LIFE CYCLE ASSESSMENT OF HEFTY® POLYSTYRENE FOAM PLATES AND TWO COATED PAPERBOARD DISPOSABLE PLATES

Final Peer-Reviewed Report

Prepared for:

Reynolds Consumer Products

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November 30, 2015

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EXECUTIVE SUMMARY

INTRODUCTION

This study was conducted to provide Reynolds Consumer Products with information about the life cycle impacts for their Hefty® Everyday™ disposable polystyrene foam plates and two leading competing coated pressware plates made from virgin bleached paperboard with a moisture- and grease-resistant coating. Life Cycle Assessment (LCA) is recognized as a scientific method for making comprehensive, quantified evaluations of the environmental benefits and tradeoffs for the entire life cycle of a product system, beginning with raw material extraction and continuing through disposition at the end of its useful life.

The analysis focused on two brands of pressware plates considered by Reynolds to be leading competitors to Hefty foam plates; the analysis did not attempt to evaluate the full range of pressware plates available in the market, and no other types of disposable plates (e.g., molded fiber plates, solid plastic plates) were included in the analysis. All plates evaluated were approximately 9 inches in diameter. The weight and composition of the pressware plates were based on multiple samples of two leading brands that Reynolds had tested by a third-party laboratory. The fiber content of the pressware plates was modeled as virgin fiber, since internet searches did not identify any use of postconsumer recycled content in pressware plates. Because the manufacturers of the pressware plates did not participate in the study or provide any manufacturing data for the study, the pressware plate results cannot be considered directly representative of these brands, and the plates are referred to as pressware Plate 1 and Plate 2. The sizes, average weights, and composition of the plates modeled and associated secondary packaging are provided in Table ES-1. The table shows that the total weight of plates and packaging for the foam plate system is less than half the total weight of the components of both pressware plate systems.

This report is the property of Reynolds Consumer Products and can be used internally for decision-making purposes. Since Reynolds intends to make comparative results from the study publicly available, including sharing with customers, a panel peer review of the report has been conducted as required for compliance with ISO standards for LCA.

FUNCTIONAL UNIT

The functional unit is the basis of comparison of the product systems studied in an LCA. For this analysis, the functional unit is 10,000 single-use plates identified as "everyday" versions of the brands (e.g., not heavy duty). Although the sizes of plates studied in this analysis are not exactly the same, it is reasonable to expect that the very small difference in diameters will not result in a difference in consumer use/functionality, so the plates are compared on a one-to-one basis.

Table ES–1. Composition of Plates and Packaging

	Hefty	Pressware Plate 1	Pressware Plate 2
Plate diameter (inches)	8.875	8.625	8.5
Average plate weight (grams)	4.49	10.98	12.03
Plate composition by weight (grams)			
General purpose polystyrene resin	4.25		
Talc	0.07		
Pentane	0.17		
Bleached paperboard		8.53	9.42
Clay coating		1.91	1.71
Styrene acrylic latex coating		0.54	0.89
Total weight of 10,000 plates			
Kilograms	44.9	110	120
Pounds	99.0	242	265
Hefty plate weight as % of pressware		***41%***	***37%***
Packaging			
Plates/shipping case	400	540	490
Cases/10,000 plates	25.0	18.5	20.4
Sleeves of product/case	8	12	10
Weight per plastic film sleeve (g)	6.6	4.6	4.4
Total weight of sleeves per case (g)	52.8	55.2	44.0
Weight of tape (g)	2.5	5.1	5.5
Weight of corrugated shipping box (g)	420	409	297
Total weight of packaging for 10,000 plates			
Kilograms	11.9	8.68	7.07
Pounds	26.2	19.1	15.6
Hefty packaging weight as % of pressware		***137%***	***168%***
Total weight of 10,000 plates + packaging			
Kilograms	56.8	118	127
Pounds	125	261	281
Hefty total weight as % of pressware		***48%***	***45%***

SCOPE AND BOUNDARIES

This LCA quantifies energy and resource use, solid waste, and environmental impacts for the following steps in the life cycle of each plate system studied:

- Raw material extraction (e.g., extraction of petroleum and natural gas as feedstocks for plastic resin, harvesting of trees for virgin paper), and intermediate material processing
- Fabrication steps to transform materials into plates
- Material extraction, intermediate material processing, fabrication, and recycling or disposal of secondary packaging components (corrugated boxes and film sleeves) used to package plates for shipment
- Transportation of plates to a distribution center

- End-of-life management of plates and secondary packaging.

The life cycle inventory and impact assessment for this study covers a variety of results categories. Categories were chosen that address global, regional, and local environmental impacts, including the following:

Life Cycle Inventory Results

- Total energy demand (MJ eq)
- Non-renewable energy demand (MJ eq)
- Solid waste by weight (kg)
- Solid waste by volume (cubic meters)
- Water consumption (liters)

Life Cycle Impact Assessment Results

- Global warming potential (kg CO2 eq)
- Acidification potential (SO2 eq)
- Eutrophication potential (kg N eq)
- Ozone depletion potential (kg CFC-11 eq)
- Smog formation potential (kg O3 eq)

This study focuses on environmental impacts; human health impact categories are outside the project scope. Modeling human health impacts introduces a higher level of uncertainty to the study results. Human health impacts are dependent not only on emission quantities but also on the fate and transport of the emitted substances and the concentrations and pathways by which exposures occur. Because these detailed types of information are not tracked in an LCI, there is greater uncertainty in the modeling of human health impacts associated with life cycle emissions. For example, two systems may release the same *total* amount of the same substance, but one quantity may represent a single high-concentration release with direct human exposure while the other quantity may represent the aggregate of many small dilute releases without direct human exposure. The actual impacts would likely be very different for these two scenarios, but the life cycle inventory does not track the temporal and spatial resolution or concentrations of releases in sufficient detail for the LCIA methodology to model the aggregated emission quantities differently. As a result of these uncertainties, life cycle impact assessment results for health impact categories are better suited to use for identifying main contributors within a system rather than as the basis for comparative statements about competing product systems. Further description of the rationale for exclusion of human health impacts is provided in the Inventory and Impact Assessment Results Categories section of Chapter 1.

Baseline results for the pressware plates are based on maximum decomposition of plates that are landfilled at end of life. The top surface of the plates has a moisture- and grease-resistant coating, but the back of the plate does not have a protective coating. Therefore, the pressware plates are expected to decompose over time in landfills where there are sufficient moisture, temperature, and microbial activity to support decomposition. Because not all landfills will have conditions favorable to maximize decomposition, and because global warming potential results for paperboard systems are sensitive to assumptions about degree of decomposition, scenarios with reduced decomposition of landfilled pressware plates are included as a sensitivity analysis.

The styrene acrylic coatings on pressware plates are applied via a flexographic process; however, the only flexographic process data sets that could be found were for flexographic printing of graphics, not surface coating application. For the baseline results in the report, the lower coating application energy was used. Scenarios using the higher coating application energy and including no coating application energy are included as a sensitivity analysis.

Normalized comparative life cycle results are shown in Figure ES-1, with the supporting data in Table ES-2. In the figure and table, results in each category are normalized against the results for the heavier pressware plate system, Plate 2, which has the highest results in most categories. Since Plate 2 is used as the reference system, all normalized results for the Plate 2 system are 100%, and results for the Hefty and Plate 1 systems are shown as percentages of the Plate 2 system results. For example, the normalized total energy bar for Hefty plates shows that the Hefty system total energy is 65% of the total energy results for Plate 2 with low coating energy.

The figure shows that the Hefty plate system has lower results than both pressware plate systems in 7 of the 10 results categories evaluated. The Hefty plate system has higher non-renewable energy requirements than the pressware plate systems due to its use of fossil fuels as both material feedstock and fuels for process and transportation energy. The pressware plate systems use more renewable energy, both as material feedstock for the fiber content of the plate and for bio-derived process energy at mills producing the virgin paperboard. The Hefty plate system also has the highest results for solid waste volume and ozone depletion potential; however, as described in the following section, the percent differences between system results for these categories is not large enough to be considered meaningful, given the uncertainties in the underlying data and modeling.

Meaningful Difference Analysis

A summary of comparative conclusions for all results categories for the Hefty plate system compared to the pressware plate systems is shown in Table ES-3. The percent differences shown in the table for each results category are calculated as the Hefty system total minus the pressware system total, divided by the average of the two systems' totals. Therefore, a positive number indicates that the Hefty plate system has higher results, and a negative number means the Hefty system has lower results.

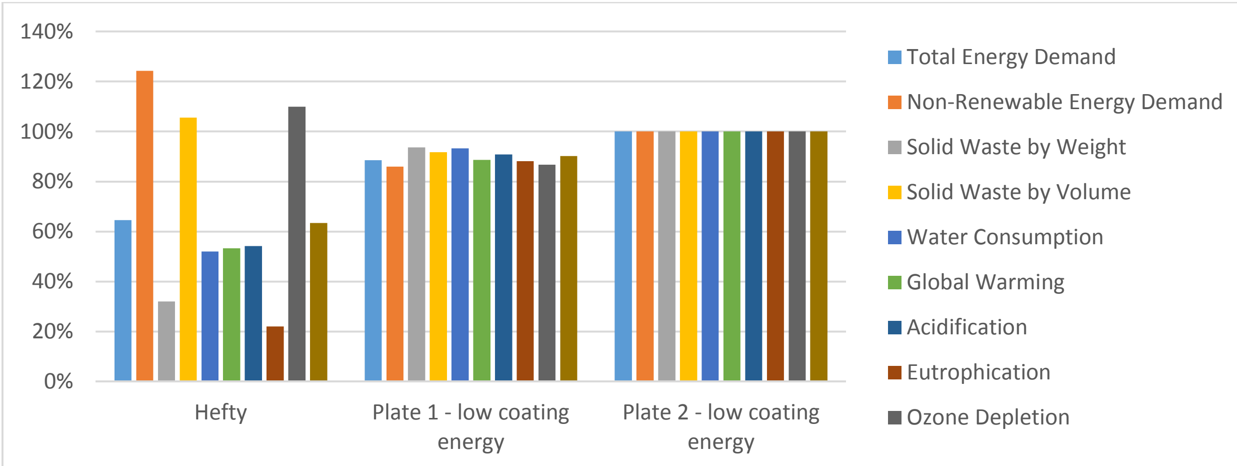

Figure ES–1. Normalized Comparative Results for Disposable Plates

Table ES–2. Results Summary

		System Totals			Normalized to Plate 2 Results		
Results Category	**Unit**	**Hefty**	**Pressware Plate 1**	**Pressware Plate 2**	**Hefty**	**Pressware Plate 1**	**Pressware Plate 2**
Total Energy Demand	MJ	5,632	7,727	8,729	65%	89%	100%
Non-Renewable Energy Demand	MJ	5,460	3,775	4,393	124%	86%	100%
Solid Waste by Weight	kg	52.0	152	162	32%	94%	100%
Solid Waste by Volume	cu m	0.29	0.25	0.28	106%	92%	100%
Water Consumption	liters	941	1,689	1,811	52%	93%	100%
Global Warming	kg CO2 eq	245	408	460	53%	89%	100%
Acidification	kg SO2 eq	0.75	1.26	1.39	54%	91%	100%
Eutrophication	kg N eq	0.028	0.11	0.13	22%	88%	100%
Ozone Depletion	kg CFC-11 eq	3.3E-06	2.6E-06	3.0E-06	110%	87%	100%
Smog	kg O3 eq	12.5	17.9	19.8	63%	90%	100%

In Table ES-3, a 10 percent minimum difference threshold is used for a meaningful difference in life cycle inventory results for total and non-renewable energy demand categories, and a 25 percent minimum difference threshold is used for both solid waste categories, water consumption results, and all life cycle impact results. Percent differences that are below these thresholds are considered to be within the margin of uncertainty of the data and are considered inconclusive.

The table uses a color-coding approach for comparative conclusions. Green indicates categories where the Hefty system has significantly lower results than the pressware systems, red is used for categories where Hefty has significantly higher results than the pressware systems, and gray indicates that the difference between Hefty and pressware plate systems is not large enough to be considered meaningful.

Table ES–3. Comparative Conclusions for Hefty and Pressware Plate Systems

		Percent Difference between Hefty and Pressware Plate Systems*	
Results Category	Minimum percent difference considered meaningful*	Plate 1 - low coating energy	Plate 2 - low coating energy
Total Energy Demand	10%	-31%	-43%
Non-Renewable Energy Demand	10%	37%	22%
Solid Waste by Weight	25%	-98%	-103%
Solid Waste by Volume	25%	14%	5%
Water Consumption	25%	-57%	-63%
Global Warming	25%	-50%	-61%
Acidification	25%	-51%	-60%
Eutrophication	25%	-120%	-128%
Ozone Depletion	25%	24%	9%
Smog	25%	-35%	-45%

** For each comparison of the foam plate system with a pressware plate, the percent difference is calculated as the difference between the foam and pressware system results divided by the average of the foam and pressware system results.*

The table shows that the Hefty plate system compares favorably with pressware plates in 7 of the 10 results categories evaluated. Although the results for solid waste volume and ozone depletion potential in Table ES-2 are somewhat higher in magnitude for the Hefty system, the percent differences between Hefty and pressware system results are not large enough to be considered meaningful, given the uncertainty in the underlying data and modeling. The only category in which the Hefty plate system has meaningfully higher results is non-renewable energy demand.

SENSITIVITY ANALYSES

In addition to the baseline scenarios, sensitivity analyses were also run to evaluate several areas with uncertainties that had the potential to influence study results and conclusions. The following sensitivity analyses were included: (1) reduced decomposition scenarios for landfilled pressware plates, and (2) different energy use scenarios for flexographic application of pressware plate coatings.

Landfill Decomposition

The baseline scenario reflects maximum decomposition of the degradable fiber in landfilled pressware plates over a 100-year period. This is considered a likely scenario because the moisture- and grease-resistant coatings that might inhibit degradation are only applied to the top surface of the plate. However, it is possible that plates may end up in landfills where conditions do not favor decomposition so that degradation occurs more slowly or does not occur at all. In addition to the maximum decomposition modeled in the baseline scenario, results were also run for 50% of maximum decomposition and for 0% decomposition. At lower decomposition rates, less of the biomass carbon is converted to methane, and a credit is given for the net carbon dioxide removed from the atmosphere and stored in the landfilled pressware plate fiber.

Table ES-3 shows the change in results and comparative conclusions for the different decomposition scenarios. The baseline results are identified in bold with red headings. As shown in the table, the only impact significantly affected by the decomposition assumption is GWP, which decreases notably for lower decomposition rates. There are also small changes in results for other impacts. These are due to the reduction in recovered energy credits, since less decomposition means less generation and utilization of landfill gas for energy; however, none of these changes affect comparative conclusions.

Table ES–4. Sensitivity Analysis on Landfill Decomposition

		Max decomposition		50% decomposition		No decomposition	
Results Category	Minimum percent difference considered meaningful	**Plate 1 - low coating energy**	**Plate 2 - low coating energy**	Plate 1 - low coating energy	Plate 2 - low coating energy	Plate 1 - low coating energy	Plate 2 - low coating energy
Total Energy Demand	10%	**-31%**	**-43%**	-43%	-31%	-44%	-32%
Non-Renewable Energy Demand	10%	**37%**	**22%**	22%	37%	20%	35%
Solid Waste by Weight	25%	**-98%**	**-103%**	-103%	-98%	-103%	-98%
Solid Waste by Volume	25%	**14%**	**5%**	5%	14%	5%	14%
Water Consumption	25%	**-57%**	**-63%**	-64%	-58%	-66%	-60%
Global Warming	25%	**-50%**	**-61%**	-24%	-11%	39%	54%
Acidification	25%	**-51%**	**-60%**	-61%	-52%	-62%	-54%
Eutrophication	25%	**-120%**	**-128%**	-128%	-120%	-128%	-121%
Ozone Depletion	25%	**24%**	**9%**	9%	24%	9%	24%
Smog	25%	**-35%**	**-45%**	-45%	-36%	-47%	-37%

Energy for Application of Pressware Plate Coatings

As discussed earlier, the coating on the pressware plate is applied in a flexographic process; however, the only flexographic process data sets that could be found were for flexographic printing of graphics (applying small amounts of inks to a fraction of the substrate surface), not for applying continuous surface coatings. Flexographic coating application energy for the pressware plates was estimated by adapting data from two different flexographic printing sources. A low estimate of flexographic coating process energy was derived from an EPA report on flexographic printing[1], and a higher energy estimate was developed based on a flexographic printing data set in the Swiss BUWAL database, available in SimaPro LCA software. The low process energy estimate was used in the baseline results. In addition, a scenario with no energy included for flexographic coating application was modeled to see if excluding coating application energy significantly affected results and conclusions. Table ES-5 shows the meaningful difference conclusions for the three coating energy scenarios for each plate compared to Hefty plates. The baseline (low coating energy) results are identified in bold with red headings. Although the percent differences change somewhat based on the coating application energy modeled, there are no changes in comparative conclusions in any results categories.

Table ES–5. Sensitivity Analysis on Coating Application Energy

		Percent Difference between Hefty and Pressware Plate Systems					
Results Category	Minimum percent difference considered meaningful	Plate 1 - no coating energy	**Plate 1 - low coating energy**	Plate 1 - high coating energy	Plate 2 - no coating energy	**Plate 2 - low coating energy**	Plate 2 - high coating energy
Total Energy Demand	10%	-31%	**-31%**	-33%	-42%	**-43%**	-46%
Non-Renewable Energy Demand	10%	38%	**37%**	33%	23%	**22%**	16%
Solid Waste by Weight	25%	-98%	**-98%**	-98%	-103%	**-103%**	-103%
Solid Waste by Volume	25%	14%	**14%**	14%	5%	**5%**	5%
Water Consumption	25%	-56%	**-57%**	-59%	-62%	**-63%**	-66%
Global Warming	25%	-49%	**-50%**	-52%	-60%	**-61%**	-64%
Acidification	25%	-50%	**-51%**	-53%	-59%	**-60%**	-62%
Eutrophication	25%	-120%	**-120%**	-120%	-128%	**-128%**	-128%
Ozone Depletion	25%	24%	**24%**	24%	9%	**9%**	9%
Smog	25%	-34%	**-35%**	-37%	-44%	**-45%**	-47%

OVERALL OBSERVATIONS AND CONCLUSIONS

Many of the foam plate system's favorable results are due to the fact that the foam plates are much lighter than the pressware plates so that the foam plate system uses substantially less material than the pressware plate systems. Overall, the results of this comparative analysis indicate that, for all scenarios evaluated, Hefty foam plates have lower environmental impacts than everyday coated paperboard pressware plates in the following areas:

- Cumulative energy demand
- Weight of solid waste
- Water consumption

[1] EPA 744-R-02-001A. Flexographic Ink Options: A Cleaner Technologies Substitutes Assessment. Design for the Environment Program. Economics, Exposure, and Technology Division. Office of Pollution Prevention and Toxics. U.S. Environmental Protection Agency. February 2002.

