2014 LIFE CYCLE ASSESSMENT OF U.S. AVERAGE CORRUGATED PRODUCT
EXECUTIVE SUMMARY

ES.1 Background and Objective

The Corrugated Packaging Alliance (CPA), a joint venture of the American Forest & Paper Association (AF&PA), Fibre Box Association (FBA), AICC, The Independent Packaging Association (AICC) and TAPPI, have commissioned NCASI to conduct a life cycle assessment (LCA) study of the 2014 U.S.-average corrugated product. There were three main objectives to the study:

1) To educate customers and stakeholders about the environmental attributes of the industry's corrugated packaging produced in 2014:
2) To contrast, to the extent possible, the updated results with those of 2006 and 2010; and
3) To present the environmental performance of a corrugated product made of 100%-recycled fiber relative to that of the industry average recycled content.

This study was performed following the principles described in the ISO 14040/14044 standards for a publicly disclosed study.

The study being an update of the 2010 LCA published in 2014, it was reviewed by one external reviewer instead of a panel. The reviewer was Lindita Bushi from Athena Institute. The critical review in no way implies that the reviewer endorses the results of the LCA study, nor that they endorse the assessed products. It ensures that the study, among other requirements, was carried out per the provisions of the ISO standards.

ES.2 Products Studied

Four different products manufactured and used in the U.S. were studied in this assessment:

1. The 2014 U.S. industry-average corrugated product (main product studied in this LCA);
2. The 2010 U.S. industry-average corrugated product;
3. The 2006 U.S. industry-average corrugated product; and
4. The 2014 U.S. industry-average corrugated product made from 100%-recycled fiber (often referred to in this study as the 100%-recycled product).

Corrugated products (for instance corrugated 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 2014 U.S.-average corrugated product studied in this LCA consists of 66.8% linerboard and 33.2% corrugated medium with an average basis weight of 131.6 lb/thousand square feet (msf, 0.643 kg/m^2). The industry-average containerboard utilizes about 52%[1] recovered fiber, primarily old corrugated containers (OCC), with the balance supplied mostly by kraft and semi-chemical pulp. More information regarding the 2010 and 2006 product can be found in the LCA reports from prior assessments (http://www.corrugated.org/ViewPage.aspx?ContentID=36 and (http://www.corrugated.org/upload/CPALCAfinalreport08-25-10.pdf, respectively). ISO 14044 requires that whenever two products are compared, these should be functionally equivalent. For that reason, the 100%-recycled product studied in this study and compared to the industry-average was modeled using the same board mix (linerboard to medium ratio). It was also assumed that the 100%-recycled product had the same basis weight as the industry-average product.

ES.3 The Study Design and Methods Employed

The functional unit for the study was ***"the domestic use of 1 kg of an average corrugated product produced in the U.S. in 2014."*** The system boundary included the entire life cycle of the corrugated product, extending through manufacturing, use, recovery, and end of life, as shown in Figure 1. The product system was separated into four life cycle stages:

1) **Pulp and papermaking operations** includes forest operations, transportation of wood to chipping, off-site chipping, on-site production of chips, off-site production of market pulp, production of on-site produced pulp, papermaking operations (to produce 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, but does not include energy and resources used during the use life cycle stage or the waste generated from use other than the product itself.
4) **End-of-life** includes end-of-life management of the packaging product (landfilling, burning with energy recovery).

Each life cycle stage is supplied by resources and necessitates residual management. Transportation between two life cycle stages is included in the downstream stage.

[1] This number is higher than that reported by AF&PA (2015). AF&PA's number (47%) include containerboard produced in the U.S. irrespective of whether it is used domestically or exported. The utilization rate of 52% reflects the fact that fewer 100%-recycled products are exported than other types of products, making the domestic utilization rate higher.

