FINAL PEER-REVIEWED REPORT

LIFE CYCLE INVENTORY OF POLYSTYRENE FOAM, BLEACHED PAPERBOARD, AND CORRUGATED PAPERBOARD FOODSERVICE PRODUCTS

Prepared for

THE POLYSTYRENE PACKAGING COUNCIL
A part of the American Chemistry Council's Non-Durables Plastics Panel

by

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PREFACE

This study was conducted for the Polystyrene Packaging Council (PSPC). The report was made possible through the cooperation of PSPC member companies who provided data on the production of polystyrene resins and on the fabrication and secondary packaging of polystyrene foodservice products.

The study was conducted at Franklin Associates from July 2002 through March 2005 under the direction of Beverly Sauer, Project Manager and Principal Analyst. Significant contributions were made by Melissa Huff, James Littlefield, and Jeff Hernbloom. William E. Franklin served as Principal in Charge. Robert G. Hunt provided technical guidance.

This study was conducted for PSPC by Franklin Associates as an independent contractor and peer reviewed prior to publication. Final revisions in response to the peer review were made in July and August 2005. The findings and conclusions presented in this report are strictly those of Franklin Associates. Franklin Associates makes no statements nor supports any conclusions other than those presented in this report.

This report should not be used by sponsors or readers to make specific statements about product systems unless the statements are clearly supported by the Life Cycle Inventory (LCI) results and are accompanied by a reference to the publicly available full report. Use of the study results for advertising purposes (e.g., public assertions or comparative assertions) should comply with Federal Trade Commission (FTC) Guides for the Use of Environmental Marketing Claims (16 CFR Part 260) and be consistent with the principles addressed in the ISO 14040 series guidelines. Per the ISO guidelines, this study should not be used as the sole basis for general comparative assertions (general claims that one system is superior or preferable to a competing system or systems). The ISO guidelines do not prohibit making specific comparative claims that are supported by study results.

Franklin Associates, the American Chemistry Council (ACC), the American Plastics Council (APC), PSPC and its members are not responsible for use of the study results by any party in a way that does not fully conform to the guidelines described herein.

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EXECUTIVE SUMMARY

LIFE CYCLE INVENTORY OF POLYSTYRENE FOAM, BLEACHED PAPERBOARD, AND CORRUGATED PAPERBOARD FOODSERVICE PRODUCTS

INTRODUCTION

A life cycle inventory (LCI), such as this study, quantifies the energy use and environmental emissions associated with the life cycle of specific products. In this case, the specific products evaluated are polystyrene and paperboard foodservice products. LCI studies do not attempt to draw conclusions about the environmental impacts of product systems.

Study Goal and Intended Audience

This LCI of selected polystyrene foam and paperboard foodservice products is an update of a 1990 LCI on foam polystyrene and bleached paperboard foodservice items. The study is being updated to incorporate the following changes that have occurred since the original study:

- Additional products/materials evaluated
- Improvements in manufacturing processes and energy usage; and
- Development of ISO standards for conducting life cycle inventory studies and making comparative assessments or claims in the marketplace.

The goal of this analysis is to provide foodservice industry stakeholders with the information needed to better understand the current environmental profiles of the foodservice products studied. This type of information can be used to target efforts to improve the environmental profiles of foodservice products.

The intent of the study was to develop life cycle profiles for the product systems using the most up-to-date data available from the representative industries producing each type of foodservice product. However, industry participation in the study was very limited despite extensive and repeated efforts to secure participation of all stakeholder industries. Environmental profiles presented in this report for participating industries were developed using the data those companies provided for this study. For non-participating industries, the environmental profiles presented in this report were developed using the best and most current data available from Franklin Associates' U.S. life cycle database, updated to the extent possible to represent current technology using the data resources available. For example, although the paperboard industry declined to participate in the study, it is known that paperboard bleaching technology has changed significantly since the original study was conducted. Franklin Associates' bleached paperboard data set was updated for this study to reflect the shift from chlorine-based bleaching technologies to elemental chlorine free bleaching. Data for most other processes and materials in this study were taken from Franklin Associates' LCI database or estimated based on secondary data sources. The quality of these data vary in terms of age, representativeness, measured values or estimates, etc.; however, all materials and process data sets used in this study were thoroughly reviewed for accuracy and currency and updated to the best of our capabilities in 1997 or later. All fuel data were reviewed and extensively updated in 1998. The report bibliography lists the published data sources that were used to develop the LCI models for each product system.

Although the original study goal also included consideration of newly developed materials, as the study progressed it became necessary to change this goal. The original intent of the study was to include biobased foodservice products, but samples were only available from one producer. Since biobased products tend to have unique proprietary formulations, no individual biobased product can be considered representative of biobased products in general. Thus, the decision was made to change the original goal by dropping biobased products from the study.

The primary intended audience for the report is foodservice industry stakeholders; however, in keeping with American Chemistry Council (ACC) policy, the final report will be publicly available upon request to any interested party. The study results should not be used inappropriately to make general comparative assertions. Guidelines regarding the use of the study are presented in the report Preface and in the Study Limitations on page ES-14 of the Executive Summary.

Study Scope and Boundaries

This study was conducted to analyze those types of foodservice products that would most closely compete with polystyrene foam products. The LCI analyzes polystyrene foam and paperboard foodservice items that are available in each of the following categories: cups for hot and cold beverage, plates, and sandwich clamshells. Secondary packaging for shipment of finished products is also considered in a separate set of results.

The scope of the analysis reflects a modification from the scope originally defined for the study, which included hot and cold cups, plates, clamshells, and meat/poultry trays. In addition, the study goal changed to remove consideration of newly developed materials (i.e., biobased products). There are two principal reasons for the change in goal and scope:

- Meat/poultry trays were excluded from the study since few non-polystyrene foam alternate material trays exist in the marketplace; and

- No biobased foodservice products were included in the analysis. While there are various biobased foodservice products available in the marketplace today, samples comparable to polystyrene foam were available from only one producer and in only two of the four product categories (plates, clamshells). It was decided that such a limited sample

> would not be acceptable as the basis for a viable ISO-compliant study providing a comparative analysis. In this case, the limited availability of biobased samples would result in comparison of a single specific biobased product weight and formulation with average generic weight and formulation data for the alternative material products in the plate and clamshell categories.

The study quantifies energy and resource use, solid waste, and individual atmospheric and waterborne emissions for the life cycle of each product system from raw material extraction through fabrication of products and secondary packaging, plus ultimate disposal. Transportation of packaged product to customers and use by consumers is not included in the study.

The scope of the project does not include testing products for strength, insulating properties, etc., nor developing data on consumer use practices. The scope of the study does not include forecasting lightweighting trends or future technology improvements for any of the foodservice products studied.

Functional Unit

Within each foodservice product category, the functional unit for this study is an equivalent number of product units of the defined size or capacity and corresponding general level of functionality based on available information. In some cases, different material products within a defined category were not available in exactly equivalent sizes and capacities. In these cases, the product configuration that most closely corresponded with the defined product category was evaluated. All foodservice product systems in this study are evaluated on the basis of 10,000 product units.

It is recognized that the different product samples available within a defined product category vary in certain properties (e.g., insulating properties of cups and clamshells, load strength and moisture resistance of plates). However, no information on individual product samples was available to quantify these functional differences. In order to evaluate differences in functional use of products due to incremental differences in product properties, it would be necessary to define specific use applications in which to evaluate individual samples' performance (e.g., for hot cups, to contain a certain temperature beverage not to exceed a defined cooling rate, or for plates, to support a load of food with a defined weight and moisture content). Such functional analysis is beyond the scope of this study.

Functional performance was taken into account to the extent possible for plates. Disposable foodservice plates come in a wide range of weights and configurations, and there can be not only large weight variations between the lightest and heaviest plates available within a single material category but also substantial differences in strength. In order to make the product comparisons as equivalent as possible, only plates of the same general grade were analyzed. The LCI results for plates include only those plates classified by their manufacturers as high-grade.

Some provisions were made in this presentation of LCI results in this report to facilitate the analysis of consumer practices that may vary based on actual or perceived differences in product functionality. For example, because it is common practice at coffeeshops and other carry-out establishments for insulating sleeves to be used with paper cups for hot beverages, the 16-oz hot cup analysis includes coated paper cups used alone and with corrugated cup sleeves. "Double-cupping" (the use of two nested cups, a fairly common practice with paper cups) to provide consumers' hands with additional protection from extremely hot or cold beverage can be evaluated by doubling the LCI results for the cup (and the packaging used to deliver the cup). Double or even triple use of plates by consumers may also occur (e.g., to provide additional strength under heavy or wet loads) and can be evaluated in the same manner.