- Acidification
- Eutrophication
- Smog

Differences between the Hefty system and the pressware systems for solid waste volume and ozone depletion are not large enough to be considered meaningful. The foam plate system has higher results for non-renewable energy demand. This is largely due to the foam plate's use of fossil fuel resources both as material and energy inputs, and the higher energy use for foam plate manufacturing, including process energy and energy for operation a thermal oxidation system to destroy captured blowing agent emissions. Almost half of the total energy requirements for the pressware plate systems are renewable energy, largely from the use of wood as feedstock for the fiber content of the plates and use of wood-derived energy at the paper mills producing the plate rollstock.

Comparative conclusions for global warming potential results change depending on modeling assumptions:

- For the baseline assumption that the fiber in landfilled pressware plates will decompose to the maximum extent, the foam plate system has lower GWP results than the foam plates.
- If the paperboard in the pressware plates is modeled as decomposing to 50% of maximum, the GWP differences between the Hefty system and the pressware plate systems are no longer large enough to be considered meaningful.
- If 0% decomposition of landfilled paperboard is modeled, the pressware plate systems receive carbon storage credits for all of the biomass carbon content of the plate, and both pressware systems would have lower overall GWP compared to the foam plate system.

CHAPTER 1
STUDY GOAL AND SCOPE

INTRODUCTION

A life cycle assessment (LCA) examines the sequence of steps in the life cycle of a product system, beginning with raw material extraction and continuing on through material production, product fabrication, use, reuse or recycling where applicable, and final disposition. An LCA consists of four phases:

- Goal and scope definition
- Life cycle inventory (LCI)
- Life cycle impact assessment (LCIA)
- Interpretation of results

The LCI identifies and quantifies the material inputs, energy consumption, and environmental emissions (atmospheric emissions, waterborne wastes, and solid wastes) over the defined scope of the study.

The full inventory of atmospheric and waterborne emissions generated in the LCI is lengthy, making it difficult to interpret systems' differences in individual emissions in a concise and meaningful manner. In the LCIA phase, the inventory of emissions is classified into categories in which the emissions may contribute to impacts on human health or the environment. Within each impact category, the emissions are then normalized to a common reporting basis, using characterization factors that express the impact of each substance relative to a reference substance.

The information from an LCA can be used as the basis for further study of the potential improvement of resource use and environmental impacts associated with product systems. It can also pinpoint areas (e.g., material components or processes) where changes would be most beneficial in terms of reducing energy use or potential impacts.

In this chapter, the goal and scope of the study is defined, including information on data sources used and methodology. Chapter 2 presents the results of the LCI and LCIA phases.

STUDY GOAL AND INTENDED USE

The principal purpose of this LCA is to document and evaluate the environmental profiles of Reynolds' Hefty brand polystyrene foam plates and two leading competing pressware plates made from virgin bleached paperboard. The primary intended use of the study results is to provide Reynolds with information about the environmental burdens and tradeoffs associated with the life cycle of these types of plates, including end-of-life management. The LCA results for the plate systems can be used as a benchmark for evaluating future designs and process changes, or the results can be used to target efforts to reduce environmental impacts of current products, based on information on the largest contributors to results.

The LCA has been conducted following internationally accepted standards for LCA methodology as outlined in the ISO 14040 and 14044 standards[2]. Under the ISO standards, a panel peer review is required for studies intended to be used as the basis for public comparative assertions. Since Reynolds wishes to be able to share comparative results of the analysis with external parties, which may include customers or the general public, a panel peer review of the study has been conducted in order to comply with the ISO standards for LCA.

SYSTEMS STUDIED

Two types of plates are analyzed: general purpose polystyrene (GPPS) foam plates and pressware plates made from virgin bleached paperboard with clay and styrene acrylic latex coatings on the top surface. The fiber content of the pressware plates was modeled as virgin fiber because internet searches did not identify any pressware plates with recycled content. The plates are identified as “everyday” versions of the brands (as opposed to heavy-duty or extra strength versions).

The foam plates are made primarily from GPPS resin with a small percentage of talc added. Pentane and carbon dioxide are used in the foamed extrusion process. The carbon dioxide diffuses out rapidly, while some residual pentane is left in the plate. About 40% of the material becomes converting scrap, which reground and recycled back into the process. The plate production energy requirements include the energy for on-site reprocessing of the scrap. All burdens for production of the blowing agent and carbon dioxide used in the process (including the pentane that ends up in the scrap and is released during reprocessing for closed-loop recycling at the plant) are charged to the plates. The plant operating data also includes use of natural gas in a thermal oxidizer to destroy pentane emissions released in the plant. Essentially all of the pentane from scrap reprocessing is captured and converted to carbon dioxide in the thermal oxidizer. Of the pentane that ends up in the foamed plates, approximately 10% diffuses out before the plates leave the plant, and more diffuses out after the plates leave the plant (released to the atmosphere as pentane emissions).Reynolds staff estimated that the total amount of pentane remaining in the plates when they reach the end of their useful life is about 2.8 pounds per 10,000 foam plates.

The pressware plates are made from virgin bleached paperboard rollstock coated on the food contact side with an overprint varnish to provide a high-gloss finish and prevent the plate from absorbing water and grease. The amounts of clay and styrene acrylic latex in the coated rollstock are based on analysis of multiple samples of two leading brands of pressware plates. The analysis was conducted by IPS Testing and submitted to

2 International Standards Organization. ISO 14040:2006 Environmental management—Life cycle assessment—Principles and framework, ISO 14044:2006, Environmental management – Life cycle assessment – Requirements and guidelines.

Underwriters Laboratories Verification Services Inc. in March 2015. The composition of the styrene acrylic latex was modeled based on composition information in the Code of Federal Regulations for styrene acrylic coatings approved for food contact uses.[3] The coated rollstock is shipped to a converting plant where it is moistened, cut into blanks, and thermoformed into plates. The scrap from cutting blanks out of rollstock leaves the plate system boundaries to be recycled for use in another system. The pressware plate is not charged with the burdens for the fiber content of the scrap, since it is used in another system; however, the coatings on the scrap material become waste during the scrap recycling, so the burdens for production and disposal of the wasted coating material is charged to the plate system.

Information on pressware plate forming was gathered from machine specifications and personal communication with a sales representative at Peerless Machine and Tool Corporation.[4] Energy and air consumption and rollstock scrap were calculated based on requirements for the Peerless ITM-HD Paperboard Moistener and P-57 Heavy Duty forming machine. The P-line HD machine is a 2-stage press: first it cuts and scores the flat rim blank and then transfers the blank to the press for thermoforming by dies heated to approximately 325 degrees F. The P57-HD is a 5 die machine that operates at 45 strokes per minute, which means that 13,500 plates are formed per hour of operation. A typical set-up uses a blank size of 9 5/16" spaced 3/16" apart and offset from each other at 30 degrees for optimal use of paper. This set up requires a paperboard roll with 42.6" web width and results in an engineered scrap rate of 15.85%. According to equipment specifications found on the Peerless website, the P57-HD forming machine consumes 45 kW of electricity and 11.8 liters of air per second at 5.5 bars of pressure.[5] Before forming, rollstock must be moistened to achieve a moisture content of 8 to 10 percent. The midpoint of this range, 9 percent moisture content, was chosen for use in this study. Water used for moistening is considered consumptive as it is assumed to evaporate during thermoforming or afterwards as the plate dries in ambient conditions. The ITM-HD Paperboard Moistener operates at a rate around 450 feet per minute. Given that an average of 5 plates are formed for every 9.5 inches (9 5/16" blank plus 3/16" space between blanks) in length, in one hour the machine can moisten enough paper to form 170,526 paper plates. According to equipment specifications found on the Peerless website, the moistener consumes 20 kW of electricity and 4.72 liters of air per second at 5.5 bars of pressure.[6]

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3 Electronic Code of Federal Regulations. §176.170 Components of paper and paperboard in contact with aqueous and fatty foods. Accessed in May 15, 2015 at http://www.ecfr.gov/cgi-bin/text-idx?rgn=div5&node=21:3.0.1.1.7#se21.3.176_1170.

4 Peerless Machine and Tool Corporation. Personal communication. May 13, 2015.

5 Peerless Machine and Tool Corporation. Peerless Roll to Roll Paperboard Moistener Machine - Model ITM-HD. Accessed May 14, 2015 at http://www.peerlessmachine.com/images/stories/manuals/pline.pdf

6 Peerless Machine and Tool Corporation. Peerless Roll to Roll Paperboard Moistener Machine - Model ITM-HD. Accessed May 14, 2015 at http://www.peerlessmachine.com/images/stories/manuals/ITM-REV0113.pdf

Plate weights, composition, and packaging information are shown in Table 2-1. As noted previously, the weight and composition of the pressware plates were based on multiple samples of two leading brands that Reynolds had tested by a third-party laboratory. Although the weight and composition of the pressware plates were modeled based on samples of these two brands, the manufacturers of the pressware plates did not participate in the study or provide any manufacturing data for the study. Therefore, the pressware plate results cannot be considered directly representative of these brands, so brand names are not used and the plates are referred to as pressware Plate 1 and Plate 2.

The table shows that the pressware plates are more than double the weight of the foam plate, but the foam plate uses more packaging per 10,000 plates shipped. Overall, the total weight of plates and packaging for the foam plate system is less than half of the total weight for both pressware plate systems. Because of the low density of foam plates, truckloads of foam plates are volume-limited (the load cubes out before reaching maximum weight), in contrast to pressware plate shipments, which are weight-limited. For each type of plate, the transportation fuel usage for plate distribution is based on the fuel economy for the volume- or weight-limited truckload and the share of the truckload occupied by 10,000 packaged plates.

FUNCTIONAL UNIT

In a life cycle study, products are compared on the basis of providing the same defined function (called the **functional unit**). The function of a disposable plate is to hold food during a single use. The functional unit used for this study is 10,000 single-use plates. Although the sizes of plates studied in this analysis are not exactly the same, it is reasonable to expect that the very small difference in diameters will not result in a difference in consumer use/functionality. A more important functional equivalence issue is the ability of the plates to hold similar loads of food. The weight and moisture content of the food on a plate can vary widely depending on the use situation. No load-bearing tests were conducted on the plates; however, all plates modeled in this analysis are described as "everyday" plates and therefore are expected to provide similar functionality across a range of common use scenarios.

SCOPE AND BOUNDARIES

This LCA quantifies energy and resource use, solid waste, and environmental impacts for the following steps in the life cycle of each plate system studied:

- Raw material extraction (e.g., extraction of petroleum and natural gas as feedstocks for plastic resin, harvesting of trees for virgin paper), and intermediate material processing
- Fabrication steps to transform materials into plates

- Life cycle of secondary packaging components used to package plates for shipment (includes material extraction, intermediate material processing, fabrication, and end of life management of corrugated boxes and film sleeves)
- Transportation of plates to a distribution center
- End-of-life management of plates.

Table 1-1. Composition of Plates and Packaging

	Hefty	Pressware Plate 1	Pressware Plate 2
Plate diameter (inches)	8.875	8.625	8.5
Average plate weight (grams)	4.49	10.98	12.03
Plate composition by weight (grams)			
General purpose polystyrene resin	4.25		
Talc	0.07		
Pentane	0.17		
Bleached paperboard		8.53	9.42
Clay coating		1.91	1.71
Styrene acrylic latex coating		0.54	0.89
Total weight of 10,000 plates			
Kilograms	44.9	110	120
Pounds	99.0	242	265
Hefty plate weight as % of pressware		***41%***	***37%***
Packaging			
Plates/shipping case	400	540	490
Cases/10,000 plates	25.0	18.5	20.4
Sleeves of product/case	8	12	10
Weight per plastic film sleeve (g)	6.6	4.6	4.4
Total weight of sleeves per case (g)	52.8	55.2	44.0
Weight of tape (g)	2.5	5.1	5.5
Weight of corrugated shipping box (g)	420	409	297
Total weight of packaging for 10,000 plates			
Kilograms	11.9	8.68	7.07
Pounds	26.2	19.1	15.6
Hefty packaging weight as % of pressware		***137%***	***168%***
Total weight of 10,000 plates + packaging			
Kilograms	56.8	118	127
Pounds	125	261	281
Hefty total weight as % of pressware		***48%***	***45%***

The following are not included in the study:

- **Miscellaneous materials and additives.** Selected materials such as catalysts, pigments, or other additives which total less than one percent by weight of the net process inputs are typically not included in the assessment. Omitting miscellaneous materials and additives helps keep the scope of the study focused and manageable within budget and time constraints. It is possible that production of some substances used in small amounts may be energy and resource intensive or may release toxic emissions; however, the impacts would have to be very large in proportion to their mass in order to significantly affect overall results and conclusions. The study included resource-intensive and/or toxic materials used in the production of the input materials listed in Table 1-1, but no other use of resource-intensive or high-toxicity chemicals or additives was identified for either plate system. Therefore, the results for the plate systems are not expected to be understated by any significant amount due to substances that may be used in small amounts. It is worth noting that the pressware plate samples evaluated for this analysis are printed with designs, while the foam plates have no graphics. No information was available regarding the weight or composition of the pigments used for printing the pressware plates. Because Hefty plates do not have printed designs, and printing is not required for the function of the plates, printing inks are excluded for the pressware plate systems.

- **Transportation of plates from distribution centers to retail stores in mixed loads and consumer transport from store to home.** Boxes of plates shipped from distribution centers would be shipped as part of a mixed load of product. Disposable plates' share of the mixed truckload of product is not known and will vary from load to load. In addition, the mixed truckloads may be weight limited (in which case the lighter weight of the foam plates would be advantageous), or the loads may be volume limited (in which case the greater amount of space occupied by foam plates would be a disadvantage). Because of these uncertainties, and the small contribution of transportation to overall results, transportation steps after the distribution center are excluded.
- **Use of plates.** There are no direct impacts associated with using the plates to hold food.
- **Capital equipment, facilities, and infrastructure.** The energy and wastes associated with the manufacture of buildings, roads, pipelines, motor vehicles, industrial machinery, etc. are not included. The energy and emissions associated with production of capital equipment, facilities, and infrastructure generally become negligible when averaged over the total output of product or service provided over their useful lifetimes.
- **Space conditioning.** The fuels and power consumed to heat, cool, and light manufacturing establishments are omitted from the calculations in most cases. For manufacturing plants that carry out thermal processing or otherwise consume large amounts of energy, space conditioning energy is quite low compared to process energy. The data collection forms completed by the foam plate producer for this project specifically requested that the data provider exclude energy use for space conditioning, and the pressware plate manufacturing energy requirements were calculated from plate manufacturing equipment specifications, with no associated information on space conditioning energy. Compared to the energy use for plate manufacturing processes, which included heated extrusion of resin and thermoforming of moistened paper rollstock, energy use for space conditioning, lighting, and other overhead activities is not expected to make a significant contribution to total energy use for the systems analyzed in this study.

- **Support personnel requirements**. The energy and wastes associated with research and development, sales, and administrative personnel or related activities have not been included in this study. Similar to space conditioning, energy requirements and related emissions are assumed to be quite small for support personnel activities.

The geographic scope of the analysis is plates manufactured, used, and disposed in North America. The majority of the data used in the modeling is from North American databases (U.S. LCI database, Franklin Associates' private database). In cases where it was necessary to use supplemental data from European database, the data sets were adapted to the extent possible to represent North American inputs and practices.

The plates evaluated are non-durable plates that are not designed or intended for reuse, so the plates were modeled as being disposed after one use. End-of-life management of plates was modeled based on national average MSW management. In the U.S., municipal solid waste (MSW) that is not recovered for recycling or composting is managed by landfilling or waste-to-energy (WTE) combustion. Recent U.S. EPA statistics indicate that 82% by weight of MSW goes to landfill and the remaining 18% goes to WTE combustion facilities.[7] For material that is disposed by WTE combustion, an energy credit is given based on the amount of each material burned, its higher heating value, and the efficiency of converting the gross heat of combustion to useful energy in the form of electricity. A detailed description of end-of-life modeling is provided later in this chapter.

INVENTORY AND IMPACT ASSESSMENT RESULTS CATEGORIES

The full inventory of emissions generated in an LCA study is lengthy and diverse, making it difficult to interpret emissions profiles in a concise and meaningful manner. Life cycle impact assessment (LCIA) helps with interpretation of the emissions inventory. LCIA is defined in ISO 14044 Section 3.4 as the "phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product." In the LCIA phase, the inventory of emissions is first classified into categories in which the emissions may contribute to impacts on human health or the environment. Within each impact category, the emissions are then normalized to a common reporting basis, using characterization factors that express the impact of each substance relative to a reference substance.

The results categories and methods applied in this study are displayed in Table 1-2. This study addresses global, regional, and local environmental impact categories. For most of the impact categories examined, the TRACI 2.1 methodology, developed by the United States Environmental Protection Agency (EPA) specific to U.S.

[7] U.S. EPA. Municipal Solid Waste in the United States: Facts and Figures. Calculated from 2010 Data Tables, Table 29. Accessed at http://www.epa.gov/wastes/nonhaz/municipal/msw99.htm.

conditions and updated in 2012, is employed.[8] For the category of Global Warming Potential (GWP), contributing elementary flows are characterized using factors reported by the Intergovernmental Panel on Climate Change (IPCC) in 2007 with a 100 year time horizon.[9] In addition, some life cycle inventory (LCI) results are included in the results reported in the analysis:

- Energy demand: this method is not an impact assessment, but rather is a cumulative inventory of all forms of renewable and non-renewable energy used for processing energy, transportation energy, and feedstock energy (including non-renewable feedstock energy for the resins and blowing agent in the foam plates, renewable feedstock energy for the fiber in the pressware plates, and non-renewable feedstock energy for the petrochemical content of the pressware plate varnish). This analysis reports both total energy demand and non-renewable energy demand. Non-renewable energy demand is reported separately to assess consumption of fuel resources that can be depleted, while total energy demand is used as an indicator of overall consumption of resources with energy value.
- Solid waste is assessed as a sum of the inventory values associated with this category.
- Water consumption is assessed as a sum of the inventory values associated with this category and does not include any assessment of water scarcity issues.

Table 1-2. Summary of LCI/LCIA Impact Categories

	Impact/Inventory Category	Description	Unit	LCIA/LCI Methodology
LCI Categories	**Total energy demand**	Measures the total energy from point of extraction; results include both renewable and non-renewable energy sources	MJ	Cumulative energy inventory
	Non-renewable energy demand	Measures the fossil and nuclear energy from point of extraction	MJ	Cumulative energy inventory

8 EPA's Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI), see: http://www.pre-sustainability.com/download/TRACI_2_1_User_Manual.pdf.