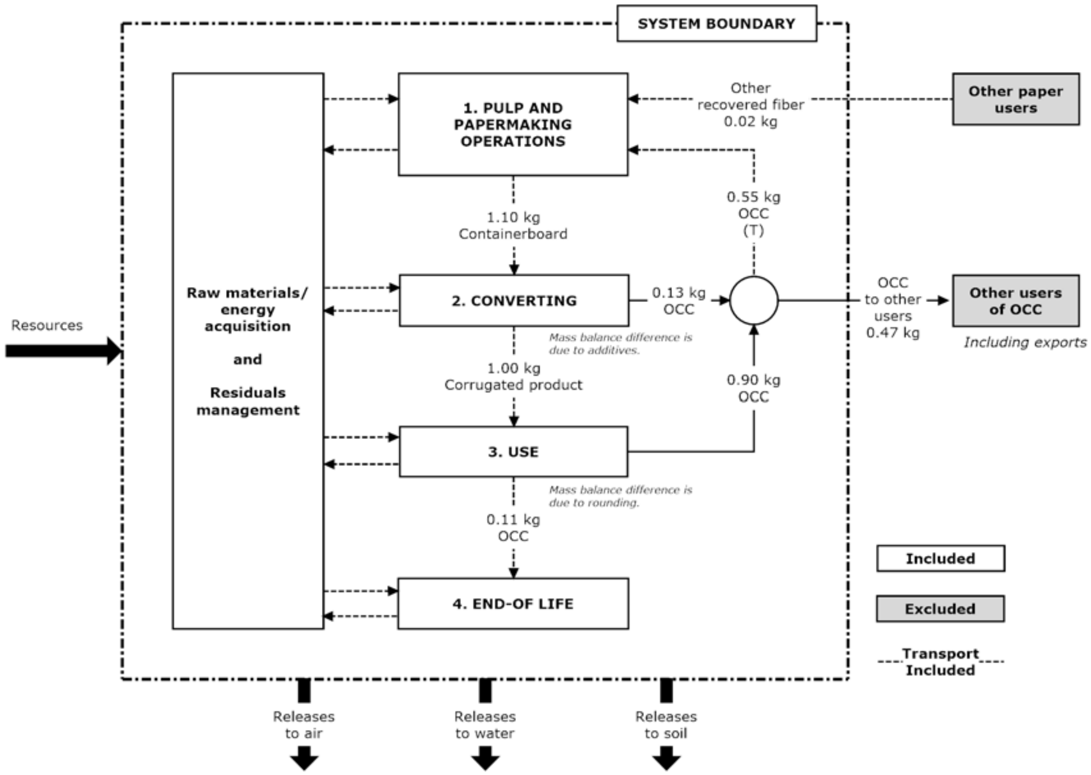


Figure 1. System Boundary

Instead of applying cut-off criteria for data completeness, attempts have been made to be as comprehensive as possible. 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 were drawn from responses to the 2014 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 was 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.
- Converting facilities in the U.S. were surveyed to collect energy and material input, 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.

Where allocation was needed to address co-products, the allocation was done using what was considered to be the most suitable method available, 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 occur in the product 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 approaches were used in this study: 1) Closed-Loop Approximation combined with the Cut-Off Method, and 2) the ISO 14049 Number of Uses (NOU) method.

The first approach (Closed-Loop Approximation w/Cut-Off Method) was used to characterize the environmental loads of the industry-average product. Using this approach, it was assumed 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 an environmental load associated with it (i.e., a cut-off method was used and all the environmental load is considered within the system).

The choice of an allocation approach for recycling can be critical for comparing paper products with different recycled fiber contents (e.g., Galeano et al. 2011, National Council for Air and Stream Improvement 2012). For this reason, two different approaches were used to express the environmental load of the 100%-recycled content product relative to that of the industry-average recycled content product, each of which provides a different perspective on how the environmental load of virgin production processes is shared between all usages of the fiber (i.e., virgin and recycled). The first approach used was the Closed-Loop Approximation with Cut-Off Method described above. The second approach employed was the Number of Uses (NOU) Method described in the ISO 14044 Standard and its accompanying Technical Report (ISO 14049). This second approach was selected for several reasons. Among them is a recommendation from an international working group addressing life cycle inventory 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 virgin and recycled fiber. The main difference between the two methods is that the Cut-Off Method assigns the environmental loads and benefits from virgin material production to the products made of virgin fiber only, while the Number of Uses method shares the loads and benefits between the product made of virgin fiber and those made of recycled fiber.

The life cycle modeling was done using the GaBi™ software package. Environmental impacts were characterized using the TRACI impact assessment method developed by U.S. EPA, using the Intergovernmental Panel on Climate Change (IPCC) AR5 factors for global warming. 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. In addition, impact indicator results were developed for the following indicators: ozone depletion, photochemical oxidation (smog), acidification, eutrophication, and fossil fuel depletion. Impacts on land use and biodiversity were not quantified as there is no consensus method suitable for forest management. The CML 2001 impact assessment method developed in the Netherlands 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 (heat of combustion) of any raw material input that is not used as an energy source in the studied product systems.

Sensitivity analyses were performed on various aspects.

ES.4 Results

This section summarizes the results obtained from this LCA.

ES.4.1 2014 Results: LCIA Profile

The cradle-to-grave life cycle impact assessment (LCIA) results obtained by applying TRACI, the IPCC factors for global warming, and GaBi non-renewable and renewable primary energy demands are shown in Table 1.

The results show that pulp and papermaking operations (primarily containerboard production) are the main contributor to all impact categories except global warming and water consumption. More detail on the global warming indicator is provided in the next section. Pulp and papermaking and converting contribute significantly to water consumption results. Converting is also a significant contributor to most other indicators. End-of-life contributes significantly to the global warming indicator results, but only when the flow approach is used for biogenic carbon accounting. Finally, the use phase (which primarily reflects the impacts of transportation) does not contribute significantly to impact categories.

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. EoL
Impact Assessment Indicators						
Global warming, flow accounting*	kg CO_2 eq.	0.533	3.6%	43.0%	5.5%	47.9%
Ozone depletion	kg CFC-11 eq.	6.89E-08	90.3%	8.9%	0.7%	0.1%
Photo-chemical oxidation (smog)	kg O_3 eq.	0.122	76.5%	17.7%	4.8%	0.9%
Acidification	kg SO_2 eq.†	1.19E-2	78.9%	17.5%	1.5%	2.0%
Eutrophication	kg N eq.†	9.46E-4	81.4%	12.0%	1.2%	5.3%
Respiratory effects (particulates)	kg PM2.5 eq.	1.23E-3	87.2%	10.9%	0.6%	1.3%
Fossil fuel depletion	MJ surplus	1.73	68.7%	27.4%	3.1%	0.7%
Additional Inventory Indicators						
Non-renewable energy demand	MJ	18.5	72.9%	24.4%	2.1%	0.6%
Renewable energy demand‡	MJ	9.6	92.8%	7.1%	0.0%	0.0%
Water use	kg	41.9	82.3%	17.3%	0.0%	0.4%
Water consumption	kg	13.1	47.4%	51.8%	0.0%	0.7%