Systems Studied

The following types of foodservice products are analyzed in this study:

- 16-oz cups used for hot beverages
  - Expanded polystyrene (EPS) foam
  - Polyethylene (PE)-coated bleached paperboard (used alone and with corrugated unbleached paperboard cup sleeves)
- 32-oz cups used for cold beverages
  - EPS foam
  - PE-coated bleached paperboard
  - Wax-coated bleached paperboard
- 9-inch high-grade (heavy-duty) plates
  - GPPS foam
  - PE-coated bleached paperboard
  - Molded pulp
- 5-inch sandwich-size clamshells
  - General purpose polystyrene (GPPS) foam
  - Insulated (corrugated) paperboard

All components and input materials for each system are assumed to be produced in the U.S. Table ES-1 presents the component weights associated with 10,000 units of each foodservice product. These data represent the range of weights of each product determined by contacting all manufacturers that could be identified through internet searches for producers and distributors of these foodservice products. In most cases, the weight data represent actual measurements of samples acquired from manufacturers, distributors, or retailers. In some cases, the weight data were reported by producers. For some products, only one manufacturer could be located. These include wax-coated paper cups and corrugated paperboard clamshells. Although only one product sample could be obtained in these categories, other studies of similar products support the assumption that other manufacturers' products within each of these categories would be similar in composition and weight, unlike biobased products, which were excluded from the study due to their unique formulations and lack of samples available. The analysis includes the

Table ES-1

FOODSERVICE PRODUCT WEIGHT DATA

	No. of Mfrs	No. of Samples	Low Wt (g)	High Wt (g)	Avg Wt (g)	Avg Wt in lb per 10,000 units
16 oz Hot Cups						
EPS Foam	2	3	4.40	5.00	4.70	104
PE-coated Paperboard	3	6	12.3	15.0	13.3	294
Unbleached Corrugated Cup Sleeves	1	4	4.10	7.50	5.76	127
32 oz Cold Cups						
EPS Foam	2	3	8.10	10.0	8.83	195
PE-coated Paperboard	3	4	19.8	23.3	21.9	483
Wax-coated Paperboard (1)	1	1	31.3	31.3	31.3	690
9 inch Plates - High Grade						
GPPS Foam - Laminated	2	3	10.4	11.1	10.8	238
Uncoated Molded Pulp	2	4	16.2	17.4	16.6	367
Coated Paperboard	2	2	18.2	18.5	18.4	405
Sandwich-size Clamshells						
5 inch Corrugated Paperboard (1, 2)	1	2	10.2	10.3	10.2	225
5 inch GPPS Foam	4	4	4.40	5.00	4.80	106

(1) Only one producer located.
(2) Bleached outer layer, unbleached inner layer and fluting.

Source: Franklin Associates

Product samples collected and weighed by Franklin Associates from January 2003 through July 2003.

full range of weights of the product samples in each product category obtained and weighed by Franklin Associates from January 2003 through July 2003.

The analysis also includes secondary packaging. Information on development of secondary packaging data is provided in Chapter 3 of this report. Table ES-2 shows the weights of secondary packaging evaluated for each product.

RESULTS

The report consists of a methodology chapter and three sets of results in separate chapters, each with a different emphasis for the various foodservice products systems analyzed. All results are presented on the basis of 10,000 units of foodservice product. The first set of results is for the range of product weights available for each type of product in each foodservice category. The results include production of the foodservice materials, fabrication of the foodservice products, and end-of-life disposal. (Note: As described in more detail in the methodology chapter, end-of-life results do not include emissions associated with the decomposition or burning of postconsumer foodservice products.) The second set of results looks at the contribution of secondary packaging to the environmental profile for average weight products in each foodservice category. The third set of results examines the reduction in environmental burdens for average weight postconsumer foodservice products if they are recycled or composted at a rate of 2 percent.

Only the results in Chapter 2, representing the full range of product weights in each category, should be used to compare different material products in the same product category. Conclusions regarding the relative performance of competing products cannot be drawn from Chapters 3 and 4 because results for the full range of product weights for each material are not shown.

To avoid disruptions to the reader in the flow of the discussion, all results figures referenced in the Executive Summary are presented at the end of this chapter.

Results for Range of Product Weights (Chapter 2)

Detailed discussion and tables for the range of product weights in each foodservice product category can be found in Chapter 2 of this report.

Energy. The total energy requirements for each system include the energy for processing, manufacturing, and transporting materials at each stage of the life cycle, as well as the energy content of fuel resources used as raw materials. Figures ES-1 through ES-4 show the total energy for the range of weights of each product broken out into the categories of process energy, transportation energy, and energy of material resource. Based on the uncertainty in the energy data, energy differences between systems are not considered meaningful unless the percent difference between systems 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 and supported by sample statistical calculations (see Chapter 5).

When the full range of product weights are considered, the comparison of energy results for polystyrene foam and alternative material products is inconclusive in several of the product categories, including comparisons with PE-coated paperboard in both hot and cold cup applications, and with molded pulp plates and fluted paperboard clamshells.

Comparisons of total energy results for polystyrene foam cups and PE-coated paperboard hot cups with sleeves and wax-coated paperboard cold cups are meaningful in favor of polystyrene foam products. The comparison of total energy for GPPS foam plates and PE-coated paperboard plates is meaningful in favor of the paperboard plates.

Table ES-2

SECONDARY PACKAGING
(pounds per 10,000 product units)

	Units per Case	**Corrugated**					**Film Sleeves**
		Meas (1)	**Rept (2)**	**Calc (3)**	**Min**	**Max**	**LLDPE**
16 oz Hot Cups							
EPS Foam							
Mfr 1	500		37.7	70.3	37.7	**70.3**	2.5
Mfr 2	500		40.8	63.9			2.1
PE-coated Paperboard							
Mfr 1	500			44.6	44.6	**50.4**	1.1
Mfr 2	500			50.4			1.4
Unbleached Corrugated Cup Sleeves	1200			35.2	35.2	**35.2**	no data available
32 oz Cold Cups							
EPS Foam							
Mfr 1	500		70.6	108.5	70.6	**108.5**	2.8
Mfr 2	500			95.4			3.9
PE-coated Paperboard	480	62.5			62.5	**62.5**	2.7
Wax-coated Paperboard	480	62.5			62.5	**62.5**	2.9
9 inch High-Grade Plates							
GPPS Foam - Laminated	500		43.8	74.0	43.8	**74.0**	2.0
Coated Paperboard							
Mfr 1	500			41.4	41.4	**41.4**	0.7
Mfr 2	500			41.4			0.7
Uncoated Molded Pulp							
Mfr 1	500			42.3	37.8	**42.3**	0.8
Mfr 2	500			37.8			0.6
Sandwich-size Clamshells							
	actual case						
5 inch GPPS Foam	500		35.8	71.9			3.4
5 inch Corrugated Paperboard	702		25.6	29.9			1.6
	normalized						
5 inch GPPS Foam	600			66.0	35.8	**71.9**	6.2
5 inch Corrugated Paperboard	600			33.4	25.6	**33.4**	1.6

(1) Measured.
(2) Weight reported by manufacturer.
(3) Weight calculated based on product dimensions, units/case, etc.

Source: Franklin Associates

The breakdown of total energy into the categories of process energy, transportation energy, and energy of material resource is different for each foodservice product material. Transportation energy is a small percentage of the total for all systems. For polystyrene foam products, energy of material resource accounts for at least 40 percent of total energy requirements, since fuel resources are the predominant raw materials for the cups. Energy of material resource accounts for only about 10 percent of the total energy for paperboard products with polymer or wax coatings.

As described in the methodology chapter, energy of material resource is assigned only to the raw material use of resources whose primary use is as fuels. Thus, energy of material resource is assigned to products made using oil and natural gas as raw materials, but not to products using wood as raw materials, since the use of wood in this country is primarily as a material input and not as a fuel. If energy of material resource is excluded from the energy totals, polystyrene products compare much more favorably with paperboard foodservice products on the basis of total process and transportation energy.

The sources of energy are also different for different foodservice product materials. For all polystyrene products, over 90 percent of the total energy is from fossil fuels. This includes not only use for process energy (including generation of electricity) and transportation energy, but also the energy content of the crude oil and natural gas used as material feedstocks for production of polystyrene resin. For the paper-based foodservice products, about 50 percent of total energy is wood-derived. Integrated pulp and paper mills that produce virgin paper products use wood wastes (e.g., bark) and black liquor from the kraft pulping process to provide a significant part of their operating energy.

Solid Waste. Solid waste is categorized into process wastes, fuel-related wastes, and postconsumer wastes. **Process wastes** are the solid wastes generated by the various processes throughout the life cycle of the foodservice product systems. **Fuel-related wastes** are the wastes from the production and combustion of fuels used for energy and transportation. **Postconsumer wastes** are the foodservice products discarded by the end users. Postconsumer disposal results are based on the current U.S. average of 20 percent waste-to-energy incineration of postconsumer materials (after recovery for recycling). The balance of the postconsumer solid waste, and the ash from incineration, is landfilled.

Based on the uncertainty in solid waste data, differences in solid waste results between systems are not considered meaningful unless the percent difference is greater than 25 percent for process and fuel-related wastes, or greater than 10 percent for postconsumer wastes. (Percent difference between systems is defined as the difference between solid waste 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 and supported by sample statistical calculations (see Chapter 5).

Weight of Solid Waste. The weight of solid waste for the range of product weights in each foodservice category is shown in Figures ES-5 through ES-8. Solid waste is reported in the categories of process wastes, fuel-related wastes, and postconsumer wastes. Postconsumer solid waste is the dominant contributor to the total weight of solid waste for all systems. It should be noted, however, that process solid waste for wax-coated cups is much higher than for other cups because the wax-coated fabrication scrap is not recyclable and is discarded as process waste.

The solid waste weight comparison of polystyrene foam products to alternative products is meaningful in favor of polystyrene in all foodservice applications studied. The total weight of polystyrene foam products is low because solid waste is dominated by the weight of postconsumer foodservice items, and polystyrene foam products have a much lower density than other foodservice materials.