9 Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, 2007: Changes in Atmospheric Constituents and in Radiative Forcing. *In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

	Impact/Inventory Category	Description	Unit	LCIA/LCI Methodology
	Solid waste by weight	Measures quantity of fuel, process and postconsumer waste to a specific fate (e.g., landfill, WTE) for final disposal on a mass basis	kg	Cumulative solid waste inventory
	Solid waste by volume	Measures quantity of fuel, process and postconsumer waste to a specific fate (e.g., landfill, WTE) for final disposal on a volume basis	m^3	Cumulative solid waste inventory
	Water consumption	Freshwater withdrawals which are evaporated, incorporated into products and waste, transferred to different watersheds, or disposed into the sea after usage	L	Cumulative water consumption inventory
LCIA Categories	**Global warming potential***	Represents the heat trapping capacity of the greenhouse gases. Important emissions: CO_2 fossil, CH_4, N_2O	kg CO_2 equivalents (eq)	IPCC (2007) GWP 100a*
	Acidification potential	Quantifies the acidifying effect of substances on their environment. Important emissions: SO_2, NO_x, NH_3, HCl, HF, H_2S	kg SO_2 eq	TRACI v2.1
	Eutrophication potential	Assesses impacts from excessive load of macro-nutrients to the environment. Important emissions: NH_3, NO_x, COD and BOD, N and P compounds	kg N eq	TRACI v2.1
	Ozone depletion potential	Measures stratospheric ozone depletion. Important emissions: CFC compounds and halons	kg CFC-11 eq	TRACI v2.1
	Smog formation potential	Determines the formation of reactive substances (e.g. tropospheric ozone) that cause harm to human health and vegetation. Important emissions: NO_x, BTEX, NMVOC, CH_4, C_2H_6, C_4H_{10}, C_3H_8, C_6H_{14}, acetylene, Et-OH, formaldehyde	kg O_3 eq	TRACI v2.1

**The GWP factor used for biogenic methane in this study is taken from TRACI v2.1 (not within IPCC characterization factors) and is lower than the GWP factor for fossil methane, reflecting the impact of biogenic methane in the atmosphere until it converts to carbon-neutral biogenic CO_2. The GWP for biogenic methane in this study is 22 and the GWP for fossil methane in this study is 25.*

This study focuses on environmental impacts and does not include comparisons of the plate systems for human health impact categories. Human health impacts are dependent not only on emission quantities but also on the fate and transport of the emitted substances and the concentrations and pathways by which exposures occur. Because these detailed types of information are not tracked in an LCI, there is greater uncertainty in the modeling of human health impacts associated with life cycle emissions. For example, two systems may release the same *total* amount of the same substance, but one quantity may represent a single high-concentration release with direct human exposure while the other quantity may represent the aggregate of many small dilute releases without direct human exposure. The actual impacts would likely be very different for these two scenarios, but the life cycle inventory does not track the temporal and spatial resolution or concentrations of releases in sufficient detail for the LCIA methodology to model the aggregated emission quantities differently.

The TRACI 2.1 impact assessment methodology used for this analysis uses the USEtox method for assessing human health and freshwater ecotoxicity impacts. USEtox is also selected as the preferred method for evaluating human health and freshwater ecotoxicity in the International Reference Life Cycle Data System (ILCD) handbook on Life Cycle Impact Assessment.[10] As noted in the ILCD handbook section 3.3.5 on human toxicity uncertainty, toxicity factors "must be used in a way that reflects the large variation of 12 orders of magnitude between characterization factors for toxicological effects for different chemicals as well as the 3 orders of magnitude uncertainty on the individual factors." The handbook goes on to state "Furthermore, spatial differentiation may influence results, especially for chemicals with short lifetimes: the population density around the point of emission in case of inhalation being the dominant route, the agricultural production intensity in case of food dominant pathways, the vicinity of the emission relative to a drinking water source, etc. No comprehensive assessment or approach currently exists to account for these spatial, as well as temporal variations in LCA studies." While this study agrees that the USEtox model has significantly increased the precision of characterization factors for human and ecosystem toxicity models and significantly decreased inter-model variability, the ILCD impact assessment handbook categorizes USEtox midpoint methods for toxicity impacts as "II/III" and goes on to state that methods categorized as III "are recommended to be used but only with caution given the considerable uncertainty, incompleteness and/or other shortcomings of the models and [characterization] factors. ***These models/factors are in need of further research and development before they can be used without reservation for decision support especially in comparative assertions***" (emphasis added). The handbook describes USEtox as a good screening-level indicator to identify the main contributors to potential toxicity impacts in product system life cycles. Therefore, life cycle human health impact results from USEtox may be useful for contribution analyses for individual systems, but due to the high uncertainties, caution should be used when considering inclusion of toxicity results in studies that may be used for comparative assertions about different product systems.

10 European Commission-Joint Research Centre - Institute for Environment and Sustainability: International Reference Life Cycle Data System (ILCD) Handbook- Recommendations for Life Cycle Impact Assessment in the European context. First edition November 2011. EUR 24571 EN. Luxemburg. Publications Office of the European Union; 2011.

DATA SOURCES

Information on polystyrene foam plate weights, composition, fabrication process data, and plate packaging were provided by Reynolds. Weights of pressware plates and packaging were based on multiple samples of two leading brands of pressware plates purchased by Reynolds. The plate manufacturing equipment data used to model converting of paperboard rollstock into pressware plates were described in the Systems Studied section of this chapter. The composition of pressware plates (weight percentages and material types of the plate fiber content and coatings) are modeled based on testing done by a third party on multiple samples of the pressware plates.[11] The following data sets were used for modeling:

- Production and combustion of process fuels (including those used for electricity generation) and transportation fuels: U.S. LCI Database (updated in 2011)_
- Mix of fuels used to produce U.S. electricity: eGRID 2010 data published in 2012.
- Production of general purpose polystyrene resin and styrene component of styrene acrylic latex coating: ACC plastics resin data in the U.S. LCI Database (updated in 2011)
- Production of pentane: 2011 data sets on petroleum and natural gas refining combined with mid-1990s percentages for pentane production from petroleum and gas refining.
- Production of clay coating and starch inputs to pressware plates and talc inputs to foam plate: primary data from Franklin private U.S. database (data sets from mid 1990s)
- Production of virgin bleached kraft paperboard: Data developed by Franklin Associates for Environmental Paper Network Paper Calculator in 2009.
- Production of methyl methacrylate component of styrene acrylic latex coating: ecoinvent (cradle-to-gate data set from 2010, aggregated so could not be adapted to use U.S. inputs)
- Production of butyl acrylate component of styrene acrylic latex coating for pressware plates and carbon dioxide input to foam plate: ecoinvent adapted to use U.S. material and energy inputs (butyl acrylate 2010 data set adapted in 2015; carbon dioxide 2004 data set adapted in 2015)
- Flexographic printing process: BUWAL 1996 data set in SimaPro adapted in 2015 to use U.S. energy inputs; EPA 2002 data set.

Data sets from European databases (ecoinvent and BUWAL) were adapted to U.S. conditions to the extent possible by linking reported material and fuel input amounts to corresponding U.S. inputs (e.g., kWh of process energy reported in European data sets were linked to data for production of U.S. 2010 average grid electricity).

[11] Report submitted by IPS Testing to Underwriters Laboratories (UL) Verification Services Inc. in March 2015.

The greenhouse gas implications of end-of-life management of disposed plates were modeled based on the relative percentages of MSW managed by landfilling and WTE combustion, U.S. EPA reports containing information on generation and management of landfill methane[12,13], and a published article on methane generation from decomposition of paper products in simulated landfill conditions.[14] A detailed description of end-of-life modeling is provided later in this chapter.

DATA QUALITY ASSESSMENT

ISO 14044:2006 lists a number of data quality requirements that should be addressed for studies intended for use in public comparative assertions. The data quality goals for this analysis were to use data that are (1) geographically representative for each plate system based on the locations where material sourcing and converting operations, box manufacturing, filling, packaging, and end-of-life management take place, and (2) representative of current industry practices in these regions. As described in the previous section, Reynolds provided current, geographically representative data for the foam plate systems. Independent laboratory testing of samples of pressware plates purchased in early 2015 provided current information on the weight and composition of pressware plates, and pressware plate manufacturing data were based on operating equipment specifications for current plate manufacturing equipment as well as interviews with manufacturers of pressware plate moistening, stamping, and thermoforming equipment and suppliers of pressware plate coatings.

As described in the previous section, the data sets used in the models were drawn largely from reliable published databases (ecoinvent and U.S. LCI Database) or from Franklin's confidential database of primary North American unit process data. The data sets used were the most current and most geographically and technologically relevant data sets available during the data collection phase of the project.

Consistency, Completeness, Precision: Data evaluation procedures and criteria were applied consistently to all primary data provided by Reynolds. All primary data obtained specifically for this study were considered the most representative available for the systems being studied. Data sets were reviewed for completeness and material balances, and follow-up was conducted as needed to resolve any questions about the input and output flows, process technology, etc. The same evaluation process was used in the development of data sets from Franklin's private LCI database that were used in this analysis.

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12 U.S. EPA. Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks. Third Edition. September 2006.

13 U.S. EPA. **Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006** (February 2008). Calculated from 2006 data in Table 8-4. Accessible at http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

14 Eleazar, William, et al. 1997. Biodegradability of Municipal Solid Waste Components in Laboratory-Scale Landfills. Environmental Science & Technology 31:911-917.

Reproducibility: To maximize transparency and reproducibility, the report identifies specific data sources, assumptions, and methodological approaches used in the analysis to the extent possible; however, reproducibility of study results is limited to some extent by the need to protect certain data sets that were judged to be the most representative data sets for modeling purposes but could not be shown due to confidentiality.

Uncertainty: Uncertainty issues and uncertainty thresholds applied in interpreting study results are described in the following section.

DATA ACCURACY AND UNCERTAINTY

An important issue to consider when using LCA study results is the reliability of the data. In a complex study with literally thousands of numeric entries, the accuracy of the data and how it affects conclusions is truly a complex subject, and one that does not lend itself to standard error analysis techniques. Techniques such as Monte Carlo analysis can be used to study uncertainty, but the greatest challenge is the lack of uncertainty data or probability distributions for key parameters, which are often only available as single point estimates. However, the reliability of the study can be assessed in other ways.

A key question is whether the LCI profiles are accurate and study conclusions are correct. The accuracy of an environmental profile depends on the accuracy of the numbers that are combined to arrive at that conclusion. Because of the many processes required to produce each packaging material, many numbers in the LCI are added together for a total numeric result. Each number by itself may contribute little to the total, so the accuracy of each number by itself has a small effect on the overall accuracy of the total. There is no widely accepted analytical method for assessing the accuracy of each number to any degree of confidence. For many chemical processes, the data sets are based on actual plant data reported by plant personnel. The data reported may represent operations for the previous year or may be representative of engineering and/or accounting methods. All data received are evaluated to determine whether or not they are representative of the typical industry practices for that operation or process being evaluated.

There are several other important points with regard to data accuracy. Each number generally contributes a small part to the total value, so a large error in one data point does not necessarily create a problem. For process steps that make a larger than average contribution to the total, special care is taken with the data quality.

There is another dimension to the reliability of the data. Certain numbers do not stand alone, but rather affect several numbers in the system. An example is the amount of material required for a process. This number will affect every step in the production sequence prior to the process. Errors such as this that propagate throughout the system are more significant in steps that are closest to the end of the production sequence. For example, changing the weight of an input to the final fabrication step for a plastic component changes the amounts of resin inputs to that process, and so on back to the quantities of crude oil and natural gas extracted.

Based on the uncertainties in LCI energy data, energy differences between systems are not considered meaningful unless the percent difference between system results is greater than 10 percent. (Percent difference between systems is defined as the difference between energy totals divided by the average of the two system totals.) This minimum percent difference criterion was developed based on the experience and professional judgment of the analysts. If the percent difference between two systems' results is less than 10 percent, the comparison is considered inconclusive. The threshold guidelines are not intended to be interpreted as rigorous statistical uncertainty analysis, but rather are provided as general guidelines for readers to use when interpreting differences in system results, to ensure that undue importance is not placed on small differences that fall within the uncertainties of the underlying data.

The emissions, solid waste, and water consumption data used to develop the LCA results (i.e., solid waste, water consumption, global warming potential, eutrophication potential, acidification potential, and smog formation potential) are based upon the best data available. Some emissions, water, and waste data are reported from industrial sources, and others are based on engineering estimates or published emission factors. Because of these uncertainties, the difference in two systems' environmental emissions, water consumption, and solid waste results are not considered meaningful unless the percent difference exceeds 25%. (Percent difference is defined as the difference between two system totals divided by their average.) This minimum percent difference criterion was developed based on the experience and professional judgment of the analysts. If the percent difference between two systems' results is less than 25%, the comparison is considered inconclusive. Again, the threshold guidelines are not intended to be interpreted as rigorous statistical uncertainty analysis, but rather are provided as general guidelines for readers to use when interpreting differences in system results, to ensure that undue importance is not placed on small differences that fall within the uncertainties of the underlying data.

In addition to the uncertainty of the LCI emissions data, there is uncertainty associated with the application of LCIA methodologies to aggregated LCI emissions. For example, two systems may release the same total amount of the same substance, but one quantity may represent a single high-concentration release to a stressed environment while the other quantity may represent the aggregate of many small dilute releases to environments that are well below threshold limits for the released substance. The actual impacts would likely be very different for these two scenarios, but the life cycle inventory does not track the temporal and spatial resolution or concentrations of releases in sufficient detail for the LCIA methodology to model the aggregated emission quantities differently. Therefore, it is not possible to state with complete certainty that differences in potential impacts for two systems are significant differences. Although there is uncertainty associated with LCIA methodologies, all LCIA methodologies are applied to the two plate system models uniformly. Therefore, comparative results can be determined with a greater confidence than absolute results for one system. Since the emissions results used as the starting point for the LCIA are considered to have a 25 percent uncertainty, and the LCIA characterization method, although applied equally to all systems, may introduce additional uncertainty, a 25 percent difference is used here as the minimum threshold required for a meaningful difference in LCIA results.

Although GWP results are generally dominated by fossil CO_2 emissions, which are closely tied to energy use, a 25% threshold is used for GWP results rather than a 10% threshold as used for energy results. The higher threshold is used for GWP because there can be significant variations in the fossil CO_2 emissions associated with the same quantity of MJ of energy, depending on the type(s) of fuel used to provide the energy. For example, a facility using coal as boiler fuel may have energy requirements similar to a facility using natural gas as boiler fuel, but the GWP profiles will be very different. Because LCI data sets are often based on a limited sample of facilities or literature sources, the fuel-related CO_2 emissions for a process are likely to have a higher uncertainty than energy results for the process. Additionally, GWP results can also be strongly influenced by small emissions of substances with high GWP characterization factors. As noted above, when primary data are not available, emissions data are often based on emissions factors that may over- or under-represent actual releases from industrial facilities.

METHODOLOGY

The LCA has been conducted following internationally accepted standards for LCA methodology as outlined in the ISO 14040 and 14044 standards, which provide guidance and requirements for conducting life cycle assessments. However, for some specific aspects of life cycle assessment, the ISO standards have some flexibility and allow for methodological choices to be made. These include the method used to allocate energy requirements and environmental releases among more than one useful product produced by a process, the method used to account for the energy contained in material feedstocks, and the methodology used to allocate environmental burdens for recycled content. The following sections describe the approach to each issue used in this study.

Co-product Credit

An important feature of life cycle inventories is that the quantification of inputs and outputs are related to a specific amount of useful output from a process. However, it is sometimes difficult or impossible to identify which inputs and outputs are associated with individual products of interest resulting from a single process (or process sequence) that produces multiple useful products. The practice of allocating inputs and outputs among multiple products from a process is often referred to as "co-product credit"[15] or "partitioning"[16].

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15 Hunt, Robert G., Sellers, Jere D., and Franklin, William E. **Resource and Environmental Profile Analysis: A Life Cycle Environmental Assessment for Products and Procedures.** Environmental Impact Assessment Review. 1992; 12:245-269.

16 Boustead, Ian. **Eco-balance Methodology for Commodity Thermoplastics.** A report for The Centre for Plastics in the Environment (PWMI). Brussels, Belgium. December, 1992.

Co-product credit is done out of necessity when raw materials and emissions cannot be directly attributed to one of several product outputs from a system. It has long been recognized that the practice of giving co-product credit is less desirable than being able to identify which inputs lead to particular outputs. In this study, co-product allocations are necessary because of multiple useful outputs from some of the "upstream" chemical processes involved in producing the resins used to manufacture plastic plates.

Franklin Associates follows the guidelines for allocating co-product credit shown in the ISO 14044:2006 standard on life cycle assessment requirements and guidelines. In this standard, the preferred hierarchy for handling allocation is (1) avoid allocation where possible, (2) allocate flows based on direct physical relationships to product outputs, (3) use some other relationship between elementary flows and product output. No single allocation method is suitable for every scenario. As described in ISO 14044 section 4.3.4.2, when allocation cannot be avoided, the preferred partitioning approach should reflect the underlying physical relationships between the different products or functions.
Some processes lend themselves to physical allocation because they have physical parameters that provide a good representation of the environmental burdens of each co-product. Examples of various allocation methods are mass, stoichiometric, elemental, reaction enthalpy, and economic allocation. Simple mass and enthalpy allocation have been chosen as the common forms of allocation in this analysis. However, these allocation methods were not chosen as a default choice, but made on a case by case basis after due consideration of the chemistry and basis for production.

In the hydrocrackers that produce olefins used in the production of polystyrene resin for the plastic foam plates, both materials and energy are produced as co-products. It was not possible to determine the amounts of individual material inputs that produced the energy co-products, nor was it possible to determine what types and quantities of fuel were displaced by use of the energy co-products. Therefore, the energy co-products from the hydrocracker are treated as an energy credit, rather than assigning system expansion credits for displacement of specific fuel(s).

Postconsumer Recycling Allocation Methodology

When material is used in one system and subsequently recovered, reprocessed, and used in another application, there are different methods that can be used to allocate environmental burdens among different useful lives of the material. ISO 14044 states that "whenever several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted to illustrate the consequences of the departure from the selected approach." The plates evaluated in this study do not have postconsumer recycled content, but recycling allocation applies to the corrugated boxes used as secondary packaging.

In the allocation hierarchy in the ISO 14044[17], avoidance of allocation where possible is the preferred approach. Therefore, system expansion is the approach used in this analysis for modeling postconsumer recycling of the corrugated boxes used to package the plates. In the system expansion approach, the system boundaries are expanded to include collection and reprocessing of postconsumer boxes, as well as the net material displacement based on the difference between the recycling rate for the boxes and the recycled content of the boxes. If the amount of postconsumer material *produced* from the recovered boxes at the specified recycling rate is greater than the amount of postconsumer material *used* in the boxes, the boxes produce more recycled material than is needed to sustain their recycled content, and a credit is given for avoiding production of unbleached paperboard displaced by the excess recovered box material. Because the sleeves of plates are removed from the shipping boxes at retail stores, the corrugated boxes are modeled at the retail recycling rate of 95 percent, which is higher than their postconsumer recycled content (41.8 percent), so each plate system receives system expansion credits for recycling of the corrugated boxes used for shipping plates.