*NOTE: Percentages not adding up to 100% is due to rounding. *The flow accounting approach was also used in the previous LCA studies. †Total of air and water. ‡Excluding feedstock energy.*

ES.4.2 2014 Results: Details on Global Warming

This section presents more details on the global warming indicator. Figure 2 presents how each life cycle stage contributes to individual GHGs. From this figure, the following can be observed:

- Pulp and papermaking is the greatest contributor to all GHGs and removals.
- Removals (primarily due to biomass grown to produce containerboard) offset a large proportion of all GHGs (biogenic CO_2 and other GHGs).
- Emissions of biogenic CO_2 occur mainly at pulp and paper mills.
- Emissions of other GHGs are spread out across pulp and papermaking operations, converting and end-of-life stages.
- Overall, the main contributors to the total global warming indicator are converting and end-of-life.

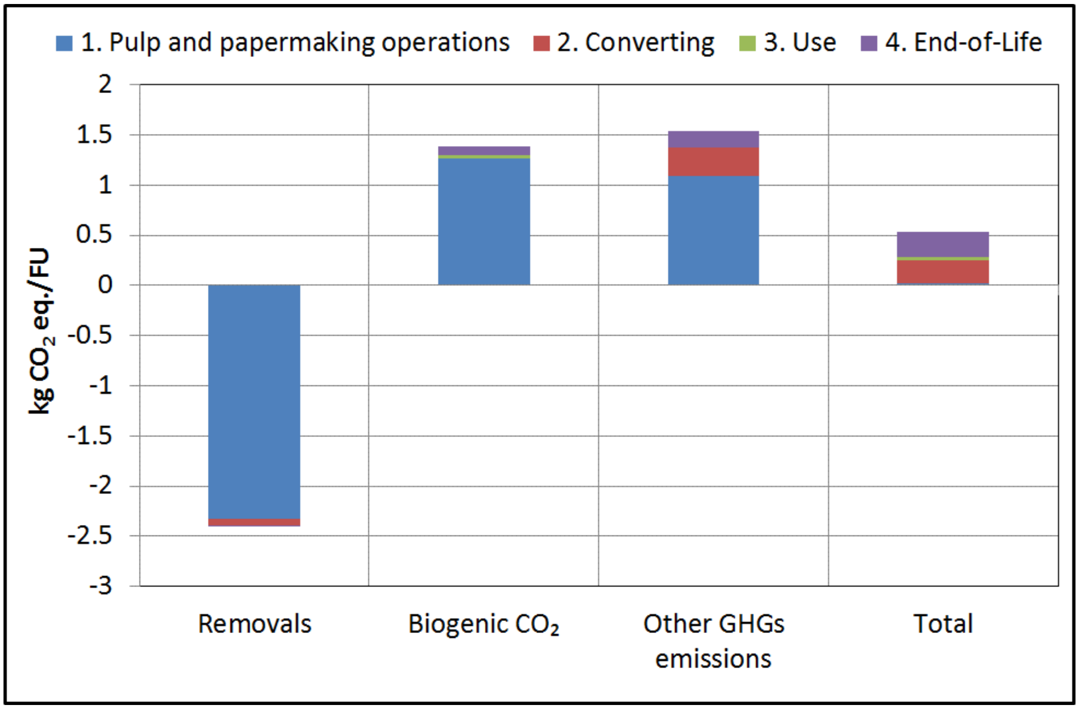


Figure 2. Contribution of the Life Cycle Stages to GHGs

Within the pulp and papermaking operations life cycle stage, forest operations are responsible for removals while energy production is the main process responsible for biogenic CO_2 and other GHG emissions. The rest, for instance chemical production and residuals management, does not contribute significantly to the global warming indicator.

On the converting side, while some removals are associated with chemical (starch) usage, 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 the end of life. Other GHGs are distributed across energy (primarily purchased electricity and natural gas), transportation of the containerboard to converting facilities, and chemicals (primarily 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 somewhat less important than in previous studies because less corrugated product was landfilled in 2014 than in 2010.

ES.4.3 2014 Results: Sensitivity Analyses

Sensitivity analyses were performed on various aspects. Some observations from these are as follows.

- As illustrated in Figure 3, the global warming indicator results are sensitive to the approach used to calculate emissions of biogenic CO_2.
- The global warming indicator results are also somewhat affected by the board mix (i.e., ratio of 100%-recycled linerboard, all other linerboard, 100%-recycled medium and all other medium), the quantity of energy used at converting facilities and the recovery rate.
- 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.