Volume of Solid Waste. Solid waste volumes for the range of product weights in each foodservice category are shown in Figures ES-9 through ES-12.

The density of postconsumer foodservice products is lower than the density of process and fuel-related solid wastes; thus, when the weights of solid waste by category are converted to volumes, postconsumer wastes account for a larger proportion of total solid waste by volume than by weight. For all foodservice product systems, postconsumer waste is the dominant contributor to both the total weight and total volume of solid waste.

When the figures for solid waste by weight are compared to the corresponding figures for solid waste by volume for each type of foodservice product, it is interesting to note that solid waste for polystyrene products is generally lower in weight than alternative paper-based systems; however, by volume, the totals for polystyrene and paper-based products are comparable (or, in the case of plates, polystyrene is higher). This is because of the very low density of polystyrene foam products (low weight = high volume).

Emissions. Detailed tables showing emissions of a variety of atmospheric and waterborne substances are shown for each system in Chapter 2 of this report. Although emissions from landfills (particularly greenhouse gas emissions) are potentially important to consider in LCI calculations, there is not general agreement among experts on an acceptable methodology for estimating actual landfill emissions; thus, they are not reported with other LCI emissions in this study.

It is important to realize that interpretation of air and water emission data requires great care. The effects of the various emissions on humans and on the environment are not fully known. The degree of potential environmental disruption due to environmental releases is not related to the weight of the releases in a simple way. Research on this evaluation problem is ongoing, but no valid impact assessment methodology currently exists for a life cycle study.

The discussion presented here focuses on the high priority atmospheric issue of greenhouse gas emissions. The primary three atmospheric emissions reported in this analysis that contribute to global warming are fossil fuel-derived carbon dioxide, methane, and nitrous oxide. (Non-fossil carbon dioxide emissions, such as those from the burning of wood, are considered part of the natural carbon cycle and are not considered a net contributor to global warming.) The 100-year global warming potential for each of these substances as reported in the Intergovernmental Panel on Climate Change (IPCC) 2001 report are: carbon dioxide 1, methane 23, and nitrous oxide 296. The global warming potential represents the relative global warming contribution of a pound of a particular greenhouse gas compared to a pound of carbon dioxide. The weights of fossil carbon dioxide, methane, and nitrous oxide released over the life cycle of each foodservice product are multiplied by their global warming potentials and summed. Figures ES-13 through ES-16 show total GHG emissions in carbon dioxide equivalents for the range of product weights in each foodservice category. The majority of global warming potential for each system is from carbon dioxide, while the contribution from nitrous oxide is very small.

Greenhouse gas totals for different foodservice products vary widely, based largely on their material compositions. Materials produced using fossil fuels as process fuels (e.g., plastics) have higher GHG profiles per pound than materials that use a significant amount of non-fossil resources for process energy (e.g., paperboard). Carbon dioxide emissions associated with the combustion of wood are considered to be part of the natural carbon cycle. Because the carbon dioxide released when wood decomposes or is burned was originally taken up from the atmosphere during the growth of the tree, the carbon dioxide is considered "carbon neutral" and not a net contribution to atmospheric carbon dioxide.

Based on the uncertainties in emissions data, some of which are reported from industrial sources, some from standard emissions tables, and some calculated, the difference in two systems' emissions of a given substance is not considered meaningful unless the percent difference (difference divided by average) exceeds 25 percent. This minimum percent difference criterion was developed based on the experience and professional judgment of the analysts and supported by sample statistical calculations (see Chapter 5). Figures ES-13 through ES-16 show that the comparisons of GHG results for most products are inconclusive. For cups, the only meaningful GHG difference is between 32-ounce PE-coated and wax-coated paperboard cold cups, in favor of PE-coated cups. For plates, PE-coated paperboard plates compare favorably with all other alternatives. For clamshells, comparisons are inconclusive.

Results for Average Weight Product Plus Secondary Packaging (Chapter 3)

Detailed discussion, tables, and figures for average weight product plus secondary packaging in each foodservice product category are presented in Chapter 3 of this report.

Weights of secondary packaging (corrugated boxes and film sleeves) used to package foodservice items for shipment were derived from various sources and methods, including packaging weights reported by foodservice product manufacturers, actual measurements of boxes and film sleeves, and calculated weights based on product dimensions and densities of packaging materials. In order to determine the maximum potential contribution of secondary packaging to foodservice system burdens, the highest weight of packaging from the three methods was analyzed for each foodservice product.

Packaging weights tend to be higher for foamed products such as the polystyrene products analyzed. Because the foamed products are generally thicker than corresponding paperboard products, their incremental stacking height is greater, requiring a larger dimension box or a greater area of film sleeve compared to paperboard products for the same number of product units. This is particularly true for polystyrene foam cups, which are not only thicker than paperboard alternatives but also have a molded rim that increases the incremental stacking height.

Figures illustrating the effect of including the production and disposal of secondary packaging along with the burdens for production and disposal of 10,000 units of average weight product in each foodservice category are shown in Figures ES-17 through ES-20 for total energy and Figures ES-21 through ES-24 for total weight of solid waste. The figures illustrate that the magnitude of secondary packaging effects is greatest for the foam products, as discussed above.

Results for Average Product at 0% and 2% Recycling or Composting (Chapter 4)

Recycling and composting are analyzed as a means of diverting postconsumer product from landfill and extending the material's useful life. National average statistics on foodservice recycling and composting were researched for this study, but no reliable quantitative data could be found. Although individual programs with measurable levels of foodservice product recycling and/or composting may exist in some specific locations, national average rates for recycling and composting of foodservice products are generally acknowledged to be very low. However, it was decided that it would give useful perspective in this study to model the effects of a low national average level of recycling for polystyrene foodservice products and composting of paperboard foodservice products. Two percent was selected as the level to be evaluated.

For plastic products that are recycled in an open-loop system, the burdens for virgin material production, collection of postconsumer products, reprocessing, and disposal of the second product made from the recycled material are shared equally between the two product systems utilizing the material. For paperboard products that are composted, the burdens for the production of the material that is composted are divided between the original use as a foodservice product and the second use as compost. The composting step is the fabrication step for the second product, i.e., compost; thus, the burdens for the composting process are allocated entirely to the compost product. Because compost remains in place where it is applied and is not collected and disposed after use, the amount of material diverted from the solid waste stream for composting is assumed to be permanently diverted from landfill.

Chapter 4 of this report presents detailed results tables, figures, and discussion for average weight products at zero percent and two percent recycling or composting. For all foodservice materials in all categories, two percent recycling or composting reduces total burdens by two percent or less. Because the added burdens for postconsumer material collection and reprocessing largely offset the savings in virgin material production burdens, two percent recycling of polystyrene products results in a very small reduction in total GHG (one-tenth of one percent). On average, two percent composting reduces GHG burdens for the paperboard systems by about one percent.

CONCLUSIONS AND OBSERVATIONS

Range of Product Weights

The following conclusions and observations can be made regarding the full range of product weights analyzed in each foodservice product category. These conclusions are observations are supported by the study results illustrated in Figures ES-1 through ES-24 and summarized in Table ES-3, which is derived from Chapter 2 Tables 2-35 through 2-38.

Energy. The difference between system energy totals is not meaningful for comparisons of polystyrene foam systems with PE-coated paperboard hot cups and cold cups, molded pulp plates, and fluted paperboard clamshells.

Energy differences between systems are meaningful in favor of polystyrene foam products in some comparisons, including PE-coated paperboard hot cups with sleeves and wax-coated paperboard cold cups. The energy comparison of GPPS foam plates and PE-coated paperboard plates is meaningful in favor of paperboard.

For polystyrene foam products, energy of material resource accounts for at least 40 percent of total energy requirements, since fuel resources are the predominant raw materials for the cups. Energy of material resource accounts for only about 10 percent of the total energy for paperboard products with polymer or wax coatings.

The sources of energy are also different for different foodservice product materials. For all polystyrene products, over 90 percent of the total energy is from fossil fuels. For the paper-based foodservice products, about 50 percent of total energy is wood-derived.

Solid Waste. For all foodservice product systems, postconsumer waste is the dominant contributor to both the total weight and total volume of solid waste. The low density of polystyrene foam products result in a low postconsumer weight but a high postconsumer volume compared to other foodservice products.

Total solid waste weight comparisons of polystyrene foam products and alternative products all are meaningful in favor of polystyrene. By volume, the solid waste totals for polystyrene and paper-based products are comparable (or, in the case of plates, polystyrene is higher).

Atmospheric and Waterborne Emissions. No overall conclusions can be made about the air and waterborne emissions released from these systems because no system produces the lowest emissions in every category.

Greenhouse Gases. Comparisons of GHG emissions for EPS cups and alternative cups are inconclusive. For plates, PE-coated paperboard plates compare favorably with all other alternatives, including GPPS. For clamshells, comparisons are inconclusive.