End of Life Management

In the U.S., municipal solid waste (MSW) that is not recovered for recycling or composting is managed 82% by weight to landfill (LF) and 18% by weight to waste-to-energy (WTE) incineration.[18] Thus, the calculations of the GWP impacts for discarded plates are based on a scenario in which 82% of the postconsumer plates and unrecycled secondary packaging go to landfill and 18% to WTE combustion.

In this study, the end results of landfilling and WTE combustion primarily affect global warming potential results. There are GWP contributions from WTE combustion of postconsumer plates and packaging and from fugitive emissions of landfill methane from decomposition of pressware plates. There are also GWP credits for grid electricity displaced by the generation of electricity from WTE combustion of postconsumer plates and packaging and from WTE combustion of methane recovered from decomposition of landfilled pressware plates. Some carbon is also sequestered in the portions of biomass-derived plates that do not decompose. The U.S. EPA greenhouse gas accounting methodology does not assign a carbon sequestration credit to landfilling of fossil-derived materials because this is considered a transfer between carbon stocks (from oil deposit to landfill) with no net change in the overall amount of carbon stored.[19]

In this study, decomposition of landfilled pressware plates is modeled based on the maximum decomposition observed in landfill simulation experiments conducted by

[17] ISO 14044: 2006, Environmental management – Life cycle assessment – Requirements and guidelines

[18] U.S. EPA. Municipal Solid Waste in the United States: Facts and Figures. Calculated from 2010 Data Tables, Table 29. Accessed at http://www.epa.gov/wastes/nonhaz/municipal/msw99.htm.

[19] U.S. EPA. **Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks.** Third Edition. September 2006. Section 1.3, subsection Carbon Stocks, Carbon Storage, and Carbon Sequestration. Page 6.

William Eleazar, et al. [20] Because the landfill simulation experiments were designed to maximize decomposition, the estimates presented here should be considered an *upper limit* for landfill gas generation from decomposition of pressware plates. Alternative results for modeling a lesser degree of decomposition are shown in the end-of-life sensitivity analysis in Chapter 3.

The landfill simulation experiments analyzed decomposition of office paper, coated paper, newspaper, and corrugated. Since the pressware plates are produced from bleached kraft, this analysis uses experimental data on bleached kraft office paper to estimate decomposition of the fiber content of the pressware plates. While the top surface of the pressware plates has a moisture- and grease-resistant coating, the back of the plate is not coated and will degrade when exposed to moisture. Therefore, the baseline results are based on eventual decomposition of the pressware plates in landfills where there are sufficient moisture, temperature, and microbial activity to support decomposition. As noted above, results of a sensitivity analysis on degree of decomposition are presented in Chapter 3.

For paper and paperboard materials, the cellulose and hemicellulose fractions of the material decompose to some extent, while the lignin fraction of the material does not tend to decompose under anaerobic conditions. Thus, the *potentially* degradable carbon content of the material is based on its cellulose and hemicellulose content. Based on the cellulose, hemicellulose, and lignin percentages in each material, and the carbon content of each fraction, the total carbon content of bleached kraft paperboard is calculated as 44.1 percent by weight (42.6 percent potentially degradable carbon in the cellulose and hemicellulose fractions, 1.5 percent carbon in lignin). In the experiments, the maximum degree of decomposition for the cellulose and hemicellulose fractions of bleached kraft paper were 98 percent and 86 percent. Overall, 41% by weight of the bleached kraft degraded to produce CO_2 and methane. The remaining carbon content did not degrade.

The composition of landfill gas as generated is approximately 50% by volume methane and 50% by volume CO_2. Currently, about 61.5% of methane generated from solid waste LFs is converted to CO_2 before it is released to the environment: 28.7% is flared, 28.5% is burned with energy recovery, and about 4.3% is oxidized as it travels through the landfill cover.[21] Biomass CO_2 released from decomposition of paper products or from oxidation of biomass-derived methane to CO_2 is considered carbon neutral, as the CO_2 released represents a return to the environment of the carbon taken up as CO_2 during the plant's growth cycle and does not result in a net increase in atmospheric CO_2. Thus, biomass-derived CO_2 is not included in the GHG results shown in this analysis. Methane releases to the environment from anaerobic decomposition of biomass are *not* considered carbon neutral, however, since these releases resulting from human intervention have a higher global warming potential (GWP) than the CO_2 taken up or released during the

[20] Eleazar, William, et al. 1997. Biodegradability of Municipal Solid Waste Components in Laboratory-Scale Landfills. Environmental Science & Technology 31:911-917.

[21] US EPA report EPA 430-R-12-001 (2012). **Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2010**, April 2012. Calculated from 2010 data in Table 8-4. Accessible at: http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

natural carbon cycle. The GWP factor used for biogenic methane is lower than the GWP factor for fossil methane, reflecting the impact of biogenic methane in the atmosphere until it converts to carbon-neutral biogenic CO_2.

The U.S. EPA's Landfill Methane Outreach Program (LMOP) Landfill Database[22] indicates that the majority of landfill gas burned with energy recovery is used to produce electricity. The gross energy recovered from combustion of LF gas from each material is converted to displaced quantities of national grid electricity using an efficiency factor of 1 kWh generated per 11,700 Btu of LF gas burned.[23] Each plate system is credited with avoiding the GWP associated with production of the offset quantity of national grid electricity.

For the biomass carbon that remains fixed in the landfilled material (i.e., in the undecomposed fraction of the pressware plates), a sequestration credit is given for the equivalent pounds of CO_2 that the sequestered carbon could produce.

Waste-to-energy combustion of postconsumer material is modeled using a similar approach to the landfill gas combustion credit. However, for WTE combustion of plates, the CO_2 releases for each plate system are modeled based on the *total* carbon content of the material being combusted to CO_2. For combustion of biomass-derived material (e.g., the fiber content of the pressware plates and corrugated packaging), the CO_2 produced is considered carbon-neutral biomass CO_2, while the CO_2 from combustion of fossil-based materials (e.g., GPPS plates, styrene-acrylic coating on pressware plates, plastic film packaging sleeves) is fossil CO_2 which is included in the net global warming potential results.

For each plate system, the gross heat produced from WTE combustion of postconsumer plates and packaging is calculated based on the pounds of material burned and the higher heating value of the material. The heat is converted to kWh of electricity using a conversion efficiency of 1 kWh per 19,120 Btu for mass burn facilities[24], and a credit is given to each plate system for avoiding the GWP associated with producing the equivalent amount of grid electricity. The grid electricity credit is based on the national average grid, since the plates are used (and disposed) across the U.S.

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22 Operational LFG energy projects spreadsheet, sorted by LFGE utilization type and project type. Accessible at http://www.epa.gov/lmop/proj/#1.

23 LMOP Benefits Calculator. Calculations and References tab. Accessible at http://www.epa.gov/lmop/res/lfge_benefitscalc.xls

24 U.S. EPA. **Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks.** Third Edition. September 2006. Chapter 5 Combustion, section 5.1.5. Calculation is based on 550 kWh produced per ton of MSW burned, with a heat value of 5,000 Btu per pound of MSW. For mass burn facilities, 523 kWh of electricity are delivered per 550 kWh generated. Full report and individual chapters of the report are accessible at http://www.epa.gov/climatechange/wycd/waste/SWMGHGreport.html.

The net end-of-life GWP for each plate system is calculated by summing the individual impacts and credits described above, based on 82% landfill and 18% WTE combustion of the postconsumer plates.

Limitations of End-of-Life Modeling Approach. As noted, the landfill methane calculations in this analysis are based on the *aggregated* emissions of methane that may result from decomposition of the degradable carbon content of the landfilled material. The long time frame over which those emissions occur has implications that result in additional uncertainties for the landfill methane GWP estimates.

- In this analysis, the management of the aggregated landfill methane emissions is modeled based on *current percentages* of flaring, WTE combustion, and uncaptured releases. Over time, it is likely that efforts to mitigate global warming will result in increased efforts to capture and combust landfill methane. Combustion of biomass-derived methane converts the carbon back to CO_2, neutralizing the net global warming impact. In addition, if the combustion energy is recovered and used to produce electricity, there are GWP credits for displacing grid electricity. With increased future capture and combustion of landfill methane, the future net effect of landfill methane could gradually shift from a negative impact (from uncaptured, untreated methane emissions) to a net credit (for capturing landfill methane and burning it to produce energy with carbon-neutral CO_2 emissions, displacing fossil fuel combustion emissions).
- The length of time required for paperboard products to decompose will vary depending on landfill conditions. Although the landfill methane releases occur gradually over many years, the global warming impacts of the total pounds of methane emissions released from decomposition are calculated using 100-year global warming potentials. In other words, regardless of the time frame over which decomposition occurs, the GWP calculation takes into account the global warming impacts of each pound of released methane in the atmosphere for 100 years after it has been released. This is consistent with the use of 100-year global warming potentials used for all other life cycle greenhouse gas emissions. Future refinements to end-of-life modeling may include time-scale modeling of landfill methane emissions; however, this is not part of the current study. Because no time-scale modeling is applied, the total landfill methane emissions are presented as a single aggregated amount, effectively treating the emissions as if they occurred at a single point in time immediately after the material was placed in the landfill, e.g., with the current mix of landfill methane management options and displacing current grid electricity.

As noted previously in this section, the baseline results in this analysis reflect maximum decomposition of the degradable cellulose and hemicellulose in landfilled plates. This assumption is used because only one side of the plates has a moisture resistant coating, so the degradable fiber content is exposed to any moisture and microbes present in the landfill. However, some plates may end up in landfills where conditions are not favorable for maximum decomposition, so additional scenarios on degree of decomposition are presented in Chapter 3.

CHAPTER 2
LCA RESULTS FOR FOAM AND PRESSWARE PLATE SYSTEMS

INTRODUCTION

This chapter presents baseline results for the following LCI and LCIA results for the disposable plate systems studied:

Life cycle inventory results:
- Total energy demand (MJ eq)
- Non-renewable energy demand (MJ eq)
- Solid waste by weight (kg)
- Solid waste by volume (cubic meters)
- Water consumption (liters)

Life cycle impact assessment results:
- Global warming potential (kg CO_2 eq)
- Acidification potential (SO_2 eq)
- Eutrophication potential (kg N eq)
- Ozone depletion potential (kg CFC-11 eq)
- Smog formation potential (kg O_3 eq)

As described in previous chapters, variations in several parameters or assumptions are modeled for the pressware plate systems. The baseline results presented in this chapter are based on the following assumptions for pressware plates:

- Low energy use for flexographic application of coatings
- Maximum decomposition of the degradable fiber content in pressware plates disposed in landfills at end of life.

Sensitivity analyses for variations in each of these assumptions are presented in Chapter 3.

Throughout the results sections, the tables and figures break system results out into the following categories:

- Raw materials production
- Coating of pressware plate rollstock (includes only the coating process; production of the coating material applied is included in the Raw Materials stage)
- Plate manufacturing
- Plate transport (transportation of packaged plates to distribution centers)
- Secondary packaging (life cycle results for production and end-of-life management of corrugated boxes, tape, and film sleeves used for packaging plates)
- End-of-life management of plates.

As described in Chapter 2, based on the uncertainties in life cycle data and impact assessment methodology, differences between plate system results are not considered meaningful unless the percent difference between systems exceeds certain thresholds. (Percent difference between systems is defined as the difference between energy totals divided by the average of the two system totals.) The percent difference thresholds were developed based on the experience and professional judgment of the analysts. A 10 percent minimum difference threshold is used for a meaningful difference in life cycle inventory results for total and non-renewable energy demand categories, and a 25 percent minimum difference threshold is used for solid waste results, water consumption results, and all life cycle impact results. Percent differences that are below these thresholds are considered to be within the margin of uncertainty of the data and are considered inconclusive.

LIFE CYCLE INVENTORY RESULTS

Energy Demand

Cumulative Energy Demand

Cumulative (total) energy demand results include all renewable and non-renewable energy sources used for process and transportation energy, as well as material feedstock energy. Process energy includes direct use of fuels as well as use of fossil fuels, hydropower, nuclear, wind, solar, and other energy sources to generate electricity used by processes. The feedstock energy is the energy content of the resources removed from nature and used as material feedstocks for each box (e.g., the energy content of oil and gas used as material feedstocks for plastic foam plates and sleeves, the energy content of wood used as material feedstock for the pressware plates and corrugated shipping boxes). Table 2-1 shows total energy demand for the life cycle of the plate systems. The results are shown graphically in Figure 2-1.

Table 2-1. Total Energy Demand for 10,000 Plates (MJ)

Results by Stage	Raw Materials	Coating Rollstock	Plate Mfg	Plate Transport	Secondary Pkg (LC)	End of Life	NET	Hefty % lower than Pressware
Hefty	4,300	0	854	117	410	-49.4	5,632	
Pressware Plate 1	6,922	62.0	472	71.4	306	-107	7,727	27%
Pressware Plate 2	7,936	62.0	523	76.7	255	-124	8,729	35%

Contribution by Stage	Raw Materials	Coating Rollstock	Plate Mfg	Plate Transport	Secondary Pkg (LC)	End of Life	
Hefty	76%	0%	15%	2%	7%	-1%	100%
Pressware Plate 1	90%	1%	6%	1%	4%	-1%	100%
Pressware Plate 2	91%	1%	6%	1%	3%	-1%	100%

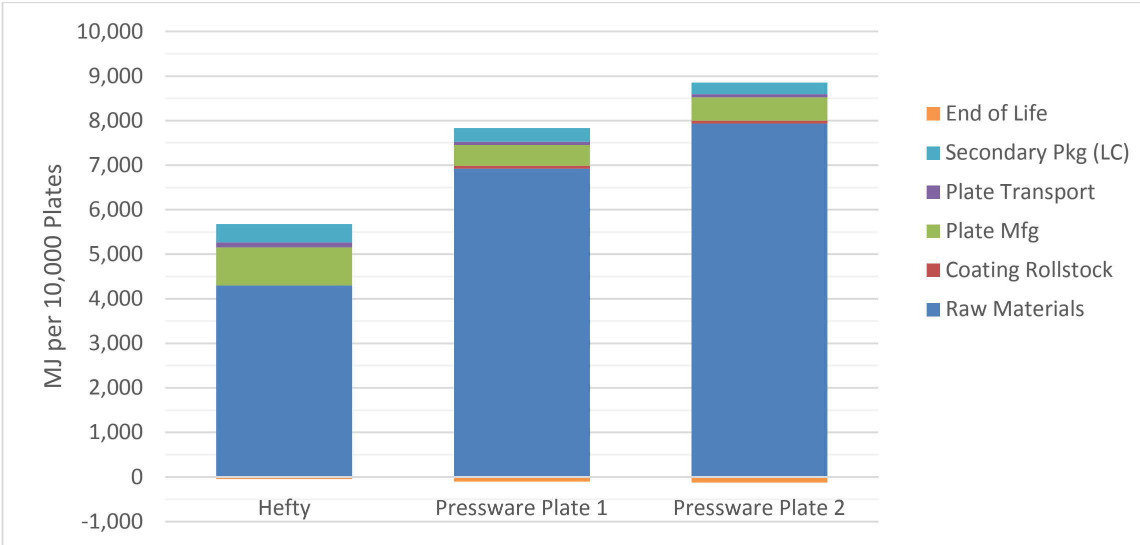

Figure 2-1. Total Energy Demand for 10,000 Plates (MJ)

For all plate systems, production of raw materials makes the largest contribution to total energy demand (76% of the total for foam plates and 90% for pressware plates). For the foam plates, plate manufacturing also makes a significant contribution at 15% of the total. The manufacturing process for foam plates includes foamed extrusion of the resin, regrinding converting scrap for reuse in the process, and combustion of captured blowing agent emissions. The pressware plate manufacturing process is a very high throughput operation that stamps blanks out of moistened rollstock and presses them into shape in the plate forming machine. The foam plate system also requires more packaging per 10,000 plates shipped. Because of the greater thickness of the foam plates, larger boxes must be used to accommodate the greater height of stacked plates. However, secondary packaging contributes less than 10% of the total energy for each system.

Overall, the foam plate system has significantly lower total energy requirements than both pressware plate systems.

Non-Renewable Energy Demand

Non-renewable energy demand results include the use of fossil fuels (petroleum, natural gas, and coal) for process energy, transportation energy, and as material feedstocks (e.g., oil and gas used as feedstocks for plastics), as well as use of uranium to generate the share of nuclear energy in the average U.S. kWh. The main difference from cumulative energy demand is that renewable biomass feedstock energy (for the wood-derived fiber in the pressware plates and corrugated shipping boxes), renewable biomass combustion energy (e.g., from combustion of wood wastes and black liquor solids at mills producing the virgin fiber content of the pressware plates and corrugated shipping boxes), and electricity derived from renewable energy sources (primarily hydropower, wind, and solar) are not included in the non-renewable energy demand results. Non-renewable energy for the plate systems are shown in Table 2-2 and Figure 2-2. The last column in the table shows the percentage of total energy that is non-renewable (NR), and the figure shows the non-renewable energy on the same scale as the cumulative energy figure, to help illustrate the relative share of non-renewable energy in each system.