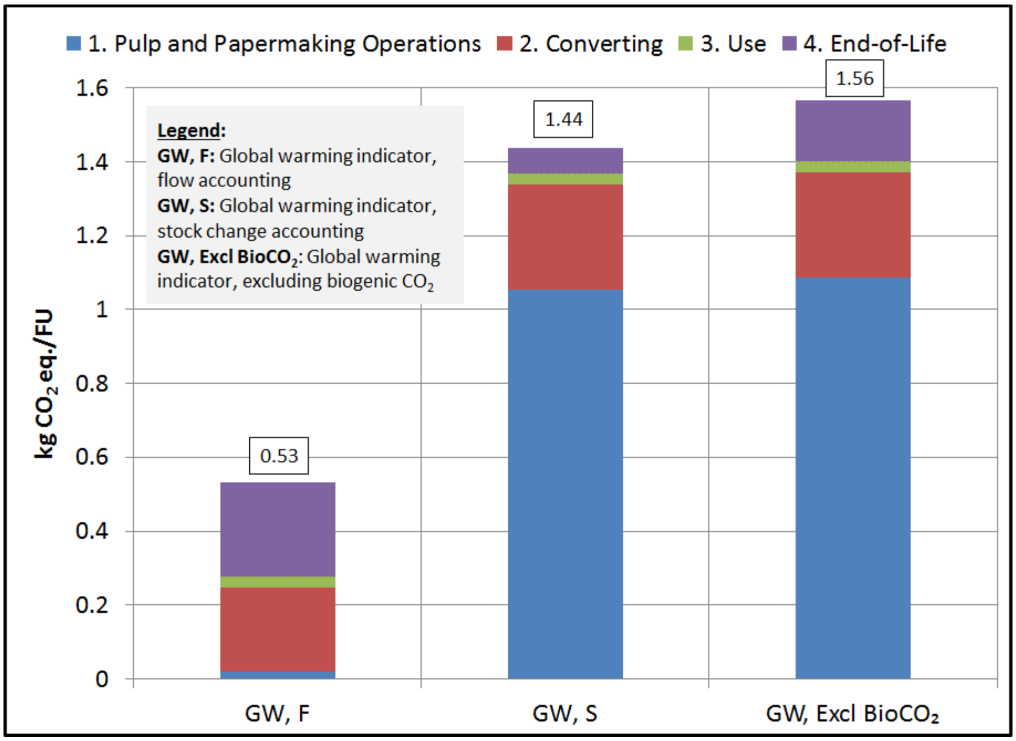


Figure 3. Effect of the Selection of the Indicator on the Observed Global Warming Results

ES.4.4 2014 vs. 2010 Results

One objective of this study was to compare the corrugated life cycle environmental performance in 2014 to that in 2010 and 2006 to document any changes. Table 2 presents an overview of the factors with an effect on the year-to-year comparison.[2]

---

[2] The results published in this report for 2006 and 2010 vary slightly compared to these published in the 2014 report, although the general findings remain unchanged. There are a few reasons for this. First, a calculation error affecting slightly the board mix was found in the original study for 2010 were corrected in this version. Second, some of the

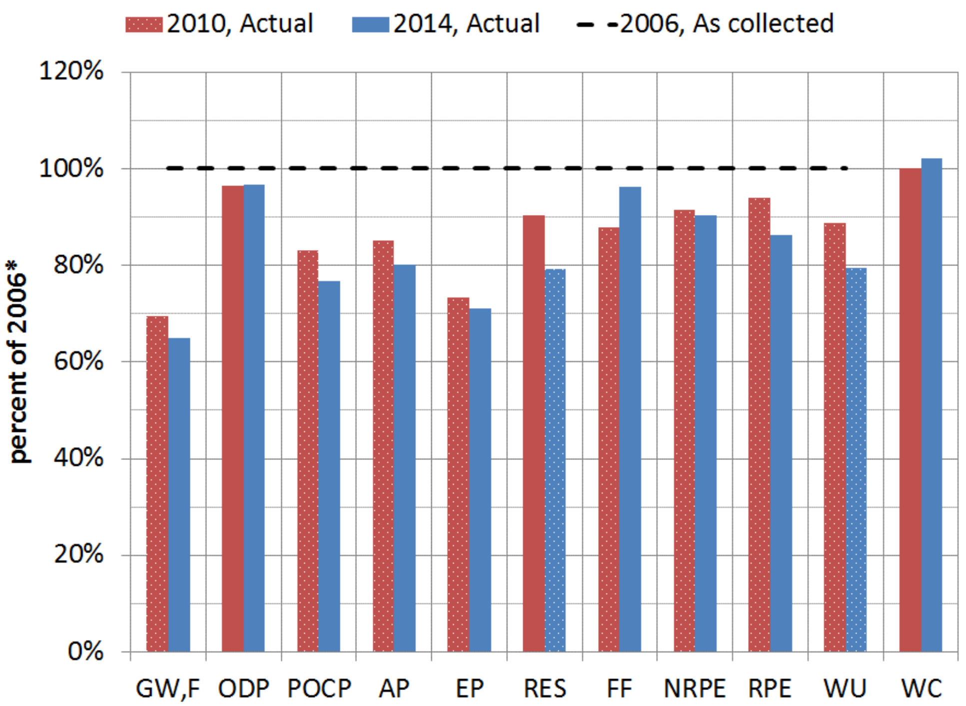
Table 2. Main Drivers for Change in Environmental Performance between 2006, 2010 and 2014