Table ES-3

Summary of Meaningful Differences* Between Product Systems
(This table summarizes conclusions based on the range of product results and percent differences shown in Tables 2-35 through 2-38)

	ENERGY	SOLID WASTE - WEIGHT	SOLID WASTE - VOLUME	GHG
16 OZ HOT CUPS				
EPS and PE-coated Paperboard	Inconclusive (a)	EPS lower	Inconclusive (a), (b)	Inconclusive (a), (b)
EPS and PE-coated Paperboard with Sleeve	EPS lower	EPS lower	EPS lower	Inconclusive (a)
PE-coated Paperboard and PE-coated Paperboard with Sleeve	Inconclusive (a), (b)	Inconclusive (a)	PE-coated ppbd lower	Inconclusive (a)
32 OZ COLD CUPS				
EPS and PE-coated Paperboard	Inconclusive (b)	EPS lower	Inconclusive (a), (b)	Inconclusive (a)
EPS and Wax-coated Paperboard	EPS lower	EPS lower	EPS lower	Inconclusive (a)
PE-coated Paperboard and Wax-coated Paperboard	PE-coated paperboard lower	PE-coated paperboard lower	PE-coated paperboard lower	PE-coated paperboard lower
9-INCH HIGH-GRADE PLATES				
GPPS and PE-coated Paperboard	PE-coated paperboard lower	GPPS lower	PE-coated paperboard lower	PE-coated paperboard lower
GPPS and Molded Pulp	Inconclusive (a), (b)	GPPS lower	Molded pulp lower	Inconclusive (a)
PE-coated Paperboard and Molded Pulp	PE-coated paperboard lower	Inconclusive (a)	Inconclusive (a)	PE-coated paperboard lower
5-INCH SANDWICH-SIZE CLAMSHELLS				
GPPS and Fluted Paperboard	Inconclusive (a), (b)	GPPS lower	Inconclusive (a), (b)	Inconclusive (a)

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003.

*** Meaningful Differences Explanatory Notes:**

As defined and used in this report, a **Meaningful Difference** between different material product systems, for example, EPS as product (1) and PE-coated Paperboard as product (2) occurs when the comparison of low weight product (1) to high weight product (2) AND the comparison of high weight product (1) to low weight product (2) BOTH meet the % difference criteria:

For **energy**, BOTH comparisons must be either <-10% OR >10%; that is, both % difference values must have the same sign (+ or -) and absolute value >10%.

For **solid waste by weight**, **solid waste by volume**, and **GHG**, BOTH comparisons must be either <-25% OR >25%; that is, both % difference values must have the same sign (+ or -) and absolute value >25%.

The difference between systems is considered inconclusive if:

(a) At least one of the % differences is less than the meaningful difference criteria, and/or

(b) One % difference is positive and the other is negative, indicating an overlap in results for the two systems.

Percent difference is defined as the difference between the system totals divided by the average of the two system totals.
In the % difference comparisons, low (1) is the low value reported for the system designated (1) in the comparison; high (2) is the high value for the system designated (2) in the comparison.
In the % difference comparisons, high (1) is the high value reported for the system designated (1) in the comparison; low (2) is the low value for the system designated (2) in the comparison.
A negative % difference indicates that system(1) is lower; a positive % difference indicates that system(2) is lower.
Percent differences for the product comparisons can be found in Chapter 2 Tables 2-35 through 2-38.

Secondary Packaging Contribution

Because foamed products (EPS, GPPS) are generally thicker than corresponding paperboard products, their incremental stacking height is greater, requiring a larger dimension box or a greater area of film sleeve compared to paperboard products for the same number of product units. As a result, the weight of secondary packaging and the corresponding environmental burdens tend to be higher for foamed products.

On average, secondary packaging increases the environmental burdens for average weight paperboard products by 4 to 12 percent, while packaging adds 14 to 46 percent to the environmental burdens for average weight foam products (EPS, GPPS).

Effect of Low Level of Recycling/Composting

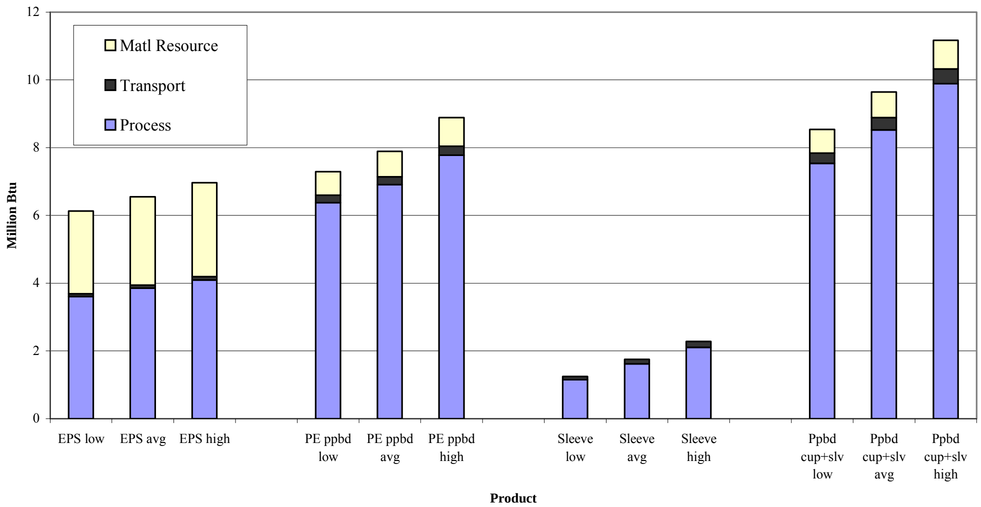
For all foodservice materials in all categories, two percent recycling or composting reduces total environmental burdens by two percent or less. The percent reduction for recycling is less than one percent, since some of the savings in virgin material production burdens are offset by the burdens for collection and reprocessing of postconsumer material.

STUDY LIMITATIONS

Participation by some industry stakeholders in this study was limited despite extensive and repeated efforts to secure participation of all stakeholder industries. In particular, the paperboard industry, which is represented in every foodservice product category studied, declined to participate in any way. Thus, the data quality goals of the study could not be realized as originally intended. However, the environmental profiles presented in this report for non-participating industries were developed using the best and most current data available from Franklin Associates' U.S. life cycle database, updated to the extent possible to represent current technology.

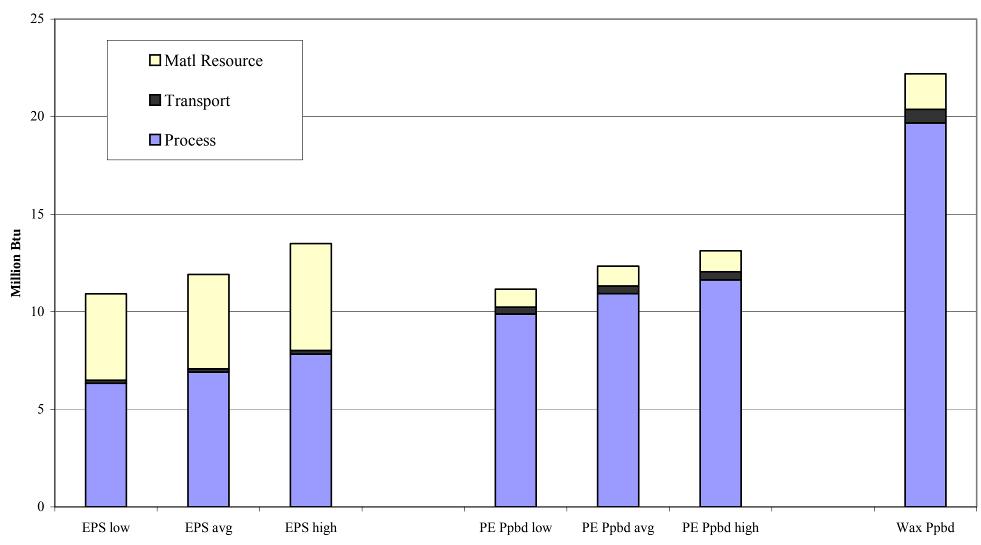
Although the methodology for this study is compliant with ISO standards, it was not possible to meet some of the ISO data quality requirements due to the limited participation by some industries. In particular, this study does not meet all the stringent data quality requirements set out in the ISO 14040 standards for life cycle studies used to make general comparative assertions regarding the overall environmental superiority or preferability of one system relative to a competing system or systems. The authors discourage the use of this study to make general comparative assertions about overall environmental performance of the systems studied. The use of this study to make public comparative assertions is limited to specific statements that are supported by the study results.

Figure ES-1. Energy by Category for 10,000 16-oz Hot Cups (Million Btu)



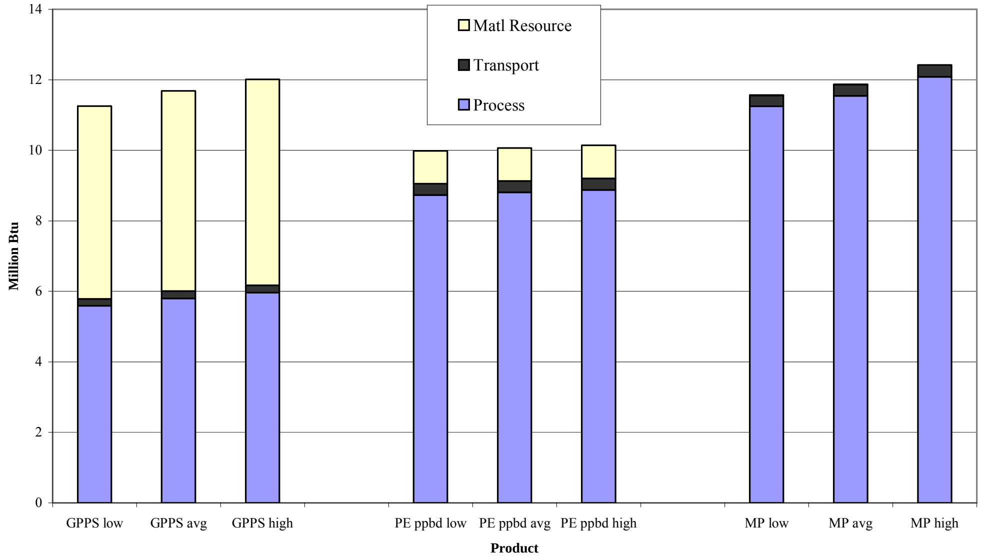
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in energy results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 10%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-32 for a summary of meaningful differences between products.