Table 2-2. Non-Renewable Life Cycle Energy Demand for 10,000 Plates (MJ)

Results by Stage	Raw Materials	Coating Rollstock	Plate Mfg	Plate Transport	Secondary Pkg (LC)	End of Life	NET	NR % of Total Energy
Hefty	4,288	0	835	117	266	-46.3	5,460	97%
Pressware Plate 1	3,082	61.1	457	71.2	202	-99.5	3,775	49%
Pressware Plate 2	3,691	61.1	508	76.6	172	-117	4,393	50%
Contribution by Stage	**Raw Materials**	**Coating Rollstock**	**Plate Mfg**	**Plate Transport**	**Secondary Pkg (LC)**	**End of Life**		
Hefty	79%	0%	15%	2%	5%	-1%	100%	
Pressware Plate 1	82%	2%	12%	2%	5%	-3%	100%	
Pressware Plate 2	84%	1%	12%	2%	4%	-3%	100%	

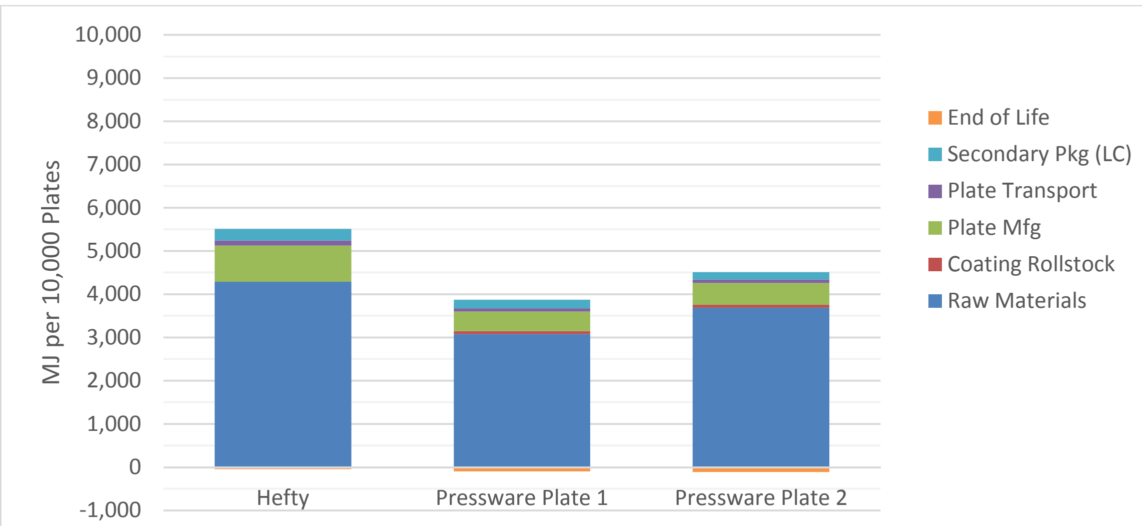

Figure 2-2. Non-Renewable Energy Demand for 10,000 Plates (MJ)

The foam plate system has higher non-renewable energy requirements compared to the pressware plate systems. For the PS foam plates, 97% of total energy use is non-renewable energy. This includes the energy content of the oil and gas used as material feedstocks for the plate resin, blowing agent, and plastic film sleeves used for packaging, as well as the non-renewable energy consumed for process and transportation energy throughout the life cycle of the plates and packaging. For the pressware plate systems, non-renewable energy accounts for only about half of the total energy. In addition to process and transportation derived from non-renewable energy sources, the pressware plate systems have non-renewable feedstock energy associated with the styrene acrylic coating on the plates and the film sleeves used for packaging plates. The other (renewable) half of total energy for the pressware plate systems is mainly associated with the energy content of the wood used as material feedstock for the fiber in the plates as well as the use of renewable wood-derived energy at the paperboard mill.

Solid Waste

Solid waste results include the following types of wastes:

- **Process wastes** that are generated by the various processes from raw material acquisition through production of plates (e.g., sludges and residues from chemical reactions and material processing steps)
- **Fuel-related wastes** from the production and combustion of fuels used for process energy and transportation energy (e.g., refinery wastes, coal combustion ash)
- **Postconsumer wastes** that include the 82% of plates that are managed by landfilling at end of life, plus ash from the 18% of plates that are managed by WTE combustion.

Solid Waste by Weight

Results for solid waste by weight are shown in Table 2-3 and Figure 2-4. The largest share of solid waste for all plate systems is postconsumer solid waste associated with plates disposed after use. The next largest contributor is raw material production, which accounts for 10% of the waste for foam plates and almost one-third of the total weight of solid waste for the pressware systems. For the foam plate system, raw material solid wastes are largely associated with production and combustion of fuels (particularly coal used to generate electricity used in raw material production processes) and the production of crude oil and natural gas used as feedstocks for the plastic resin and blowing agent. Raw material production solid wastes for pressware plates are mainly sludges and combustion ash from paperboard mills and solid wastes from production of the clay coating. Secondary packaging does not make a large contribution to solid waste results, since the heaviest packaging component, corrugated shipping boxes, are recycled at a high rate.

Due to the heavier weight of the disposed pressware plates and the greater amount of wastes from paperboard production compared to plastic resin production, the pressware plate systems produce more than twice as much total weight of solid waste as the foam plate system.

Table 2-3. Solid Waste by Weight for 10,000 Plates (kg)

Results by Stage	Raw Materials	Coating Rollstock	Plate Mfg	Plate Transport	Secondary Pkg (LC)	End of Life	NET	Hefty % lower than Pressware
Hefty	5.40	0	4.35	0.12	3.22	39.0	52.0	
Pressware Plate 1	48.3	0.22	8.72	0.072	2.44	92.4	152	66%
Pressware Plate 2	50.9	0.22	8.70	0.078	2.06	101	162	68%

Contribution by Stage	Raw Materials	Coating Rollstock	Plate Mfg	Plate Transport	Secondary Pkg (LC)	End of Life	
Hefty	10%	0%	8%	0%	6%	75%	100%
Pressware Plate 1	32%	0%	6%	0%	2%	61%	100%
Pressware Plate 2	31%	0%	5%	0%	1%	62%	100%

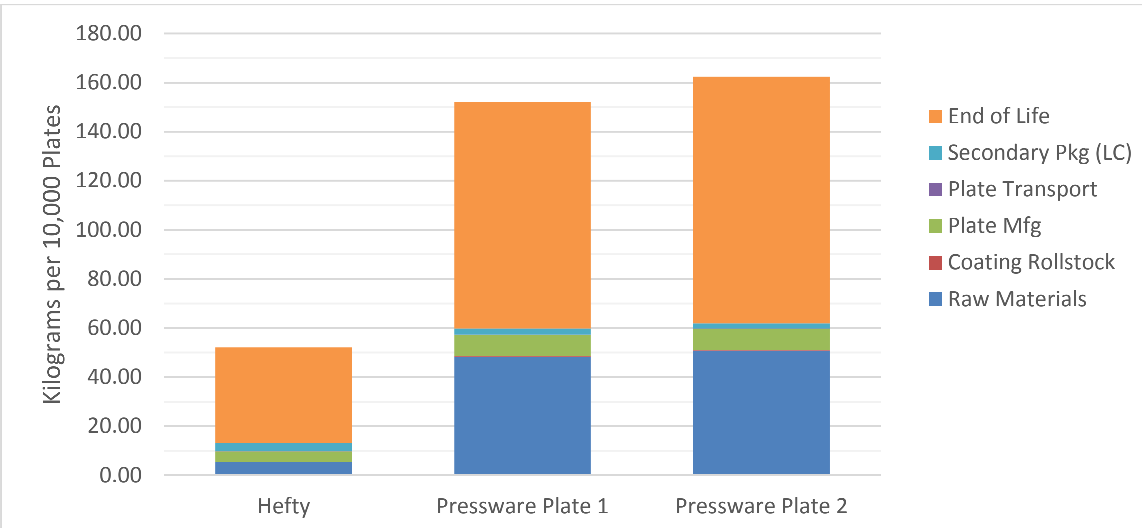

Figure 2-3. Solid Waste by Weight for 10,000 Plates (kg)

Solid Waste by Volume

Weights of solid waste are converted to volume using landfill density factors for products and materials derived from landfill samples and compaction tests.[25] Table 2-4 shows solid wastes on a volume basis, with results presented graphically in Figure 2-4.

25 Estimates of the Volume of MSW and Selected Components in Trash Cans and Landfills. Prepared for The Council for Solid Waste Solutions by Franklin Associates, Ltd. and The Garbage Project. February 1990.

Table 2-4. Solid Waste by Volume for 10,000 Plates (cubic meters)

Results by Stage	Raw Materials	Coating Rollstock	Plate Mfg	Plate Transport	Secondary Pkg (LC)	End of Life	Hefty % higher than Pressware
Hefty	0.0067	0	0.0054	1.5E-04	0.0059	0.27	
Pressware Plate 1	0.060	2.7E-04	0.012	9.0E-05	0.0045	0.18	15%
Pressware Plate 2	0.063	2.7E-04	0.012	9.7E-05	0.0039	0.20	6%

Contribution by Stage	Raw Materials	Coating Rollstock	Plate Mfg	Plate Transport	Secondary Pkg (LC)	End of Life
Hefty	2%	0%	2%	0%	2%	94%
Pressware Plate 1	24%	0%	5%	0%	2%	70%
Pressware Plate 2	23%	0%	4%	0%	1%	71%

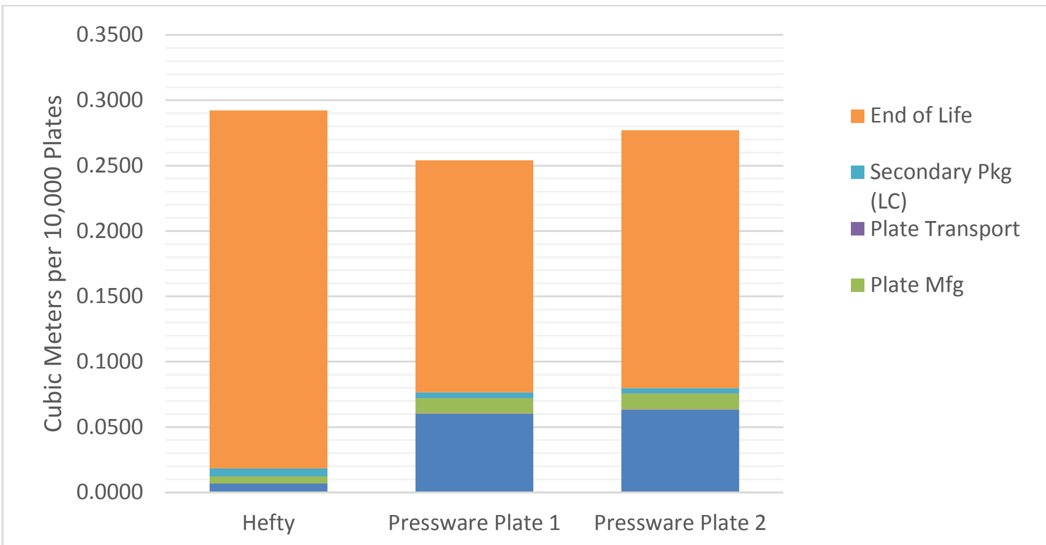

Figure 2-4. Solid Waste by Volume for 10,000 Plates (cubic meters)

In the previous section, disposed postconsumer plates were shown to make the largest contribution to the *weight* of solid waste for each system, but the contribution of postconsumer plates to solid waste *volume* is proportionally larger, particularly for foam plates. Disposal of postconsumer plates accounts for 94% of the total volume of solid waste for the foam plate system, and about 70% of total solid waste volume for the pressware systems. Because polystyrene foam plates have a much lower landfill density than pressware plates, a kg of foam plate occupies a greater amount of landfill space than a kg of paperboard plate. Therefore, even though the weight of postconsumer foam plates is lower than the weight of postconsumer pressware plates, the solid waste volume for postconsumer plates is greater for foam plates.

Water Consumption

Consumptive use of water in this study includes freshwater that is withdrawn from a water source or watershed and not returned to that source. Consumptive water use includes water consumed in chemical reactions, water that is incorporated into a product or waste stream, water that becomes evaporative loss, and water that is discharged to a different watershed or water body than the one from which it was withdrawn. Water consumption results shown for each life cycle stage include process water consumption as well as water consumption associated with production of the electricity and fuels used in that stage. Electricity-related water consumption includes evaporative losses associated with thermal generation of electricity from fossil and nuclear fuels, as well as evaporative losses due to establishment of dams for hydropower.

Water consumption results are shown in Table 2-5 and Figure 2-5. Process water consumption at paperboard mills dominates raw material stage results for pressware plates, while water consumption for pressware plate manufacturing is associated with evaporative losses of water used for moistening the rollstock prior to forming. The foam plate system has lower water consumption, and over half of the total water consumption results are associated with generation of electricity used in the processes, followed by extraction of oil and gas for material and fuel uses.

Table 2-5. Consumptive Water Use for 10,000 Plates (liters)

Results by Stage	Raw Materials	Coating Rollstock	Plate Mfg	Plate Transport	Secondary Pkg (LC)	End of Life	NET	Hefty % lower than Pressware
Hefty	529	0	319	15.3	124	-46.2	941	
Pressware Plate 1	1,426	16.1	253	9.32	90.8	-106	1,689	44%
Pressware Plate 2	1,574	16.1	257	10.0	74.1	-120	1,811	48%

Contribution by Stage	Raw Materials	Coating Rollstock	Plate Mfg	Plate Transport	Secondary Pkg (LC)	End of Life	
Hefty	56%	0%	34%	2%	13%	-5%	100%
Pressware Plate 1	84%	1%	15%	1%	5%	-6%	100%
Pressware Plate 2	87%	1%	14%	1%	4%	-7%	100%

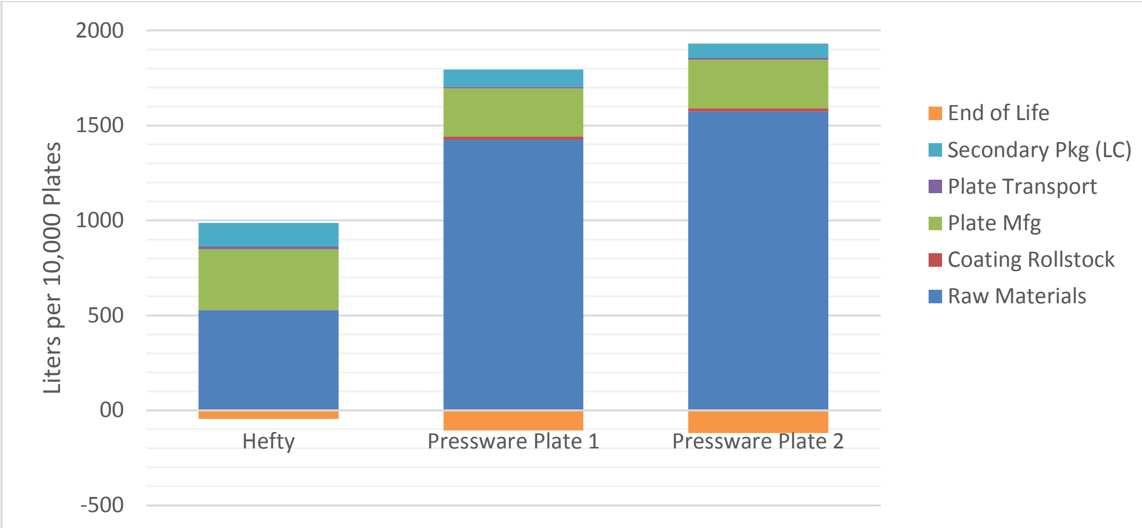

Figure 2-5. Consumptive Water Use for 10,000 Plates (liters)

LIFE CYCLE IMPACT ASSESSMENT RESULTS

Global Warming Potential

The primary atmospheric emissions reported in this analysis that contribute over 99% of the total global warming potential for each system are fossil fuel-derived carbon dioxide, methane, and nitrous oxide. Non-fossil carbon dioxide emissions, such as those from the burning of wood-derived fuel, is a return of carbon dioxide to the atmosphere in the same form as it was originally removed from the atmosphere during the biomass growth cycle; therefore, carbon dioxide emissions from combustion or decomposition of biomass-derived products are not considered a net contributor to global warming.

The 100-year global warming potential (GWP) factors for each of these substances as reported in the Intergovernmental Panel on Climate Change (IPCC) 2007 report[26] are: fossil carbon dioxide 1, fossil methane 25, and nitrous oxide 298. The GWP factor for a substance represents the relative global warming contribution of a pound of that substance compared to a pound of carbon dioxide. The weights of each greenhouse gas are multiplied by its GWP factor to arrive at the total GWP results. The majority of the greenhouse gas emissions and GWP for each system are fuel-related emissions rather than process emissions.

Because the fiber content of the pressware plates includes carbon that was removed from the atmosphere by trees during their growth cycle, the plate end-of-life results also include credits for net storage of biogenic carbon in landfilled plates as well as emissions

26 Intergovernmental Panel on Climate Change. Fourth Assessment Report. **Climate Change 2007: The Physical Science Basis.** Chapter 2 Changes in Atmospheric Constituents and in Radiative Forcing. Table 2.14 (page 212). Accessible at http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf.

associated with methane from landfill decomposition of pressware plates. The methodology and data sources used to estimate GWP from WTE combustion of postconsumer plates, GWP from landfill gas emissions, GWP credits for displacement of grid electricity, and carbon sequestration credits are described in detail in the **End of Life Management** section of Chapter 1. As noted in that section, the GWP factor used for biogenic methane releases from decomposition of biomass is lower than the fossil methane factor of 25, to account for the impact of biogenic methane in the atmosphere until it converts to CO_2, at which time it is considered carbon neutral CO_2.

Table 2-6 and Figure 2-6 show life cycle GWP results for the plate systems. For the foam plate system, raw material production accounts for the largest share of GWP (58%), followed by plate manufacturing at 24%. The GWP emissions from the raw material stage are mainly associated with fossil fuel resources used as fuel and as feedstocks for the plastic resin and blowing agent. GWP from foam plate manufacturing includes emissions of carbon dioxide used in the plate manufacturing process, emissions from operation of a natural gas-fired thermal oxidizer used to destroy blowing agent emissions at the manufacturing plant (includes carbon dioxide from combustion of the natural gas and pentane burned in the thermal oxidizer), as well as emissions associated with production of the electricity used in the plate manufacturing processes. End-of-life management of disposed foam plates contributes 10% of the total GWP for the foam plate system; this is largely carbon dioxide emissions from the portion of the foam plates that are disposed by waste-to-energy combustion. There is no GWP impact for landfilled PS foam plates, since they do not decompose.