Model parameter	2006	2010	2014	Expected effect on the results
Recovery rate	72%	85%	89.5%	Increasing the recovery rate decreases the quantity of product going to landfill within the system boundaries with the primary effect of reducing GHG releases.
Utilization rate of recovered fiber (kg/kg CBD)	0.42*	0.46*	0.52*	The main anticipated effects of increasing the percent board from recycled fiber, and more specifically increasing the utilization rate, are to reduce the quantity of carbon removal in the system (sequestration), to reduce total energy use at containerboard mills (and more specifically energy from renewable sources) and to reduce water use.
Board from 100%-recycled fibers	22.3%	26.6%	30.5%	
Carbon removal (kg CO_2 eq./kg CP)	-2.8	-2.6	-2.4	Higher carbon removal reduces the total reported global warming results.
Total fossil fuels used at containerboard mills (MJ HHV/kg CP)	23.8	23.4	22.1	Less energy means lower emissions of GHGs and other air releases.
Share of natural gas in containerboard fossil fuels mix excluding purchased energy	46%	54%	73%	More natural gas in the fuel mix generally results in lower releases of several air pollutants. However, natural gas contributes more towards the fossil fuel depletion indicator (MJ surplus) than other fossil fuels because it is harder to extract.
Total energy used at converting (MJ/kg CP)	2.1	1.9	1.9	Less total energy means lower emissions of GHGs and other air releases. It also means lower total non-renewable energy demand.
Natural gas used at converting (MJ HHV/kg CP)	0.82	1.03	1.09	More natural gas in the fuel mix generally results in lower releases of several air pollutants. However, natural gas contributes more towards the fossil fuel depletion indicator (MJ surplus) than other fossil fuels because it is harder to extract.

NOTE: CBD is for containerboard and CP is for corrugated product.
*Numbers are different than reported by AF&PA. AF&PA numbers include containerboard that is exported. These numbers have been corrected to exclude the exports.

Figure 4 compares the impact scores obtained for 2014 with those obtained for 2010 and 2006. Changes by less than 10% are not considered meaningful (Franklin Associates 2004). From 2010 to 2014 the environmental performance generally remained stable, with most of the environmental improvements occurring between 2006 and 2010. More details regarding the different indicators are provided below.

data source and impact assessment methodologies were updated. Third, data collection for chemical usage at containerboard mills was streamlined. As a consequence, the 2006 and 2010 datasets were recalculated.



Indicator	Unit	2006	2010	2014	% change 2006-2010	% change 2010-2014	% change 2006-2014
GW,F	kg CO_2 eq.	0.82	0.57	0.53	-30%	-6.6%	-35%
ODP	kg CFC11 eq.	7.1E-08	6.9E-08	6.9E-08	-3.6%	0.3%	-3.4%
POCP	kg O_3 eq.	0.16	0.13	0.12	-17%	-7.6%	-23%
AP	kg SO_2 eq.	0.015	0.013	0.02	-15%	-5.8%	-20%
EP	kg N eq.	1.3E-03	9.8E-4	9.5E-4	-27%	-3.1%	-29%
RES	kg PM2.5 eq.	1.6E-3	1.4E-3	1.2E-3	-9.7%	-12%	-21%
FF	MJ Surplus	1.80	1.58	1.73	-12%	+9.6%	-3.8%
NRPE	MJ	20.5	18.7	18.5	-8.6%	-1.3%	-9.8%
RPE	MJ	11.1	10.5	9.6	-5.9%	-8.4%	-13.8%
WU	kg	52.8	46.8	41.9	-11%	-10%	-21%
WC	kg	N/Av.	12.8	13.1	N/Av.	2.1%	N/Av.

Figure 4. Comparing the Life Cycle Environmental Performance in 2014, 2010 and 2006
(In this figure, the bars with white dots indicate environmental indicators for which the score varied by 10% or more from the previous year. *Except for water consumption for which the reference year is 2010.)

The respiratory effects (particulates) indicator result was reduced by 12% between 2010 and 2014 mainly due to reduction of emissions of SO_2 and particulates from containerboard mills, primarily due to more natural gas in the fuel mix and less combustion of other fossil fuels.

There was a 10% reduction in water use between 2010 and 2014. The reduction in water use occurred mainly in the pulp and papermaking operations life cycle stage. There are two principal sources of water use reduction: water reduction in containerboard mills and, more importantly, a greater share of 100%-recycled products in the board mix. Water consumption remained relatively stable.

Between 2010 and 2014, the global warming indicator (flow accounting; GW,F) result decreased by 6.6%, a change that is not considered meaningful[3]. Figure 5 provides insight into the different parameters that affected the difference between the two years.

GHGs were reduced in some respects:

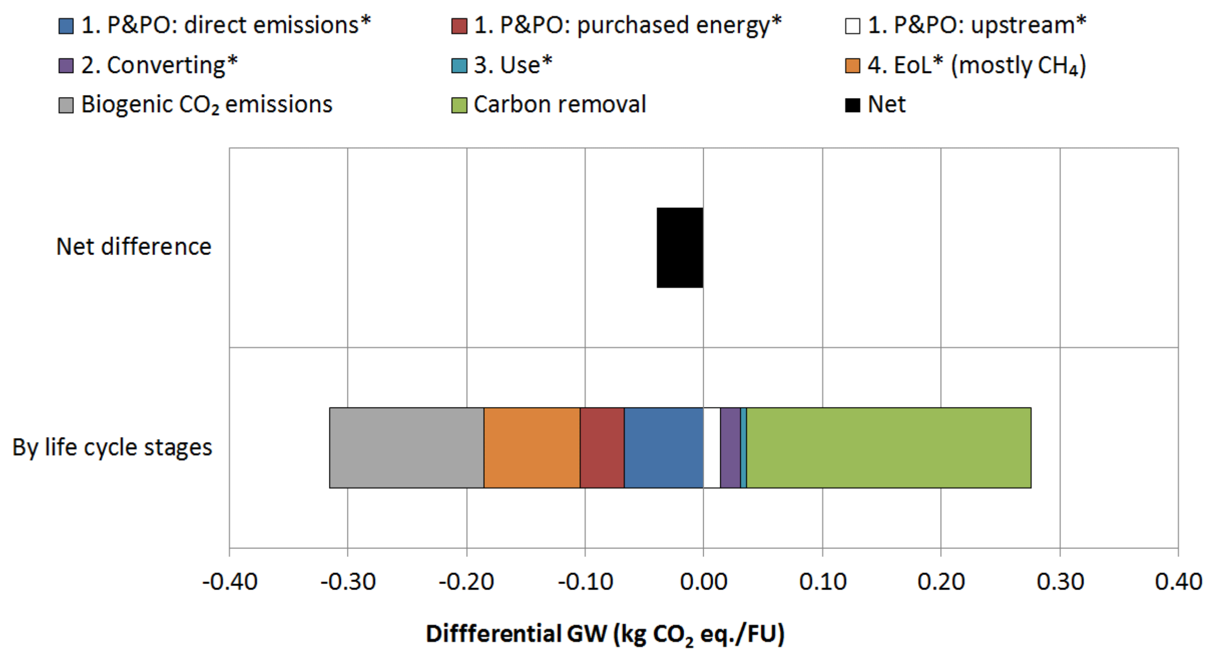
- The recovery rate in 2014 was higher than in 2010, resulting in less corrugated containers sent to landfills and in turn decreased methane emissions.
- In 2014, the utilization rate was higher than in 2010, reducing total energy consumption and corresponding direct and indirect releases of GHGs. In addition, the share of fossil fuels from natural gas increased from 2010 to 2014, further reducing GHG emissions.

GHGs were increased in some other respects:

- The higher utilization rate in 2014 corresponds to reduced wood consumption, and hence less carbon removal through sequestration.
- Converting shows a modest increase in GHG releases due to an increased usage of additives (other than starch) and the fact that more containerboard passed through sheet feeder plants, representing more transportation.

Two other global warming indicators were tested in sensitivity analyses: one that uses the stock change accounting method and one that ignores biogenic CO_2. Using these two indicators, emissions of GHGs were reduced by 4% and 6%, respectively. More information concerning the different global warming indicators can be found in Section 5.2.

[3] Any change of less than 10% in environmental indicator results is not considered meaningful.



*In this figure, P&PO means pulp and papermaking operations. The pulp and paper making life cycle stage was separated in direct emissions from pulp and paper mills (e.g., fuel combustion at containerboard mill), emissions from pulp and paper mills purchased energy, and other upstream emissions (e.g., from producing the chemicals needed in pulp and papermaking). Emissions from the four life cycle stages exclude biogenic CO_2, for which a net value is presented separately.

Figure 5. Factors Contributing to Difference in GHG Emissions between 2010 and 2014

Between 2010 and 2014, the impact score for fossil fuel depletion was increased by 9.6%, which is not considered to be meaningful. The main driver for this is increased consumption of natural gas in the life cycle of the product. Total non-renewable energy remained approximately stable. Total renewable energy decreased by 8%, mostly due to an increase in the share of 100%-recycled products in the board mix.

There was no meaningful change in the ozone depletion, smog, acidification and eutrophication indicators.

Sensitivity analyses showed that results of the comparison were generally robust. However, the global warming indicator results are sensitive to the relative contribution of the different board types in the industry-average board mix.

ES.4.5 100%-Recycled vs. Industry-Average

The environmental performance of the 100%-recycled content product relative to that of the industry-average recycled content product was derived using two allocation methods for recycling: the number of uses (NOU) method and the closed-loop approximation with cut-off (cut-off) method. Table 3 presents the main drivers for difference in environmental performance between the two products.

Table 3. Main Drivers for Difference in Environmental Performance between the Industry-Average and 100%-Recycled Products

Model parameter	2014 Industry-Average	2014 100%-Recycled	Expected effect on the results
Utilization rate of recovered fiber (kg/kg CBD)	0.52*	1.23	The main anticipated effects of increasing the percent board from recycled fiber, and more specifically increasing the utilization rate, are to reduce the quantity of carbon removal in the system (sequestration), to reduce total energy use at containerboard mills (more specifically, energy from renewable sources), and to reduce water use.
Carbon removal (kg CO_2 eq./kg CP)	-2.4	-0.2	Higher carbon removal reduces the total reported global warming results.
Total fossil fuels used at containerboard mills (MJ HHV/kg CP)	22.1	9.70	Less fossil fuels means lower emissions of GHGs and other air releases. It also means lower total non-renewable energy demand.
Total biomass fuels	13.9	0.64	Biomass fuels produce greater air emissions than natural gas.
Net virgin production load transfer (applicable only to the NOU method)	26%†	≈15%‡	Exporting/importing virgin environmental load means exporting/importing environmental impacts (e.g., related to energy production) and benefits (e.g., carbon removal) of producing virgin material.