Figure ES-2. Energy by Category for 10,000 32-oz Cold Cups (Million Btu)



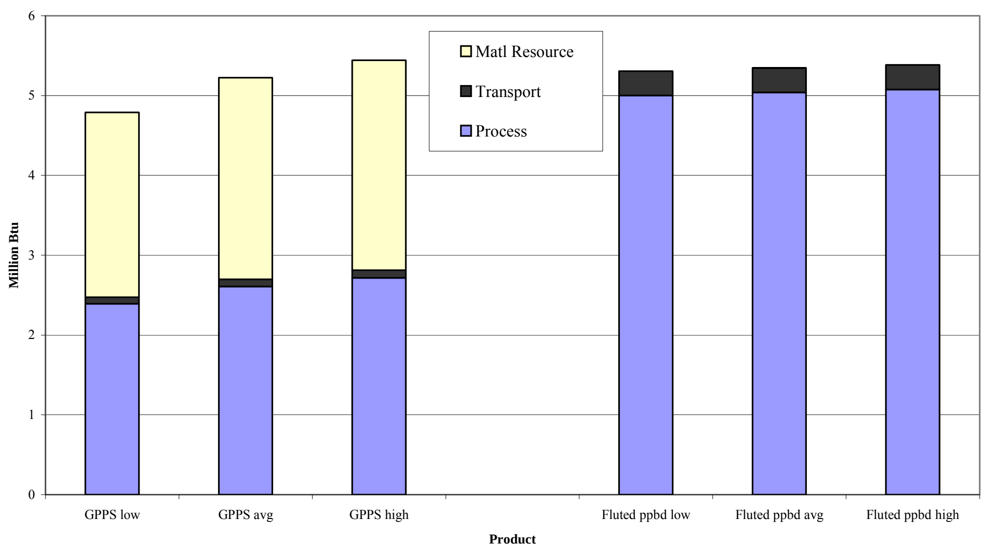
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in energy results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 10%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-33 for a summary of meaningful differences between products.

Figure ES-3. Energy by Category for 10,000 9-inch High-Grade Plates (Million Btu)



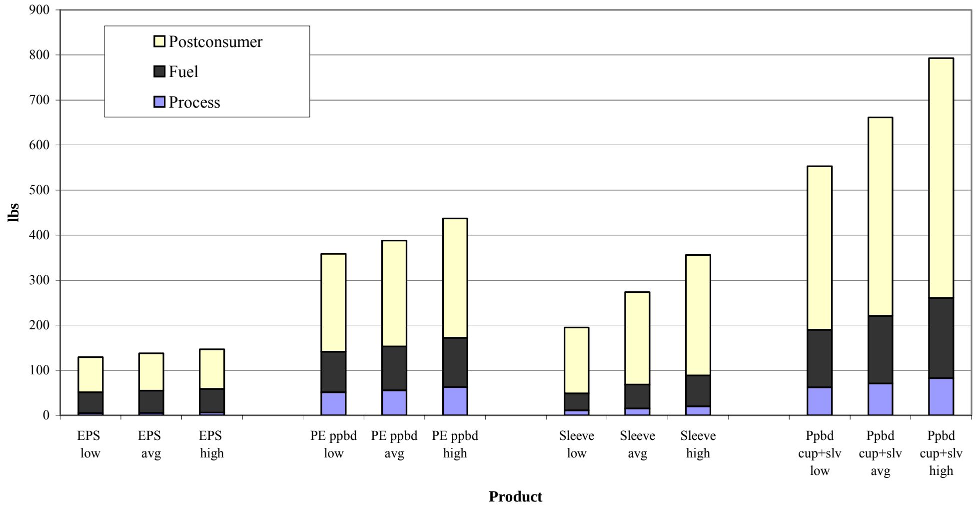
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in energy results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 10%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-34 for a summary of meaningful differences between products.

Figure ES-4. Energy by Category for 10,000 5-inch Sandwich-Size Clamshells (Million Btu)



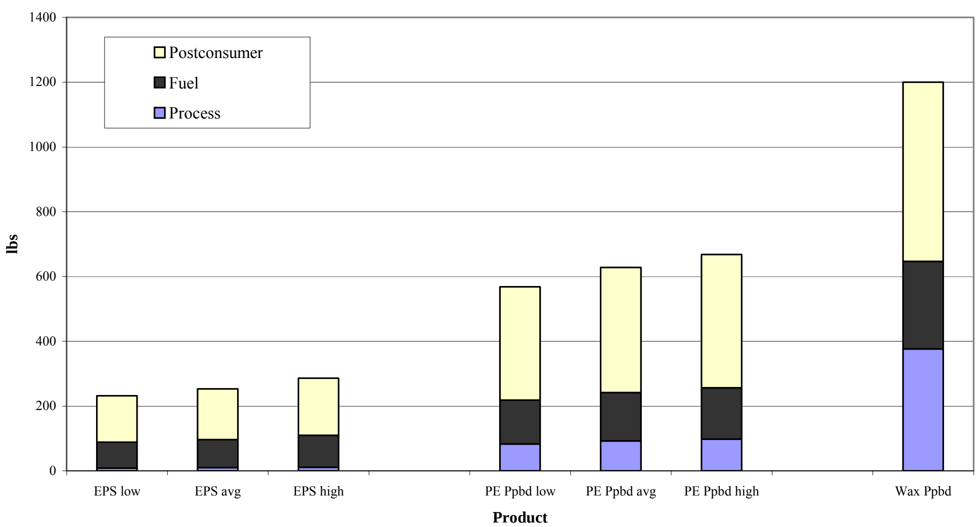
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in energy results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 10%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-35 for a summary of meaningful differences between products.

Figure ES-5. Solid Waste by Weight for 10,000 16-oz Hot Cups (Pounds)



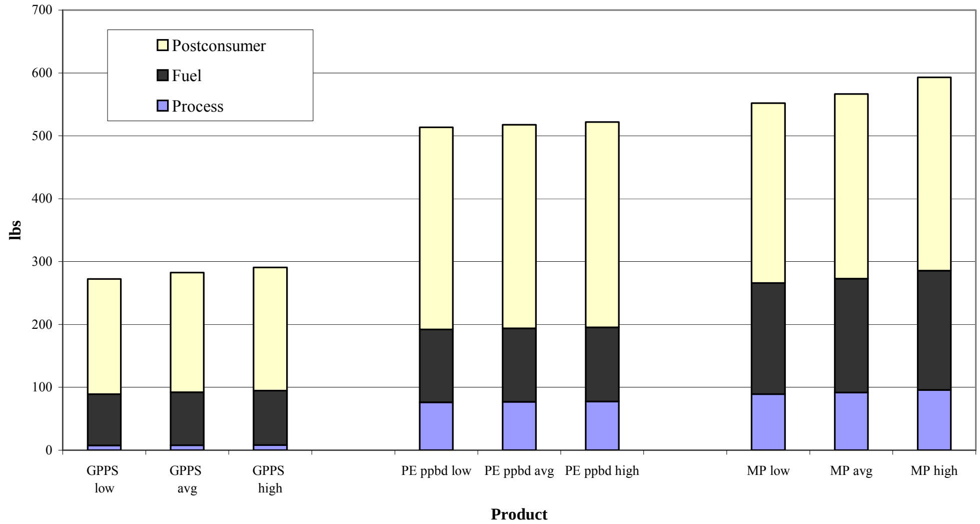
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-32 for a summary of meaningful differences between products.

Figure ES-6. Solid Waste by Weight for 10,000 32-oz Cold Cups (Pounds)



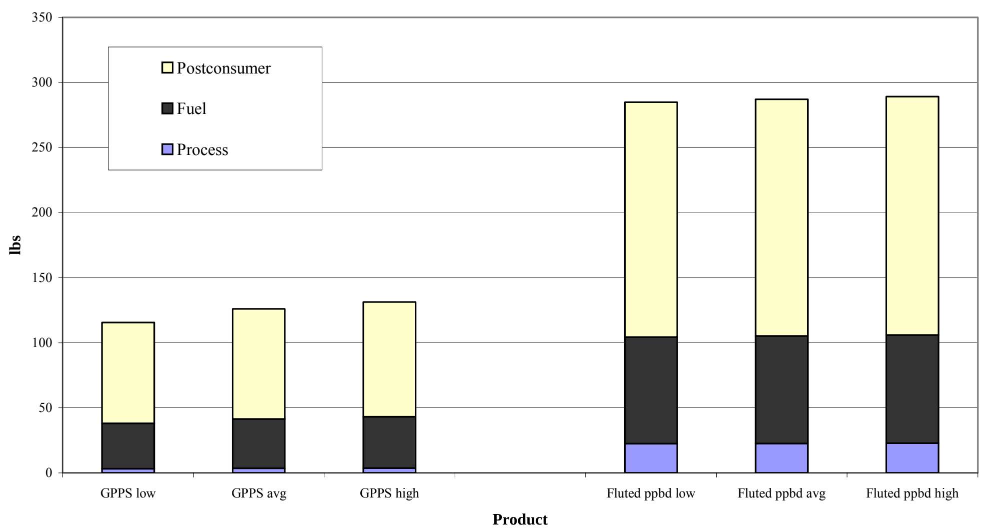
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-33 for a summary of meaningful differences between products.

