014

Ottawa, Ontario, Canada

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For more information, visit the Corrugated Packaging Alliance (CPA) at ***www.corrugated.org*****.**

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