Table 2-6. Global Warming Potential Results for 10,000 Plates with Maximum Decomposition of Landfilled Paperboard (kg CO_2 Equivalents)

Results by Stage	Raw Materials	Coating Rollstock	Plate Mfg	Plate Transport	Secondary Pkg (LC)	End of Life	NET	Hefty % lower than Pressware
Hefty	143	0	58.2	8.18	10.2	25.7	245	
Pressware Plate 1	210	3.93	27.3	4.97	7.72	154	408	40%
Pressware Plate 2	243	3.93	29.5	5.34	6.54	172	460	47%

Contribution by Stage	Raw Materials	Coating Rollstock	Plate Mfg	Plate Transport	Secondary Pkg (LC)	End of Life	
Hefty	58%	0%	24%	3%	4%	10%	100%
Pressware Plate 1	51%	1%	7%	1%	2%	38%	100%
Pressware Plate 2	53%	1%	6%	1%	1%	37%	100%

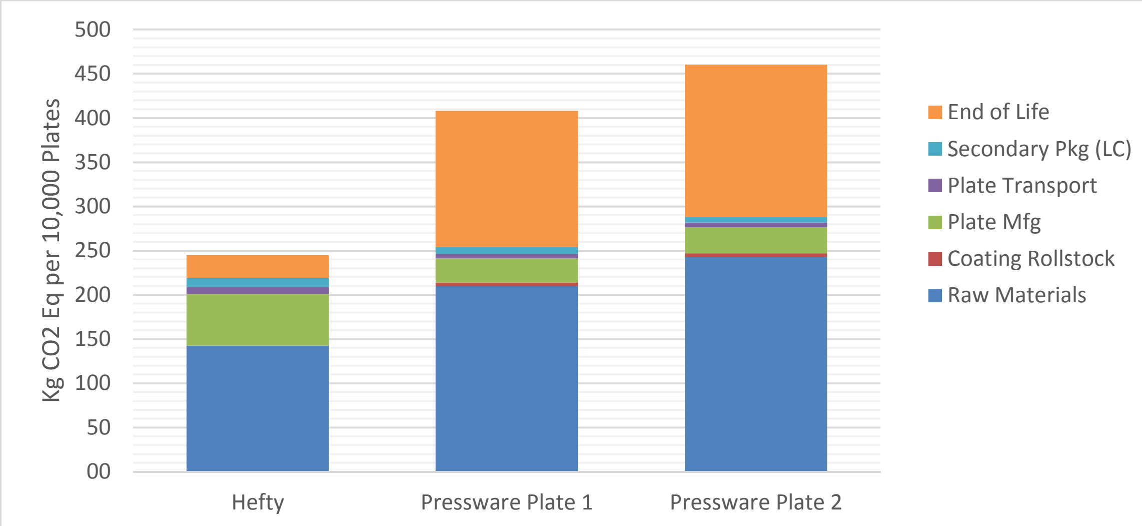

Figure 2-6. Global Warming Potential Results for 10,000 Plates with Maximum Decomposition of Landfilled Paperboard (kg of CO_2 Equivalents)

For the pressware plates, raw material production accounts for just over half the total GWP (mainly from fuel use at paperboard mills), and emissions from maximum decomposition of the fiber in landfilled plates contributes over 35% of the total GWP. For this scenario based on maximum decomposition of the fiber in landfilled plates, the pressware plate systems have significantly higher total GWP compared to foam plates.

It is important to note that the end-of-life GWP estimates have a larger uncertainty than other LCI emissions data. Some of the modeling assumptions contributing to the uncertainty include the following:

- The CO_2 emissions from WTE combustion of postconsumer materials are based on complete conversion of the carbon content of the material to CO_2.
- GWP results for landfilled pressware plates are strongly influenced by assumptions about the degree of decomposition of the degradable fiber content in the plates. The end-of-life GWP results shown in this section are modeled based on results from landfill simulation experiments designed to maximize decomposition and should be considered the upper limit for end-of-life GWP. The ultimate degree of decomposition may be different in actual landfills where moisture, temperature, and other factors are less favorable for decomposition than in the landfill simulation experiments.
- Electricity offset credits are based on average efficiencies for converting combustion energy to electricity at municipal solid waste mass burn WTE combustion facilities and landfill gas WTE facilities. Actual efficiencies for individual energy recovery facilities will vary.
- Management of landfill methane is based on applying current landfill gas management practices to the cumulative methane emissions from decomposition of

the material. However, the methane would be released gradually over many years, during which time landfill gas collection may be increased or WTE combustion of landfill gas may be increased.

Assumptions about end-of-life decomposition can significantly affect the end-of-life GHG results for paperboard products such as pressware plates. At lower levels of decomposition, more carbon remains stored in the landfilled plates, and less methane is produced, reducing the net GWP from landfilled plates. The results in the tables and figures presented in this chapter are based on maximum decomposition of landfilled pressware plates. Sensitivity analysis is conducted to determine the effect on GWP results for a scenario in which the pressware plates degrade to a lesser extent or do not degrade at all. Results for the sensitivity analysis are presented in Chapter 3. By considering the minimum and maximum decomposition scenarios, the sensitivity analysis results cover the possible range of results for landfill decomposition of pressware plates.

Acidification

Acidification assesses the potential of emissions to contribute to the formation and deposit of acid rain on soil and water, which can cause serious harm to plant and animal life as well as damage to infrastructure. Acidification potential modeling in TRACI utilizes the results of an atmospheric chemistry and transport model, developed by the U.S. National Acid Precipitation Assessment Program (NAPAP), to estimate total North American terrestrial deposition due to atmospheric emissions of NO_x and SO_2, as a function of the emissions location.[27,28]

Acidification impacts are typically dominated by fossil fuel combustion emissions, particularly sulfur dioxide (SO_2) and nitrogen oxides (NO_x). Emissions from combustion of fossil fuels, especially coal, to generate grid electricity is a significant contributor to acidification impacts for all systems. Table 2-7 shows total acidification potential results for the plate systems. Results are shown graphically in Figure 2-7.

For the foam plate system, raw material production accounts for just over half of the total acidification potential, followed by plate manufacturing (33%) and the life cycle of secondary packaging components (15%).

For the pressware systems, about 80% of total acidification is associated with raw material production (mainly associated with fuels and energy used at paperboard mills), and plate manufacturing contributes 13% of total acidification results (dominated by emissions from coal's share of the grid electricity used in the manufacturing processes).

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27 Bare JC, Norris GA, Pennington DW, McKone T. (2003). TRACI: The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts, *Journal of Industrial Ecology,* **6**(3–4): 49–78. Available at URL: http://mitpress.mit.edu/journals/pdf/jiec_6_3_49_0.pdf.

28 Bare JC. (2002). Developing a consistent decision-making framework by using the US EPA's TRACI, AICHE. Available at URL: http://www.epa.gov/nrmrl/std/sab/traci/aiche2002paper.pdf.

Table 2-7. Acidification Potential Results for 10,000 Plates (kg SO_2 Equivalents)

Results by Stage	Raw Materials	Coating Rollstock	Plate Mfg	Plate Transport	Secondary Pkg (LC)	End of Life	NET	Hefty % lower than Pressware
Hefty	0.39	0	0.25	0.030	0.11	-0.022	0.75	
Pressware Plate 1	1.00	0.013	0.16	0.018	0.079	-0.0045	1.26	40%
Pressware Plate 2	1.14	0.013	0.16	0.020	0.064	-0.0089	1.39	46%

Contribution by Stage	Raw Materials	Coating Rollstock	Plate Mfg	Plate Transport	Secondary Pkg (LC)	End of Life	
Hefty	52%	0%	33%	4%	15%	-3%	100%
Pressware Plate 1	79%	1%	13%	1%	6%	0%	100%
Pressware Plate 2	82%	1%	12%	1%	5%	-1%	100%

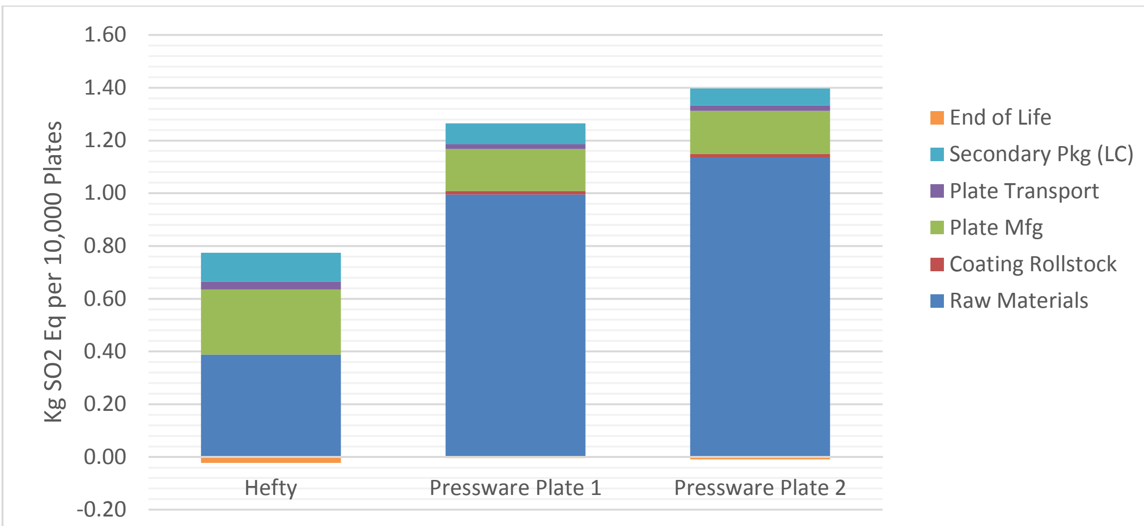

Figure 2-7. Acidification Potential Results for 10,000 Plates (kg SO_2 Equivalents)

Eutrophication

Eutrophication occurs when excess nutrients are introduced to surface water causing the rapid growth of aquatic plants. This growth (generally referred to as an "algal bloom") reduces the amount of dissolved oxygen in the water, thus decreasing oxygen available for other aquatic species. The TRACI characterization factors for eutrophication are the product of a nutrient factor and a transport factor.[29] The nutrient factor is based on the

29 Bare JC, Norris GA, Pennington DW, McKone T. (2003). TRACI: The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts, *Journal of Industrial Ecology,* **6**(3–4): 49–78. Available at URL: http://mitpress.mit.edu/journals/pdf/jiec_6_3_49_0.pdf.

amount of plant growth caused by each pollutant, while the transport factor accounts for the probability that the pollutant will reach a body of water. Atmospheric emissions of nitrogen oxides (NO_x) as well as waterborne emissions of nitrogen, phosphorus, ammonia, biochemical oxygen demand (BOD), and chemical oxygen demand (COD) are the main contributors to eutrophication impacts.

Eutrophication potential results for PS foam and pressware plate systems are shown by stage in Table 2-8 and illustrated in Figure 2-8.

Table 2-8. Eutrophication Potential Results for 10,000 Plates (kg N Equivalents)

Results by Stage	Raw Materials	Coating Rollstock	Plate Mfg	Plate Transport	Secondary Pkg (LC)	End of Life	NET	Hefty % lower than Pressware
Hefty	0.017	0	0.0042	0.0018	0.0043	3.2E-04	0.028	
Pressware Plate 1	0.10	2.3E-04	0.0038	0.0011	0.0031	0.0022	0.11	75%
Pressware Plate 2	0.12	2.3E-04	0.0045	0.0012	0.0025	0.0023	0.13	78%
Contribution by Stage	**Raw Materials**	**Coating Rollstock**	**Plate Mfg**	**Plate Transport**	**Secondary Pkg (LC)**	**End of Life**		
Hefty	61%	0%	15%	7%	16%	1%	100%	
Pressware Plate 1	91%	0%	3%	1%	3%	2%	100%	
Pressware Plate 2	91%	0%	4%	1%	2%	2%	100%	

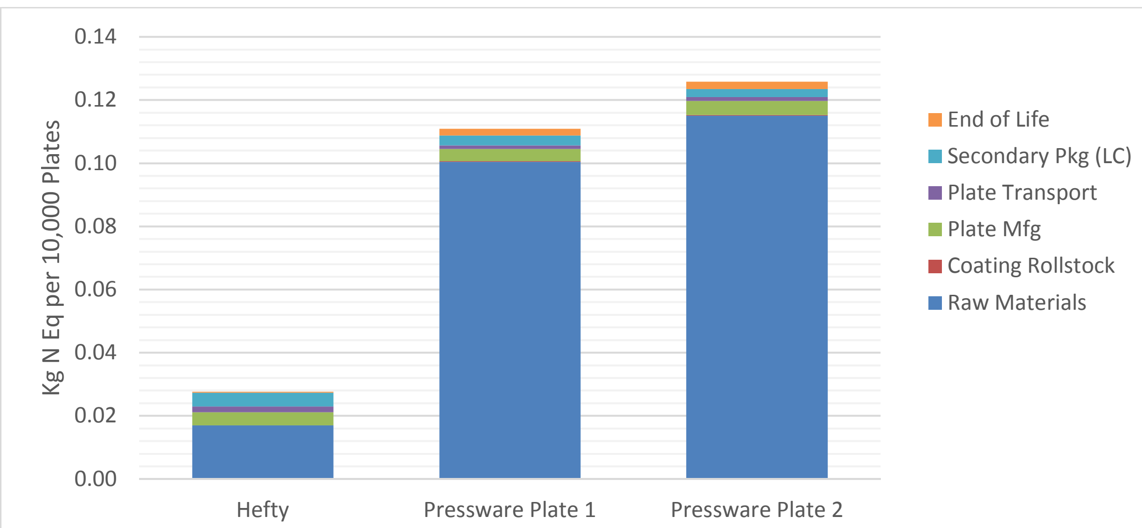

Figure 2-8. Eutrophication Potential Results for 10,000 Plates (kg N Equivalents)

Eutrophication impacts for the foam plate system are mainly from raw material production (61%) followed by plate manufacturing and secondary packaging (15-16% each). The largest share of raw material eutrophication is from processes associated with the polystyrene resin, including fuel combustion emissions for ocean transport of crude oil, process emissions from benzene production, and emissions from combustion of fuels used in chemical processing steps). Plate manufacturing eutrophication is primarily from the coal-derived portion of process electricity and emissions from combustion of natural gas at the manufacturing plant. Secondary packaging eutrophication is mostly associated with production of paperboard for the corrugated shipping boxes.

For the pressware plate systems, 91% of eutrophication impacts are from raw material production, associated primarily with emissions in the paperboard mill discharge water and emissions from production of components of the styrene acrylic plate coating. The remaining eutrophication impacts are mainly from plate manufacturing (combustion emissions associated with electricity used by the manufacturing equipment) and secondary packaging (dominated by impacts for corrugated shipping boxes).

Ozone Depletion

Stratospheric ozone depletion is the reduction of the protective ozone within the stratosphere caused by emissions of ozone-depleting substance (e.g. CFCs and halons). The ozone depletion impact category characterizes the potential to destroy ozone based on a chemical's reactivity and lifetime. Damage related to ozone depletion can include skin cancer, cataracts, material damage, immune system suppression, crop damage, and other plant and animal effects.

Table 2-9 shows total ODP results for plates broken out by life cycle stage. The results are shown graphically in Figure 2-9.

Table 2-9. Ozone Depletion Potential Results for 10,000 Plates (kg CFC-11 Equivalents)

Results by Stage	Raw Materials	Coating Rollstock	Plate Mfg	Plate Transport	Secondary Pkg (LC)	End of Life	NET	Hefty % higher than Pressware
Hefty	3.0E-06	0	8.4E-09	5.4E-08	2.4E-07	1.7E-08	3.3E-06	
Pressware Plate 1	2.3E-06	4.3E-10	7.8E-08	3.3E-08	1.8E-07	3.3E-08	2.6E-06	27%
Pressware Plate 2	2.7E-06	4.3E-10	1.0E-07	3.5E-08	1.5E-07	3.8E-08	3.0E-06	10%

Contribution by Stage	Raw Materials	Coating Rollstock	Plate Mfg	Plate Transport	Secondary Pkg (LC)	End of Life	
Hefty	90%	0%	0%	2%	7%	1%	100%
Pressware Plate 1	87%	0%	3%	1%	7%	1%	100%
Pressware Plate 2	89%	0%	4%	1%	5%	1%	100%

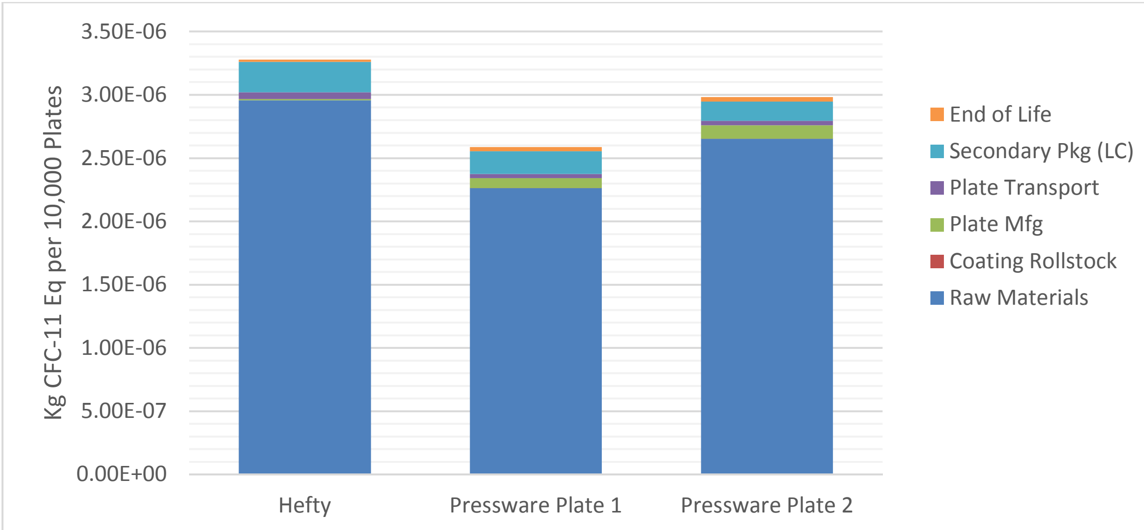

Figure 2-9. Ozone Depletion Potential Results for 10,000 Plates (kg CFC-11 Equivalents)

Ozone depletion results for all plate systems are dominated by raw material production, contributing around 90% of the total ozone depletion impacts for all systems. For the foam plate system, the raw material ozone depletion is primarily associated with process emissions from polystyrene resin production and emissions from refining the petroleum used as a resin feedstock. For the pressware systems, the raw material ODP impacts are mostly from emissions from fuels used at the paperboard mill and from emissions from production of the styrene acrylic coating. The next largest contributor to ozone depletion for all systems is secondary packaging, at 5-7% of total ODP. The ODP impacts for secondary packaging are mainly associated with emissions from wood boilers at mills producing the paperboard used in the corrugated shipping boxes.

Smog Formation

The smog formation impact category characterizes the potential of airborne emissions to cause photochemical smog. The creation of photochemical smog occurs when sunlight reacts with NO_x and volatile organic compounds (VOCs), resulting in tropospheric (ground-level) ozone and particulate matter. Endpoints of such smog creation can include increased human mortality, asthma, and deleterious effects on plant growth. Smog formation impacts, like the other atmospheric impact indicators included in this study, are generally dominated by emissions associated with fuel combustion, so that impacts are higher for life cycle stages and components that have higher process fuel and transportation fuel requirements. In this case, NO_x makes up over 90% of the smog formation emissions for the plate systems. Smog formation potential results for the plate systems are shown by stage in Table 2-10 and illustrated in Figure 2-10.

For the foam plates, 57% of smog formation potential is from production of plate raw materials, 21% is from plate manufacturing, and 12% is from secondary packaging. For the raw material stage, most of the smog formation is associated with the polystyrene resin content. For plate manufacturing, emissions from combustion of fuels for process energy dominate, although about 10% of the manufacturing smog contribution is from pentane emissions at the plant. Overall, emissions of pentane released at the plant and from the plates after they leave the plant account for about 3% of the total smog impacts for the foam plate system. Smog for secondary packaging is mainly from emissions at mills producing the paperboard for the corrugated shipping boxes.