Figure ES-7. Solid Waste by Weight for 10,000 9-inch High Grade Plates (Pounds)



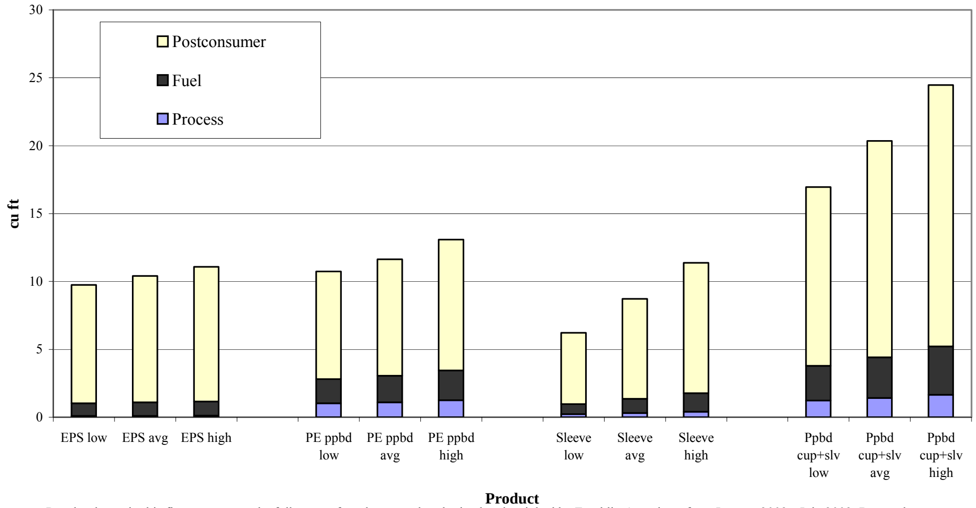
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-34 for a summary of meaningful differences between products.

Figure ES-8. Solid Waste by Weight for 10,000 5-inch Sandwich-Size Clamshells (Pounds)



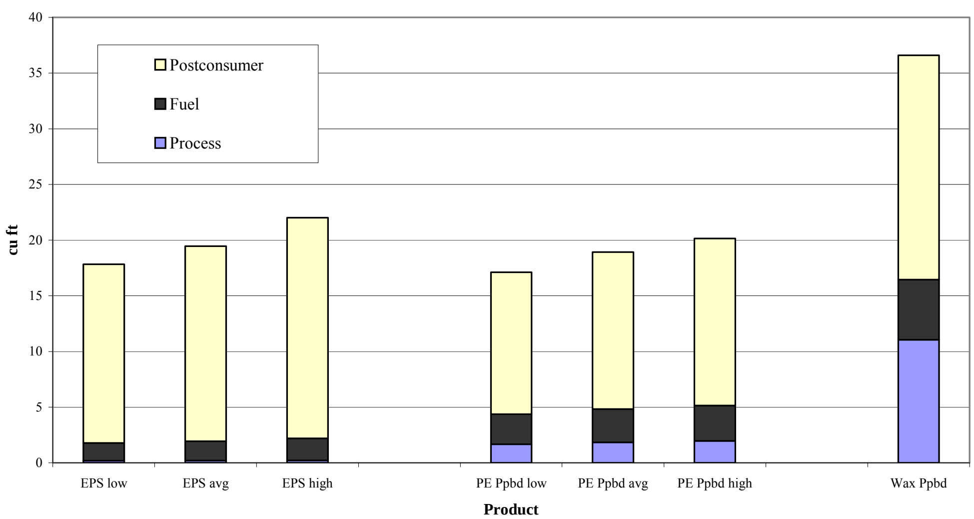
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-35 for a summary of meaningful differences between products.

Figure ES-9. Solid Waste by Volume for 10,000 16-oz Hot Cups (cubic feet)



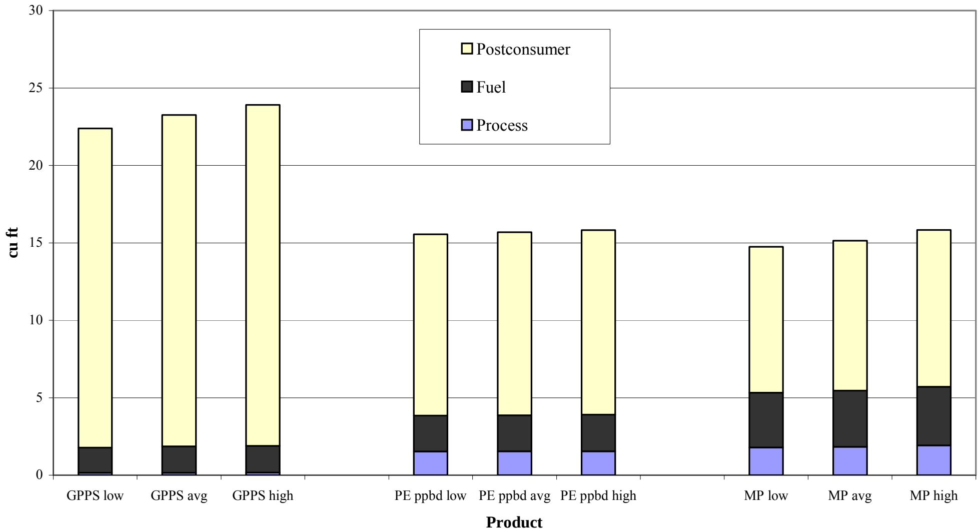
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-32 for a summary of meaningful differences between products.

Figure ES-10. Solid Waste by Volume for 10,000 32-oz Cold Cups (cubic feet)



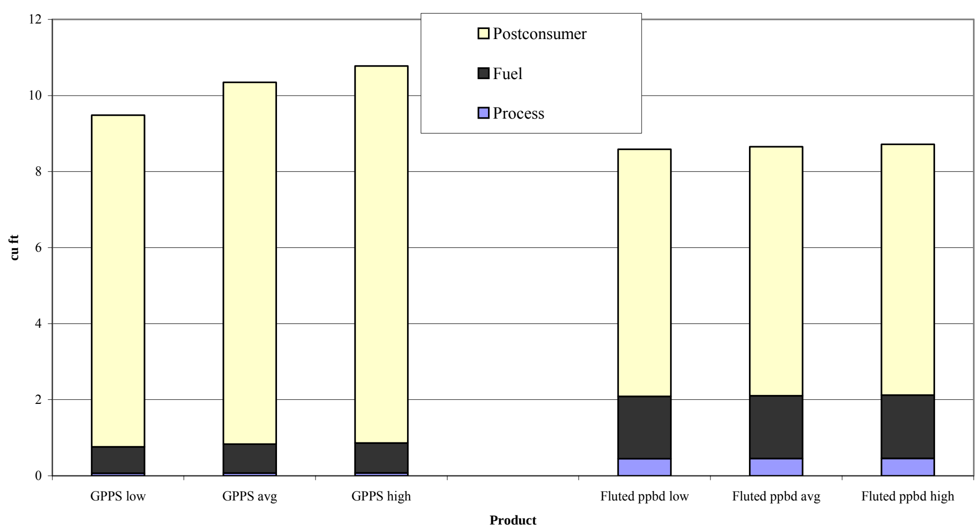
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-33 for a summary of meaningful differences between products.

Figure ES-11. Solid Waste by Volume for 10,000 9-inch High-Grade Plates (cubic feet)



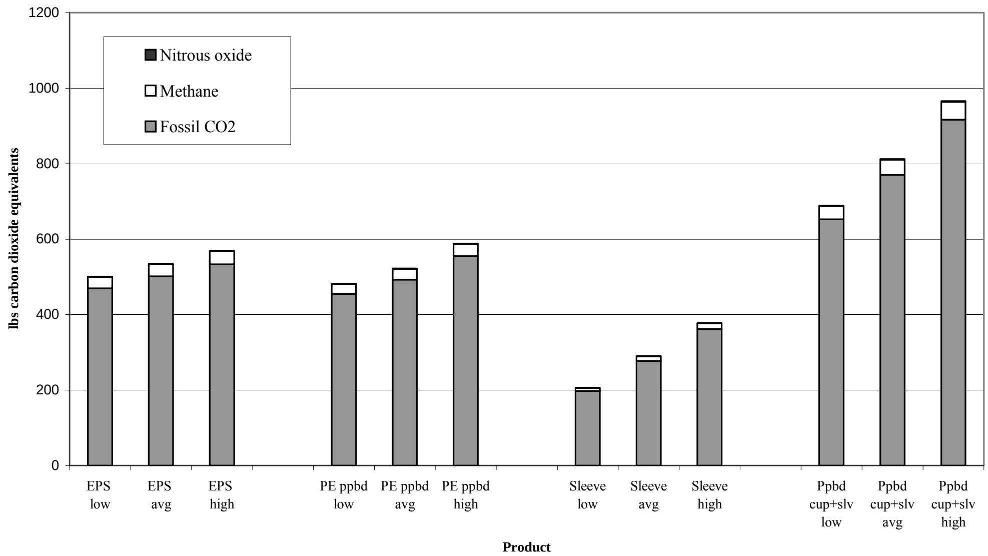
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-34 for a summary of meaningful differences between products.