NOTES: Unless otherwise specified, numbers presented in the table do not account for virgin production load transfer applied with the NOU method. CBD is for containerboard and CP is for corrugated product.
*Number is different than reported by AF&PA. AF&PA numbers includes exports while this number was corrected to account for only domestic use of containerboard. †Meaning that, when accounting for the net generation/use of recovered fiber, 26% of the environmental load from producing virgin fibers in the industry-average is exported to subsequent uses of the fiber. ‡Meaning that, for each kg of recovered fiber (mainly OCC) used in the 100%-recycled product, the environmental load equivalent of producing 0.15 kg of virgin fibers is imported within the system boundaries.

Number of Uses (NOU) Method

The environmental indicator results of the 100%-recycled product relative to that of the industry-average product obtained using the Number of Uses method are presented in Figure 6. The following observations can be made from this figure:

- Using the NOU method, the industry-average product results in lower environmental impact scores for the global warming, smog, acidification, respiratory effects (particulates), fossil fuel depletion, non-renewable energy demand and water consumption indicators.
- Using the NOU method, the 100%-recycled product results in lower environmental impact scores for the renewable energy demand and water use indicators.
- Using the NOU method, there is no significant difference between the industry-average and 100%-recycled products for the ozone depletion and eutrophication indicators.

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 are relatively robust.

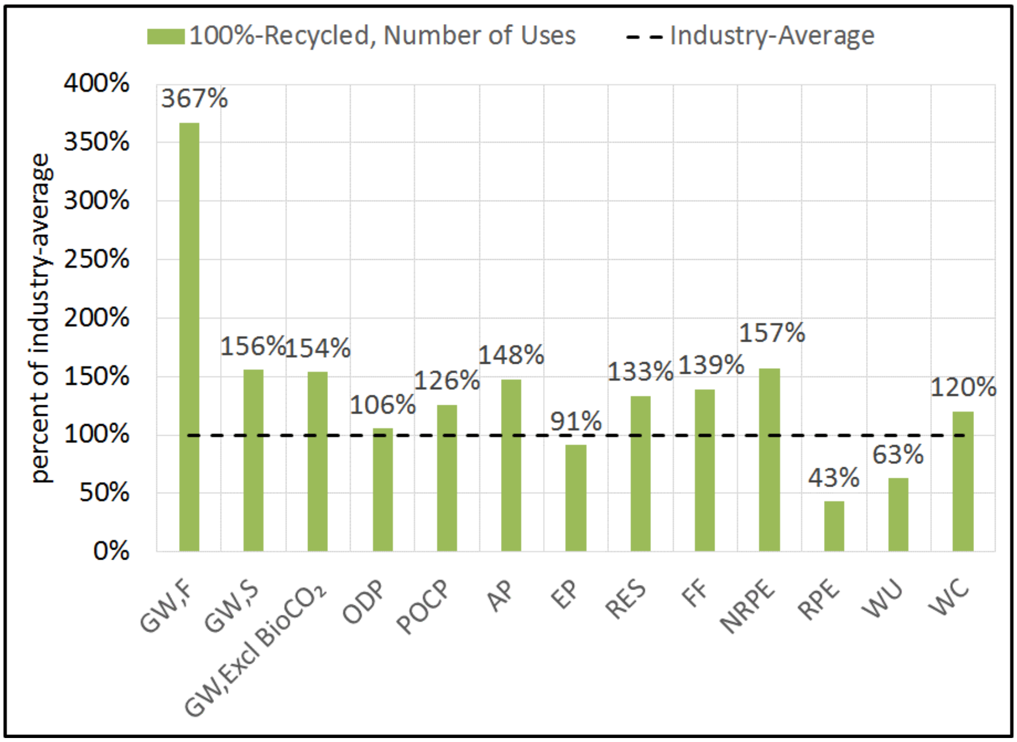


Figure 6. Impact Scores for the 100%-Recycled Product Relative to that of the Industry-Average Product (Number of Uses Method)

Closed-Loop Approximation with Cut-Off Method

The environmental indicator results of the 100%-recycled product relative to that of the industry-average product obtained using the closed-loop approximation with cut-off (cut-off) method are presented in Figure 7. The following observations can be made from this figure:

- Using the cut-off method, the industry-average product results in lower environmental impact scores for the global warming (flow accounting approach) indicator.
- Using the cut-off method, the 100%-recycled product results in lower environmental impact scores for the ozone depletion, smog, eutrophication, respiratory inorganic, renewable energy demand and water use indicators.
- Using the cut-off method, there is no significant difference between the industry-average and 100%-recycled products for the acidification, fossil fuel depletion, non-renewable energy demand and water consumption indicator.

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 are relatively robust. One exception is worth mentioning. The results for the global warming indicator are very sensitive to the selection of the accounting approach for biogenic CO_2. On one hand, the industry-average product performs significantly better than the 100%-recycled product when using the flow accounting approach. On the other hand, the difference is not significant when applying the stock change accounting method or when ignoring the emissions of biogenic CO_2.