For the pressware plates, raw material production is the source of 75% or more of the smog potential impacts, followed by plate manufacturing (8%). Smog for the raw material stage is mainly from production of the paperboard content of the plates, although production of the styrene acrylic coating contributes about 9% of the raw material smog. The majority of the plate manufacturing smog is from combustion emissions from the share of process electricity that is derived from coal.

Table 2-10. Smog Formation Potential Results for 10,000 Plates (kg O_3 Equivalents)

Results by Stage	Raw Materials	Coating Rollstock	Plate Mfg	Plate Transport	Secondary Pkg (LC)	End of Life	NET
Hefty	7.13	0	2.68	1.00	1.55	0.18	12.5
Pressware Plate 1	13.5	0.13	1.51	0.61	1.13	1.04	17.9
Pressware Plate 2	15.4	0.13	1.58	0.65	0.92	1.07	19.8

Contribution by Stage	Raw Materials	Coating Rollstock	Plate Mfg	Plate Transport	Secondary Pkg (LC)	End of Life	
Hefty	57%	0%	21%	8%	12%	1%	100%
Pressware Plate 1	75%	1%	8%	3%	6%	6%	100%
Pressware Plate 2	78%	1%	8%	3%	5%	5%	100%

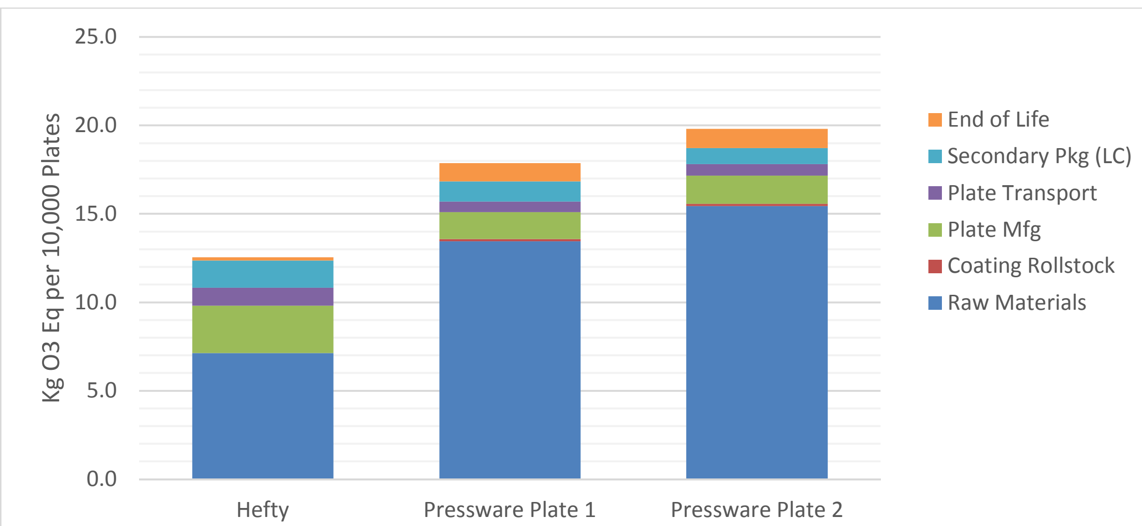

Figure 2-10. Smog Formation Potential Results for 10,000 Plates (kg O_3 Equivalents)

OBSERVATIONS AND CONCLUSIONS

Conclusions about results for PS foam and pressware plates are summarized in Table 2-11, based on percent differences between system totals. The calculation is based on foam plate results minus pressware plate results, so negative percent differences indicate that the system total is higher for the pressware system, while positive percent differences mean that the foam plate system total is higher. The table uses a 10 percent minimum difference threshold for a meaningful difference in results for energy and weight of solid waste, and a 25 percent minimum difference threshold for solid waste volume and life cycle impact results. Percent differences that are below these thresholds are considered to be within the margin of uncertainty of the data and are considered inconclusive.

The table uses a color-coding approach for comparative conclusions. Green indicates categories where PS foam plates have significantly lower results than pressware plates, red indicates results where PS foam is significantly higher than pressware, and gray indicates that the difference between PS foam and pressware results is not large enough to be considered meaningful.

Table 2-11. Summary of Comparative Conclusions for Foam and Pressware Plate Systems

		Percent Difference between Hefty and Pressware Plate Systems*	
Results Category	Minimum percent difference considered meaningful*	Plate 1 - low coating energy	Plate 2 - low coating energy
Total Energy Demand	10%	-31%	-43%
Non-Renewable Energy Demand	10%	37%	22%
Solid Waste by Weight	25%	-98%	-103%
Solid Waste by Volume	25%	14%	5%
Water Consumption	25%	-57%	-63%
Global Warming	25%	-50%	-61%
Acidification	25%	-51%	-60%
Eutrophication	25%	-120%	-128%
Ozone Depletion	25%	24%	9%
Smog	25%	-35%	-45%

** For each comparison of the foam plate system with a pressware plate, the percent difference is calculated as the difference between the foam and pressware system results divided by the average of the foam and pressware system results.*

The Hefty plate system compares favorably with pressware plates in 7 of the 10 results categories evaluated. In two categories, solid waste volume and ozone depletion potential, the Hefty plate system shows somewhat higher total results; however, the percent differences between results for the foam and pressware plate systems are not large enough to be considered meaningful given the uncertainty in the underlying data and modeling. The Hefty plate system has higher non-renewable energy requirements than the pressware plate systems. The pressware plate systems have a higher use of renewable wood as both a feedstock (for the fiber content of the pressware plate) and as an energy source (via combustion of wood wastes and black liquor containing lignin extracted from the wood during the kraft pulping process) at pulp mills.

Main differences driving the results include the following:

- ***Plate Material and Weight:*** As shown in Table 1-1, it takes **60% less material** by weight to make a foam plate than it does to make a paper plate of comparable functionality. The results tables and figures show that raw material production makes the largest contribution to all results categories for all plate systems, with the exception of solid waste results, which are dominated by disposal of plates after use. The raw material burdens are calculated as the product of the burdens per pound of each plate material multiplied by the pounds of each material used in the plate system. Compared to the virgin bleached paperboard in the pressware plates, the plastic resin in the foam plates has higher energy requirements per pound of material, largely because the foam plate uses fossil fuel resources as both material and energy inputs. The higher impacts per pound of polystyrene compared to paperboard are offset by the heavier weight of the pressware plates (over twice the weight of the foam plate), so that the foam plate has lower total energy requirements for raw materials compared to the pressware plates. Overall, making, using and disposing of foam plates **requires about 30% less total renewable and non-renewable energy** than paper plates of comparable functionality (see Table 2-1 and Figure 2-1).
- ***Plate Manufacturing Energy:*** Manufacturing energy requirements are higher for PS foam plates (see "Plate Mfg" results in Table 2-1 and Figure 2-1). The foam plate manufacturing plant not only uses significant amounts of energy for the converting process but also consumes natural gas in the thermal oxidizer used to destroy blowing agent emissions.
- ***Water Consumption:*** Paperboard production consumes more water per pound than production of petrochemical resins. Making, using, and disposing of foam plates **consumes almost 50% less water** than paper plates of comparable functionality (see Table 2-5 and Figure 2-5).
- ***Greenhouse Gas Emissions (Global Warming Potential):*** Due in large part to the pressware plates' greater weight and greater amount of raw materials required, global warming results for raw material production are notably higher for the pressware systems compared to the foam plate system (see Raw Materials results in Table 2-6 and Figure 2-6) . In addition, the fiber in paper plates is not protected from moisture on all sides and therefore is likely to decompose gradually over time in landfills, producing methane gas, as modeled in the baseline scenario. Some landfill methane is captured and converted to carbon dioxide, but some escapes untreated from the

landfill, contributing to global warming (see End of Life results in Table 2-6 and Figure 2-6). Overall, making, using and disposing of foam plates generates 40% less greenhouse gas emissions than paper plates of comparable functionality, in the baseline scenario with maximum decomposition of landfilled paperboard.

- ***Solid Waste:*** Postconsumer plates account for the largest share of solid waste for each plate system.
  - ***Solid Waste by Weight.*** The foam plates weigh about half as much as the pressware plates, so the foam plate systems produce significantly less weight of solid waste compared to pressware plates (see Table 2-3 and Figure 2-3).
  - ***Solid Waste by Volume.*** Because foam plates have a much lower landfill density than paperboard, the foam plate system has higher postconsumer solid waste volume results compared to the pressware plates, despite the lower weight of landfilled foam plates (see End of Life results in Figure 2-4).

CHAPTER 3
SENSITIVITY ANALYSIS

INTRODUCTION

Sensitivity analyses were run to evaluate several areas where uncertainties in the modeling had the potential to influence study results and conclusions. The following sensitivity analyses were included: (1) reduced decomposition scenarios for landfilled pressware plates, and (2) different energy use scenarios for flexographic application of pressware plate coatings.

The baseline results in Chapter 2 reflect the following modeling assumptions:

- Maximum decomposition of the degradable fiber content in pressware plates that are disposed in landfills at end of life.
- Low energy use for flexographic application of coatings

Each section of this chapter shows how results based on different modeling assumptions affect the results and conclusions compared to the baseline scenario.

SENSITIVITY ANALYSIS ON PRESSWARE PLATE LANDFILL DECOMPOSITION

Assumptions about end-of-life decomposition can significantly affect the end-of-life global warming potential results for paperboard products such as pressware plates. The higher the degree of decomposition, the more methane is produced and the less carbon is stored in the landfilled product. The results in the tables and figures presented in Chapter 2 are based on maximum decomposition of the fiber in landfilled pressware plates. Maximum decomposition is used as the baseline assumption because the moisture- and grease-resistant coatings are only applied to the top surface of the plate, and there is no protective coating on the back side of the plate that might inhibit degradation of the pressware plate fiber.

It is possible that the coating on the top surface of the pressware plates may slow down degradation of the plate fiber, or the plates may end up in landfills where conditions do not favor decomposition, so that degradation occurs very slowly or does not occur at all. Therefore, in addition to the maximum decomposition modeled in the baseline scenario, results were also run for 50% of maximum decomposition and for 0% decomposition. At lower decomposition rates, less of the biomass carbon is converted to methane, and a credit is given for the net carbon dioxide removed from the atmosphere and stored in the landfilled pressware plate fiber.

Table 3-1 shows the change in results and comparative conclusions for the different decomposition scenarios compared to the baseline scenario. The tables use the same color-coding approach used in other comparative conclusion tables. Green indicates categories where PS foam plates have significantly lower results than pressware plates based on the percent difference threshold shown for each impact, red indicates results where PS foam plate results are significantly higher than pressware plate system results, and gray indicates that the difference between PS foam and pressware plate system results is not large enough to be considered meaningful. Bold red text identifies the baseline scenario results that were presented in Chapter 2.

An additional set of landfill decomposition sensitivity results were run using maximum landfill decomposition factors from the U.S. EPA Waste Reduction Model (WARM) documentation.[30] These results are shown in Table 3-2. The GWP percent differences for the maximum and 50% decomposition scenarios are slightly smaller than in Table 3-1, but the conclusions are the same.

As shown in the tables, the only impact significantly affected by the decomposition assumption is GWP, which decreases notably for lower decomposition rates. There are small changes in results for some other impacts, associated with the reduction in recovered energy credits at lower decomposition levels (since less decomposition means less generation and recovery of landfill gas that is utilized for energy); however, none of these other changes is large enough to affect comparative conclusions. As shown in the tables, for a scenario in which 50% of the degradable carbon content of the paperboard decomposes, the difference in total GWP results for the foam and pressware plate systems is inconclusive. If the pressware plates are modeled with no decomposition, then the plates receive a large credit for biogenic carbon storage, and the pressware plate systems have lower net GWP results than the foam plate system. The "no decomposition" scenario is presented here as a lower bound for GWP results and is not expected to be a realistic scenario.

Table 3-1. Comparative Conclusions for Variations in Pressware Plate Decomposition

		Percent Difference between Hefty and Pressware Plate Systems					
		Max decomposition		**50% decomposition**		**No decomposition**	
Results Category	Minimum percent difference considered meaningful	**Plate 1 - low coating energy**	**Plate 2 - low coating energy**	Plate 1 - low coating energy	Plate 2 - low coating energy	Plate 1 - low coating energy	Plate 2 - low coating energy
Total Energy Demand	10%	**-31%**	**-43%**	-31%	-43%	-32%	-44%
Non-Renewable Energy Demand	10%	**37%**	**22%**	37%	22%	35%	20%
Solid Waste by Weight	25%	**-98%**	**-103%**	-98%	-103%	-98%	-103%
Solid Waste by Volume	25%	**14%**	**5%**	14%	5%	14%	5%
Water Consumption	25%	**-57%**	**-63%**	-58%	-64%	-60%	-66%
Global Warming	25%	**-50%**	**-61%**	-11%	-24%	54%	39%
Acidification	25%	**-51%**	**-60%**	-52%	-61%	-54%	-62%
Eutrophication	25%	**-120%**	**-128%**	-120%	-128%	-121%	-128%
Ozone Depletion	25%	**24%**	**9%**	24%	9%	24%	9%
Smog	25%	**-35%**	**-45%**	-36%	-45%	-37%	-47%

30 http://epa.gov/climatechange/wycd/waste/downloads/landfilling-chapter10-28-10.pdf

Table 3-2. Comparative Conclusions for Variations in Pressware Plate Decomposition, Using WARM Factors

		Percent Difference between Hefty and Pressware Plate Systems					
		Max decomposition		50% decomposition		No decomposition	
Results Category	Minimum percent difference considered meaningful	Plate 1 - low coating energy	Plate 2 - low coating energy	Plate 1 - low coating energy	Plate 2 - low coating energy	Plate 1 - low coating energy	Plate 2 - low coating energy
Total Energy Demand	10%	-32%	-43%	-31%	-43%	-32%	-44%
Non-Renewable Energy Demand	10%	36%	21%	36%	21%	35%	20%
Solid Waste by Weight	25%	-98%	-103%	-98%	-103%	-98%	-103%
Solid Waste by Volume	25%	14%	5%	14%	5%	14%	5%
Water Consumption	25%	-57%	-64%	-58%	-65%	-60%	-66%
Global Warming	25%	-43%	-54%	-7%	-20%	54%	39%
Acidification	25%	-51%	-60%	-52%	-61%	-54%	-62%
Eutrophication	25%	-120%	-128%	-120%	-128%	-121%	-128%
Ozone Depletion	25%	24%	9%	24%	9%	24%	9%
Smog	25%	-35%	-45%	-36%	-46%	-37%	-47%

SENSITIVITY ANALYSIS ON ENERGY FOR APPLICATION OF PRESSWARE PLATE COATING

Pressware plates have a styrene acrylic coating applied to the food contact surface to prevent the paperboard from absorbing moisture and grease from foods placed on the plate. Based on plate coating patents and conversations with coating industry representatives, the coating is commonly applied by a flexographic process. However, for the purpose of modeling energy use for applying the coating to the plate rollstock, the only flexographic process data sets that could be found were for flexographic printing of graphics, not for applying continuous surface coatings. Flexographic coating application energy for the pressware plates was estimated by adapting data from two different sources: (1) a flexographic printing data set in the BUWAL database, available in SimaPro LCA software, and (2) an EPA report on flexographic printing.[1] For both of these data sources, the energy requirements in the original data set for graphics printing were scaled up based on the ratio of applied material, since more energy would be needed to dry the greater amount of applied plate coating material compared to the smaller amount of ink applied in flexographic graphics printing. In addition, a scenario with no energy included for flexographic coating application was modeled to see if excluding the application energy significantly affected results and conclusions.

Regardless of the coating application process energy modeling, the amount of coating materials applied to a given pressware plate was not changed. The amount of coating applied to each of the two pressware plates was based on laboratory testing of the samples of each plate, and production of the coating materials used on each plate is included in the raw materials stage results. The baseline results in the report are based on the lower estimated flexographic application energy.

Table 3-3 shows the meaningful difference conclusions for the three coating energy scenarios for each plate compared to Hefty plates. Results for the baseline scenario presented in Chapter 2 are indicated in bold. Although the percent differences between systems change somewhat based on the coating application energy modeled, there are no changes in comparative conclusions in any results categories.

Table 3-3. Comparative Conclusions for Variations in Pressware Plate Coating Application Energy

		Percent Difference between Hefty and Pressware Plate Systems					
Results Category	Minimum percent difference considered meaningful	Plate 1 - no coating energy	**Plate 1 - low coating energy**	Plate 1 - high coating energy	Plate 2 - no coating energy	**Plate 2 - low coating energy**	Plate 2 - high coating energy
Total Energy Demand	10%	-31%	**-31%**	-33%	-42%	**-43%**	-46%
Non-Renewable Energy Demand	10%	38%	**37%**	33%	23%	**22%**	16%
Solid Waste by Weight	25%	-98%	**-98%**	-98%	-103%	**-103%**	-103%
Solid Waste by Volume	25%	14%	**14%**	14%	5%	**5%**	5%
Water Consumption	25%	-56%	**-57%**	-59%	-62%	**-63%**	-66%
Global Warming	25%	-49%	**-50%**	-52%	-60%	**-61%**	-64%
Acidification	25%	-50%	**-51%**	-53%	-59%	**-60%**	-62%
Eutrophication	25%	-120%	**-120%**	-120%	-128%	**-128%**	-128%
Ozone Depletion	25%	24%	**24%**	24%	9%	**9%**	9%
Smog	25%	-34%	**-35%**	-37%	-44%	**-45%**	-47%

SENSITIVITY ANALYSIS CONCLUSIONS

The sensitivity analyses can be summarized as follows:

- Only the global warming potential conclusion are affected by changing the degree of decomposition modeled for the fiber in landfilled paperboard plates. The GWP comparison of pressware plates with foam plates shifts from unfavorable for pressware plates at maximum decomposition to favorable for pressware plates in the scenario with no decomposition. Maximum decomposition of the degradable fiber content of pressware plates is considered a likely scenario since the plates only have protective coating on one surface and the fiber on the back side of the plate is exposed.
- Variations in energy for flexographic application of plate coatings do not affect any of the comparative conclusions.

APPENDIX A
PEER REVIEW

PEER REVIEW

of

Life Cycle Assessment of Polystyrene Foam and Coated Paperboard Disposable Plates

Prepared for

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September 4, 2015

SUMMARY

At the request of Franklin Associates, the peer review panel evaluated Franklin Associate's life cycle assessment (LCA) of Hefty polystyrene plates as well as of two types of pressware plates made of coated bleached paperboard.

This study was prepared for Reynolds Consumer Products, for purposes of internal decision making as well as potentially communication to customers.