Figure ES-12. Solid Waste by Volume for 10,000 5-inch Sandwich-Size Clamshell (cubic feet)



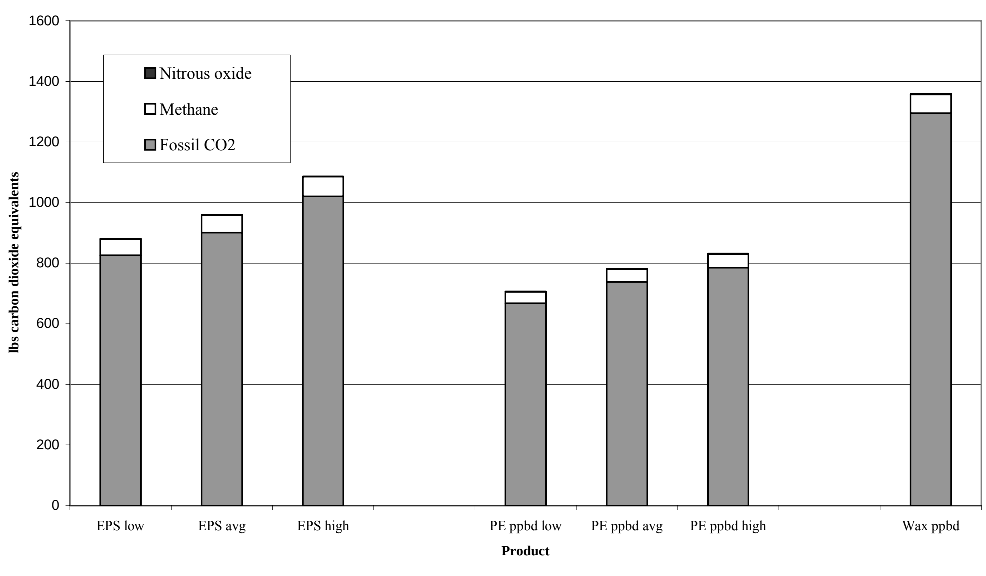
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-35 for a summary of meaningful differences between products.

Figure ES-13. Atmospheric Emissions for 10,000 16-oz Hot Cups (lbs carbon dioxide equivalents)



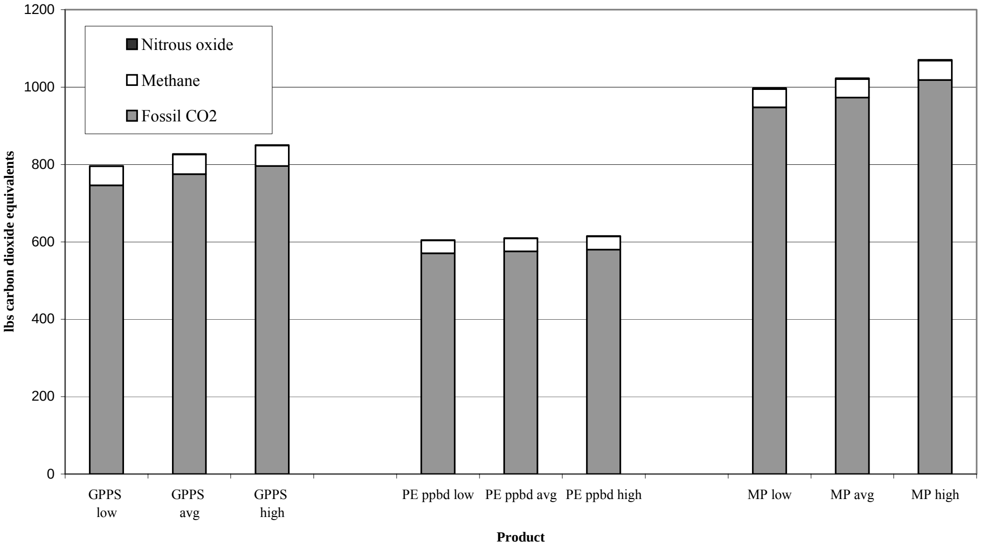
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in GHG results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-32 for a summary of meaningful differences between products.

Figure ES-14. Atmospheric Emissions for 10,000 32-oz Cold Cups (lbs carbon dioxide equivalents)



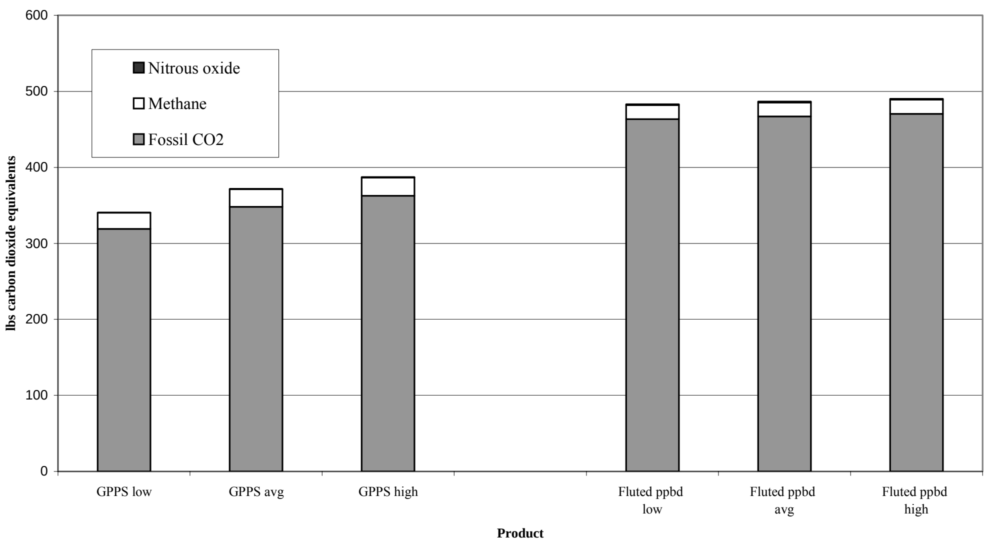
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in GHG results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-33 for a summary of meaningful differences between products.

Figure ES-15. Atmospheric Emissions for 10,000 9-inch High-Grade Plates (lbs carbon dioxide equivalents)



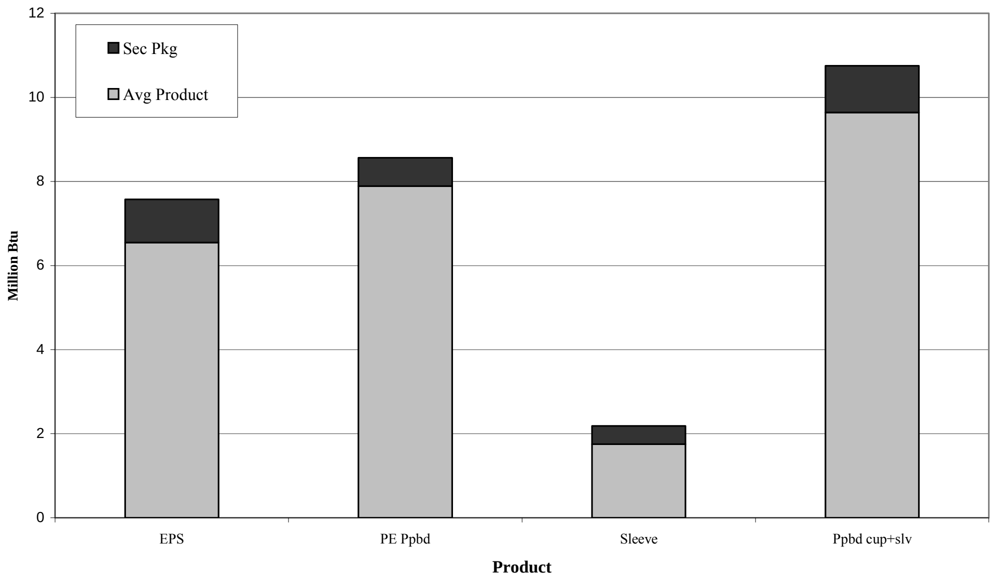
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in GHG results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-34 for a summary of meaningful differences between products.

Figure ES-16. Atmospheric Emissions for 10,000 5-inch Sandwich-Size Clamshells (lbs carbon dioxide equivalents)



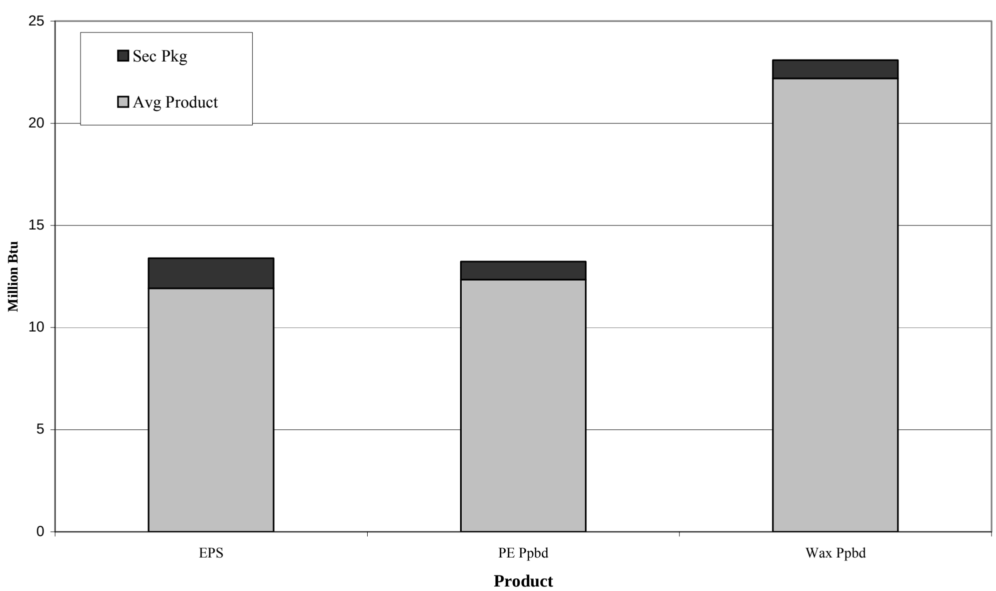
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in GHG results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-35 for a summary of meaningful differences between products.