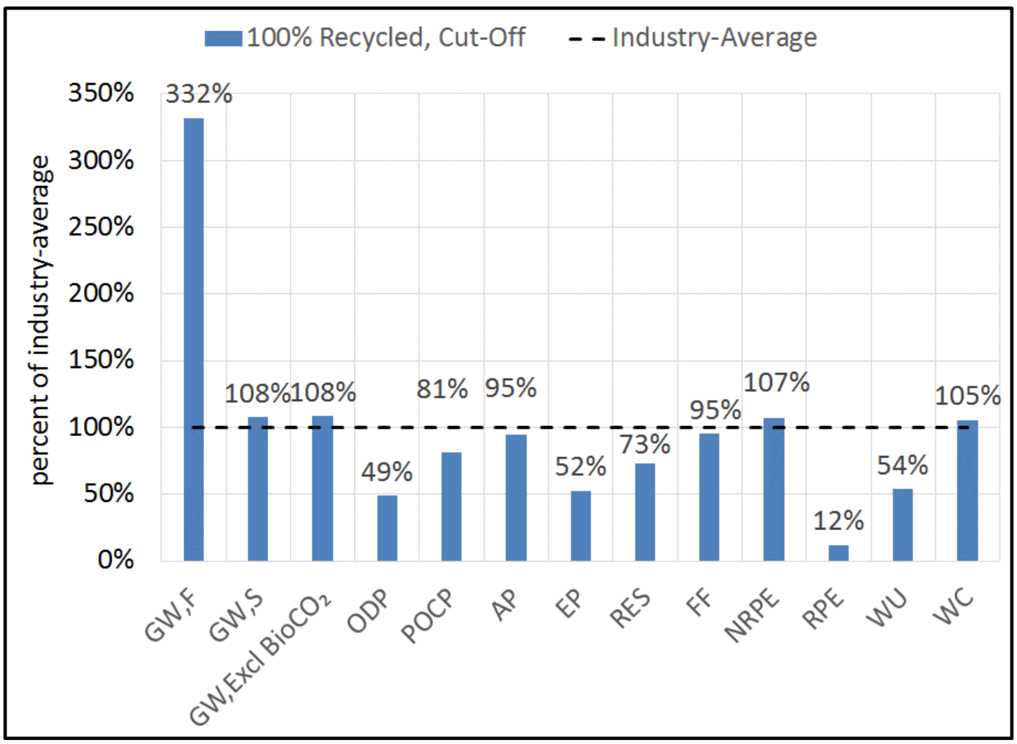


Figure 7. Impact Scores for the 100%-Recycled Product Relative to that of the Industry-Average Product (Closed-Loop Approximation w/ Cut-Off Method)

ES.5 Conclusions

This study represents a comprehensive LCA of the 2014 U.S. industry-average corrugated product. The main conclusions that can be drawn from the study include the following.

Pulp and papermaking production (containerboard) is the main driver of the life cycle environmental performance. For all impact categories, material and energy flows from paper mills dominate the results (positively or negatively). Environmental impacts are dominated by energy demands at the mill. Bio-based energy (e.g., hog-fuel, liquor, etc.) substantially reduces the global warming contribution from mills. Converting facilities also contribute relatively significantly to most impact categories.

End-of-Life is only significant with respect to the global warming indicator results. Other life-cycle impact indicators show little or no response from the end-of-life stage. The global warming potential observed at end-of-life is mainly due to methane released from landfill operations. Sensitivity analyses clearly showed that increasing the recovery rate has the potential to improve overall environmental performance.

The global warming indicator results are highly dependent on the accounting method for biogenic CO_2. Two different accounting approaches can be used to compute the results for the global warming indicator: flow accounting, which was the main method employed in this study, and stock accounting, which was examined in a sensitivity analysis. Flow accounting is the accounting method the most used in LCA studies. Stock change accounting is mostly used in national inventories. Another approach sometimes used in LCA is simply ignoring biogenic CO_2 when calculating the global warming indicator results to get an understanding of how non-biogenic CO2 GHG contribute to the global warming indicator. Note that this approach ignores any removal/storage of biogenic carbon. The pulp and papermaking operations life cycle went from being an insignificant contributor to global warming when applying the flow accounting approach to a very significant contributor when applying the stock change method or ignoring biogenic CO_2. When applying the stock change accounting approach or ignoring biogenic CO_2, the contribution of end-of-life to the overall global warming results was reduced compared to when applying the flow accounting method.

Overall, the life cycle environmental performance was essentially stable between 2010 and 2014. However, significant improvements were observed for the respiratory effects (particulates) and water use indicators. The main drivers for the reduction in particulate release is the increase share of natural gas in the containerboard mills energy mix. The reduction in water use is mainly due to an increase in recycled content.

The results of comparisons of the industry average product to 100%-recycled product varied by indicator with some results being strongly dependent on the allocation method chosen for recycling. In summary, the industry-average indicator results were lower for the global warming, acidification and non-renewable energy indicators regardless of the allocation method used, although for the non-renewable indicator the results obtained with the cut-off allocation method showed that the difference between the two products was not significant. Results also suggest that the 100%-recycled product generates lower emissions of eutrophying substances and uses less water and renewable energy than the industry-average, although for the eutrophication indicator the results obtained with the Number of Uses allocation method showed that the difference between the two products was not significant. The results for the other environmental indicators (i.e., ozone depletion, smog, eutrophication, respiratory effects, fossil fuel depletion) depend on the allocation method.