All plates evaluated were approximately 9 inches in diameter. The functional unit for the study was 10,000 plates. The LCA study included production of the plates and their transportation to a distribution center and end-of-life management.

Franklin performed a life cycle inventory and impact assessment across a range of categories: energy demand, non-renewable energy demand,
solid waste by weight, solid waste by volume, water consumption, global warming potential, acidification potential, eutrophication potential, ozone depletion potential, and smog formation potential.

In conformance with ISO 14044:2006 Section 6.3, the panel consisted of 3 external experts independent of the study. They reviewed the draft LCA report against the following criteria, to ensure the analysis had been conducted in a manner consistent with ISO standards for LCA:

- Is the methodology consistent with ISO 14040/14044?
- Are the objectives, scope, and boundaries of the study clearly identified?
- Are the assumptions used clearly identified and reasonable?
- Are the sources of data clearly identified and representative?
- Is the report complete, consistent, and transparent?
- Are the conclusions appropriate based on the data and analysis?

The panel also reviewed the Life Cycle Impact Assessment (LCIA) sections of the LCA report using the following additional criteria:

- Does the LCIA employ a sufficiently comprehensive set of category indicators?
- Is the comparison conducted category indicator by category indicator with no weighting of indicators?
- Are the category indicators scientifically/technically valid, environmentally relevant, and internationally accepted?
- Is there sufficient analysis of the sensitivity of the LCIA results?

With the exceptions detailed below, the panel found the study calculations, assumptions employed, and data analysis methods to be consistent with ISO 14040 series documents. The sources of data were generally identified and representative. Since the panel was given no special access to data or methods beyond what was included in the report, panel members did not replicate the calculations.

More detailed responses to each of the questions listed above are given below. In some cases not all comments fit neatly into the category where they are listed, but are included because that category appeared to be the best fit. For example, a particular comment may have followed naturally from a comment that "belonged" in that category.

Is the methodology consistent with ISO 14040/14044?

In general this study follows ISO 14040/14044 guidelines regarding the objectives, scope, and methods. The analysis is fundamentally sound. A few areas for improvement are identified below.

System expansion was used to model postconsumer recycling of the corrugated boxes used to package the plates. A credit was given for avoiding production of the materials displaced by the generation of more recycled material than that used as recycled content in the boxes. It is presumed that this credit is for production of the recycled material; the wording on p. 25 should be adjusted to make this clear.
Response: The wording has been revised to clarify that credit is given for the amount of unbleached paperboard production that is displaced by collection and recycling of postconsumer boxes.

Are the objectives, scope, and boundaries of the study clearly identified?

The objective to compare the life cycle impacts of Hefty® Everyday™ disposable polystyrene foam plates and competing coated pressware plates was clearly stated in the report. Statements were made that <u>if</u> comparative assertions are to be made, a peer review is required. Obviously a peer review is being carried out, which causes confusion about whether or not comparative assertions are planned. Rewording to address this confusion is recommended.
Response: The wording has been updated to reflect that the peer review has been conducted.

The functional unit was defined as the "~~production and end-of-life management of~~ 10,000 single-use plates identified as "everyday" versions of the brands (e.g., not heavy duty)." The functional unit should be stated without including the scope.
Response: The wording has been revised as suggested.

The function of the plates is to contain and serve food for eating. Ideally the load weight and strength would be defined but, as discussed, no load bearing tests were conducted, and size of the plates varies slightly. The assumption of functional equivalence of the plates is reasonable.

There are other types of disposable plates that could be compared to the Reynolds plate, so an explicit statement that these were not considered would be useful and should be required if public comparative assertions are made. Similarly, there are other manufacturers of foam plates but the title of the report is more generic and appears to imply a broader comparison. How the Reynolds plates compare with typical polystyrene foam plates should be addressed explicitly, or the title should be modified.

Response: The title has been modified to clarify that the report is specific to Hefty brand foam plates, and the introduction to the Executive Summary has been revised to explicitly state that the analysis does not include the full range of pressware plates in the market or any other types of disposable plates.

Are any pressware plates made with recycled content? This should be stated explicitly.
Response: An internet search on pressware plates, including sites specifically focused on eco-friendly products, did not identify any pressware plates with recycled content. Language has been added to the descriptions of pressware plates in the Executive Summary and Chapter 1 to clarify this.

The scope of the analysis is reasonable. Justification for not including the phases between the distribution center and end of life is provided.

Both non-renewable and total primary energy (non-renewable and renewable) are commonly used life cycle metrics. The statement is made: "To avoid potential bias against product systems derived from fossil fuels (e.g., foam plates), it is important to include renewable energy use when comparing to systems with substantial use of biomass for feedstock and process energy (e.g., the paperboard content in the pressware plates)." This statement itself sounds biased and should be deleted.
Response: The statement has been removed as suggested, and language has been added to clarify that the feedstock energy for the plate systems includes both renewable and non-renewable feedstock energy.

Are the assumptions used clearly identified and reasonable?

Sensitivity analyses were conducted for the following two assumptions which represent the largest potential uncertainties from the data collection and modeling steps:

- Percent of landfill decomposition of potential degradable carbon content. Landfill decomposition and related carbon emissions and sequestration is highly uncertain and therefore the scenario analysis was useful to understand implications of potential errors from parameters used.

- Different energy use scenarios for flexographic application of pressware plate coatings. Scenarios using the higher coating application energy and no coating application energy were modeled.

The statement is made on p. 16: "Because Hefty plates do not have printed designs, exclusion of printing inks is favorable to the pressware plate systems energy." However, there is no process requirement that pressware plates be printed, so this should be reworded to something like: "Because Hefty plates do not have printed designs, printing inks are excluded from the inventory for the pressware plates to maintain functional equivalency."
Response: Wording to address this suggestion has been added.

On p. 16, the discussion of the exclusion of energy for space conditioning should more

clearly state that this exclusion was justified because these processes use large amounts of energy, so therefore space conditioning, lighting, etc., is not expected to make a significant contribution. As currently written, this is not clear.
Response: Wording has been added to clarify reasons for exclusion of space conditioning.

Under miscellaneous materials and additives it states that "no use of resource-intensive or high-toxicity chemicals or additives was identified for either plate system." However, styrene, which is used to make foam, is toxic. Presumably styrene was included in the PS manufacturing process. This statement should be clarified to indicate that no "resource-intensive or high-toxicity chemicals or additives" that were not included in the analysis were identified.
Response: The wording has been clarified as suggested.

The use of maximum decomposition of the pressware plates as the baseline assumption is somewhat problematic. The maximum decomposition value was based on lab conditions designed to achieve maximum rates, and is less likely in practice. While alternative scenarios are addressed in the sensitivity analysis, they should be given more attention in the base discussion. There is increasing evidence that actual decomposition is likely less than the maximum obtained from the 1997 source. Additionally, the EPA WARM model has been recently updated and may have some more relevant emission factors for different paper products. See http://dx.doi.org/10.1016/j.scitotenv.2015.05.132 and http://epa.gov/climatechange/wycd/waste/downloads/landfilling-chapter10-28-10.pdf.
Response: More description about the uncertainty around degree of decomposition and the effect on GWP results has been added at the end of Chapter 1 and in the GWP results section of Chapter 2. Additional decomposition sensitivity results have also been added in Chapter 3 based on updated decomposition factors used in the EPA WARM document referenced by the reviewers. The other article referenced by the reviewers described some recent landfill simulation experiments on various grades of paper, including unexpectedly low decomposition results for one bleached paper sample in one reactor. This article further highlights the uncertainty around landfill decomposition of paper products but does not conclusively indicate whether or not maximum decomposition achieved in landfill simulation experiments might occur in actual landfills, or what the most likely decomposition scenario would be for bleached paper products in landfills. The sensitivity analyses in Chapter 3 of this LCA report cover the full range of possible decomposition scenarios.

Are the sources of data clearly identified and representative?

The description of the data used is very generic, referring to several different databases in SimaPro LCA software as well as Franklin Associates' own LCI database. More information should be provided to the extent possible – for example, which datasets were used from which SimaPro databases? What electricity fuel mix was used, for what year, in adapting data sets from European databases to U.S. conditions? The range of age of the data should also be indicated.
Response: More specific information on the data used has been added in the Data Sources section, as suggested.

It appears that transportation of the plates to the distributor is modeled as weight-limited, since the values for the Hefty plates are about half of those for the pressboard. It is not immediately obvious that the Hefty plates should not be volume limited. There does not appear to be an explicit statement justifying this modeling choice.
Response: Follow-up with Reynolds indicated that foam plate shipping is volume limited. Information on volume- and weight-limited transport of plates has been added to the Systems Studied section of the report, and the Hefty plate results throughout the report have been updated to reflect volume-limited transport.

Is the report complete, consistent, and transparent?

In general the report is well written and complete. Further documentation on data sources as indicated above is recommended.
Response: Additional data documentation has been added as suggested.

Are the conclusions appropriate based on the data and analysis?

The conclusions are reasonable for the results presented. Minor changes to a few statements in the conclusions are recommended:

- The concluding section would be more complete to state that results for the Hefty system indicated higher impacts for solid waste volume and ozone depletion. A follow up statement would then indicate that "Differences between the Hefty system and the pressware systems for solid waste volume and ozone depletion are not large enough to be considered meaningful."
Response: The paragraphs immediately following Table ES-3 and Table 2-11 noted that solid waste volume and ozone depletion differences were not large enough to be considered meaningful; wording has been added as suggested to also note that the magnitude of the results for those impacts were higher for the foam plate system (although not enough higher to be considered a meaningful difference).

- "The Hefty plate system has higher non-renewable energy requirements than the pressware plate systems, due to the pressware plate systems' higher use of renewable wood as both a feedstock (for the fiber content of the pressware plate) and as an energy source (via combustion of wood wastes and black liquor containing lignin extracted from the wood during the kraft pulping process) at pulp mills." This would be better stated as two separate sentences: The Hefty plate system has higher non-renewable energy requirements than the pressware plate systems. The pressware plate system has a higher use of renewable wood as both a feedstock (for the fiber content of the pressware plate) and as an energy source (via combustion of wood wastes and black liquor containing lignin extracted from the wood during the kraft pulping process) at pulp mills.
Response: The wording has been revised as suggested.

- Seven of the 10 impacts were higher for the pressware plate system. Which impacts are most significant would require weighting, which is a subjective process.

Does the LCIA employ a sufficiently comprehensive set of category indicators?

The LCIA indicators include acidification, eutrophication, GWP, ozone depletion, and smog formation, which cover a reasonable set of impact categories. A rationale is provided for why human toxicity based indicators were not included, but could be strengthened.
Response: Additional explanation of the reasons for exclusion of human toxicity indicators has been added to Chapter 1 in the section Inventory and Impact Assessment Results Categories.

Is the comparison conducted category indicator by category indicator with no weighting of indicators?

No weighting of indicators was conducted in this study.

Are the category indicators scientifically/technically valid, environmentally relevant, and internationally accepted?

The characterization methods used in this study represent the established methods from US EPA (TRACI 2.1). In addition, inventory results for energy demand, solid waste mass and volume, and water consumption are presented.

Is there sufficient analysis of the sensitivity of the LCIA results?

Sensitivity analysis was conducted to investigate landfill decomposition and energy use scenarios for flexographic application of pressware plate coatings.

Editorial Comments

P. 12, 3rd full paragraph, the amount of pentane is listed but the basis (how many plates) is not. Presumably the 2.8 lbs is per functional unit of 10,000 plates, but this functional unit is not introduced in the body of the report until p. 14, so "per 10,000 plates" (or the other appropriate qualifier) needs to be added.
Response: The wording has been revised as suggested to clarify that the 2.8 lb of pentane is for 10,000 plates.

P. 24, 3rd paragraph, it seems like this is a background process in the perspective of the plate manufacturer; Why not simply use an existing process from the USLCI or ecoinvent? Is the same consideration given for potential co-products of paperboard

manufacturing-energy derived from black liquor? If specific fuels are not displaced, how is this credit calculated? And how is this credit different than system expansion?
Response: The referenced paragraph about the hydrocracker energy credit is not describing an adjustment done specifically for the plate LCA but is describing the approach used in the U.S. LCI Database background unit process data set for ethylene production. The hydrocracker energy credit is based on the Btu of co-produced energy that was reported by hydrocracker operators as being exported for use in other processes, whereas no credit is given for black liquor energy at the paper mill because the black liquor energy is consumed within the paper manufacturing operations and not exported for use in some other process. The hydrocracker energy credit is different from system expansion because the exported energy is treated as a coproduct with an allocated share of the hydrocracker inputs and emissions, and there is no modeling of fuel production inputs or emissions that are displaced by the exported energy. Further description of the hydrocracker energy credit can be found on pages B-15 and B-16 of the appendices[31] for the ACC plastic resins database report that is the source of the plastics data in the U.S. LCI Database.

P. 27, 4th full paragraph, it is not stated explicitly that emissions from the WTE or landfill facility are assigned to the plates along with the credit for offset of grid electricity. It is not clear if this is a local or national grid.
Response: The second paragraph at the beginning of the "End of Life Management" section provides an overview of all the end-of-life burdens and credits assigned to the plate systems. The wording in the later paragraphs about combustion has been expanded to clarify the WTE burdens and credits (including the credit for avoiding emissions associated with kWh of national grid electricity).

p. 36, first paragraph, a question was raised about whether the evaporative losses associated with establishment of dams for hydropower are calculated as the difference from the lake compared to the un-dammed river, or in some other manner.
Response: The evaporative losses for hydropower are based on a 2011 report by Pfister et al[32] with U.S. results based on a 2003 NREL study.[33] The NREL report contains the following description of the basis used for hydropower evaporative loss: "Water flowing through the turbines and into the river is not considered consumptive because it is still immediately available for other uses. However, the increased surface area of the reservoir, when compared to the free flowing stream, results in additional water evaporation from the surface. A Free Water Surface Evaporation (FWSE) map was used to calculate the amount of water evaporated off the reservoirs (Farnsworth et al. 1982). The map contains isopleths with values of evaporation in inches per year…

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31 http://plastics.americanchemistry.com/LifeCycle-Inventory-of-9-Plastics-Resins-and-4-Polyurethane-Precursors-APPS-Only

32 Pfister, Stephan, Dominik Saner, and Annette Koehler. "The environmental relevance of freshwater consumption in global power production." *The International Journal of Life Cycle Assessment* 16.6 (2011): 580-591.

33 Torcellini P, Long N, Judkoff R (2003) Consumptive water use for U.S. power production. National Renewable Energy Laboratory (NREL), Colorado, United States.

…The map was used to approximate the average evaporation per year by location in the United States. Based on the latitude and longitude of the dam given by the Army Corp of Engineers (ACE), the amount of water evaporated could be approximated by estimating the average value of the isopleths covering the reservoir (ACE 2001). Isopleths are lines of constant yearly evaporation rates that are drawn on maps to represent the third dimension. The surface areas of the reservoirs were measured in acres at a normal height as defined by the National Inventory of Dams (ACE 2001). With this information the volume of water evaporated can be calculated from each reservoir.

This analysis was completed on a collection of hydroelectric dams, most of which produced more than 1 TWh/yr (1012 Wh/yr) or the 120 largest hydroelectric facilities in the United States. These hydroelectric facilities represent approximately 65% of the total electricity produced by hydroelectric facilities in 1999."

APPENDIX B
PEER REVIEW APPROVAL LETTER

November 30, 2015

Franklin Associates, a Division of ERG
110 Hartwell Avenue
Lexington, MA 02421

Subject: Peer Review Panel Conclusion – "Life Cycle Assessment of Hefty® Polystyrene Foam Plates and Two Coated Paperboard Disposable Plates"

To Whom It May Concern:

The Panel performed a peer review of a draft version of Franklin Associates' report for Reynolds Consumer Products, entitled "Life Cycle Assessment of Hefty® Polystyrene Foam Plates and Two Coated Paperboard Disposable Plates," according to ISO 14040/14044 guidelines.

Franklin Associates has responded to the Panel's comments on the draft study, which related primarily to assumptions, data sources, and presentation of results.

After reviewing these responses, the Panel has found them to be reasonable and consistent with both ISO standards and current LCA practice. The Panel concludes that the revised report is complete and meets ISO 14040/14044 guidelines for its intended use.

Sincerely,

<u>Peer Review Panel Members:</u>

Greg Keoleian
Director
Center for Sustainable Systems
University of Michigan

Greg Thoma
Professor
Ralph E. Martin Dept. of Chemical Engineering
University of Arkansas

Susan Selke (Chair)
Professor and Associate Director
School of Packaging
Michigan State University

APPENDIX C
PEER REVIEW PANEL QUALIFICATIONS

Dr. Susan Selke, Chair
Dr. Susan E. Selke is a Professor at Michigan State University and Director of the School of Packaging, where she has been a faculty member for 30 years. She received a Distinguished Faculty Award from MSU in 2012. She holds M.S. and Ph.D. degrees in chemical engineering from Michigan State. Her research interests include environmental impacts of packaging; sustainability; plastics recycling; biodegradable and biobased plastics; composites of plastics with natural fibers; life cycle assessment; nanotechnology and packaging, and other areas. She has authored or coauthored several books on packaging materials and on packaging and environmental issues, as well as over 150 articles and book chapters. Courses she teaches include plastics packaging, packaging materials, packaging and the environment, stability and recycling of packaging materials, and analytical solutions to packaging design.

Dr. Greg Keoleian
Dr. Keoleian co-founded and serves as director of the Center for Sustainable Systems at the University of Michigan. His research focuses on the development and application of life cycle models and metrics to enhance the sustainability of products and technology. He has pioneered new methods in life cycle design, life cycle optimization of product replacement, life cycle cost analysis and life cycle based sustainability assessments ranging from energy analysis and carbon footprints to social indicators. In over 25 years of life cycle work, he has studied systems including alternative vehicle technology, renewable energy systems such as photovoltaics and willow biomass electricity, buildings and infrastructure, information technology, food and agricultural systems, household appliances, and packaging alternatives. Dr. Keoleian earned his M.S. and Ph.D. degrees in chemical engineering at the University of Michigan.

Dr. Greg Thoma
Dr. Thoma has been on the faculty at the University of Arkansas since receiving his Ph.D. in Chemical Engineering from Louisiana State University, and is a Registered Professional Engineer in the state of Arkansas. He has held the Ray C. Adam Chair in Chemical Engineering and is currently the Bates Teaching Professor in Chemical Engineering. He has served as the Quality Assurance Officer for the Integrated Petroleum Environmental Consortium, and as a Director for the Environmental Division of the American Institute of Chemical Engineers. He is a Senior Advisor for The Sustainability Consortium. His research, including over 30 journal publications, focuses on the application of chemical engineering principles to find solutions to environmental problems. He has recently served as lead investigator for a number of life cycle initiatives in the food and agriculture sector including studies on fluid milk, cheese, milk delivery systems, and swine.