Figure ES-17. Total Energy for 10,000 16-oz Hot Cups and Secondary Packaging (Million Btu)



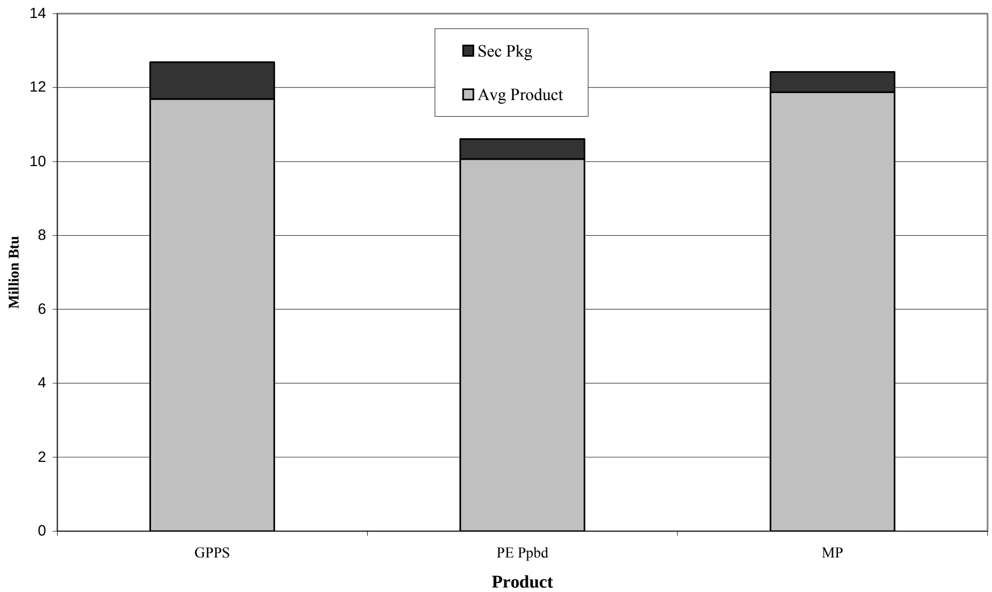
Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure ES-18. Total Energy for 10,000 32-oz Cold Cups and Secondary Packaging (Million Btu)



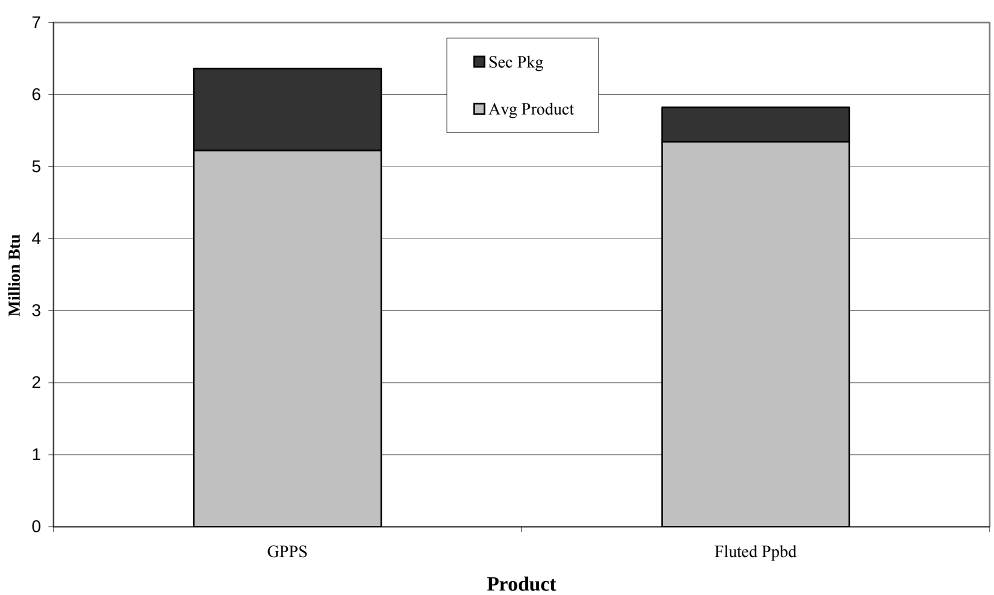
Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure ES-19. Total Energy for 10,000 9-inch High-Grade Plates and Secondary Packaging (Million Btu)



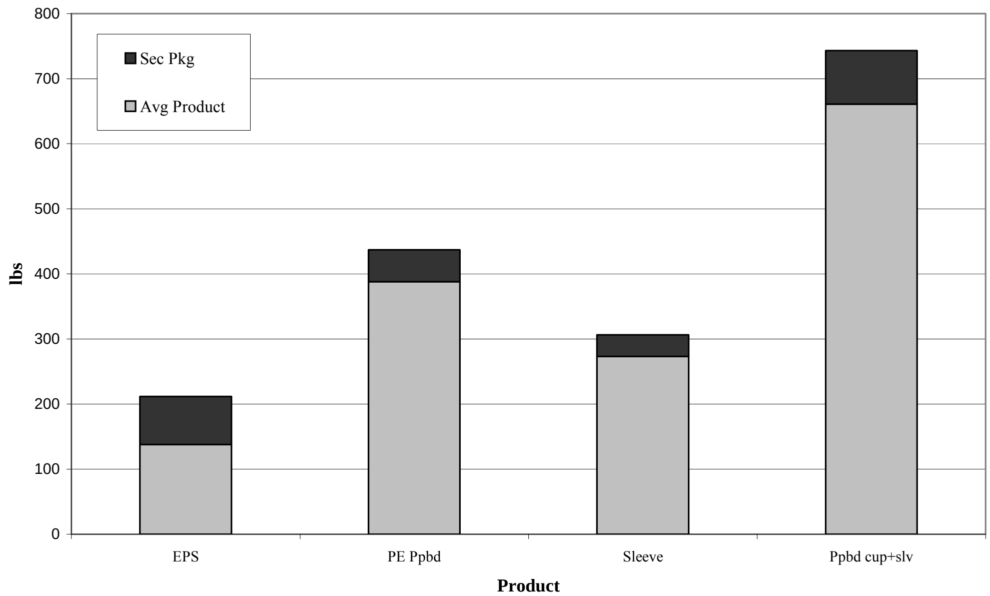
Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure ES-20. Total Energy for 10,000 5-inch Sandwich-Size Clamshells and Secondary Packaging (Million Btu)



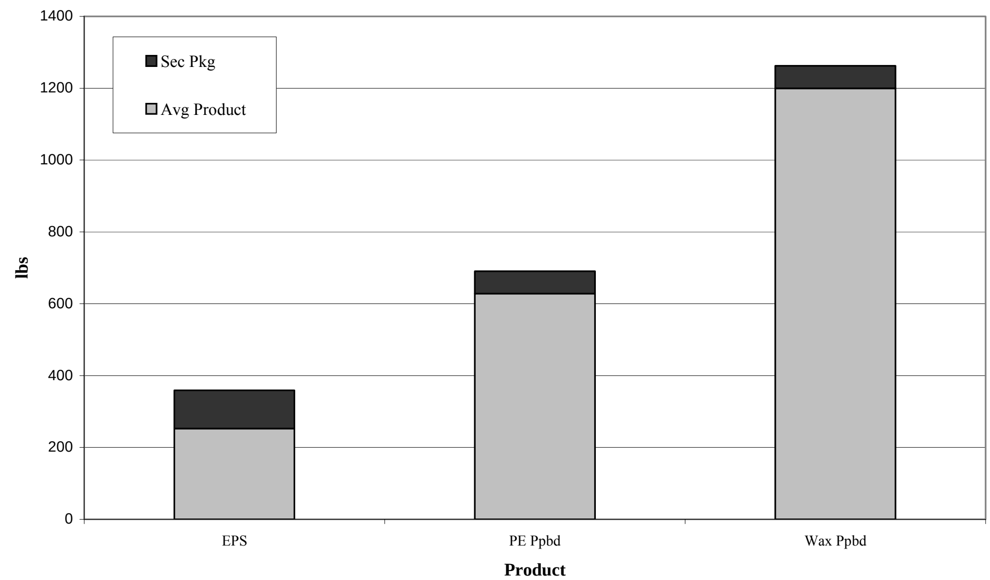
Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure ES-21. Solid Waste by Weight for 10,000 16-oz Hot Cups and Secondary Packaging (lbs)



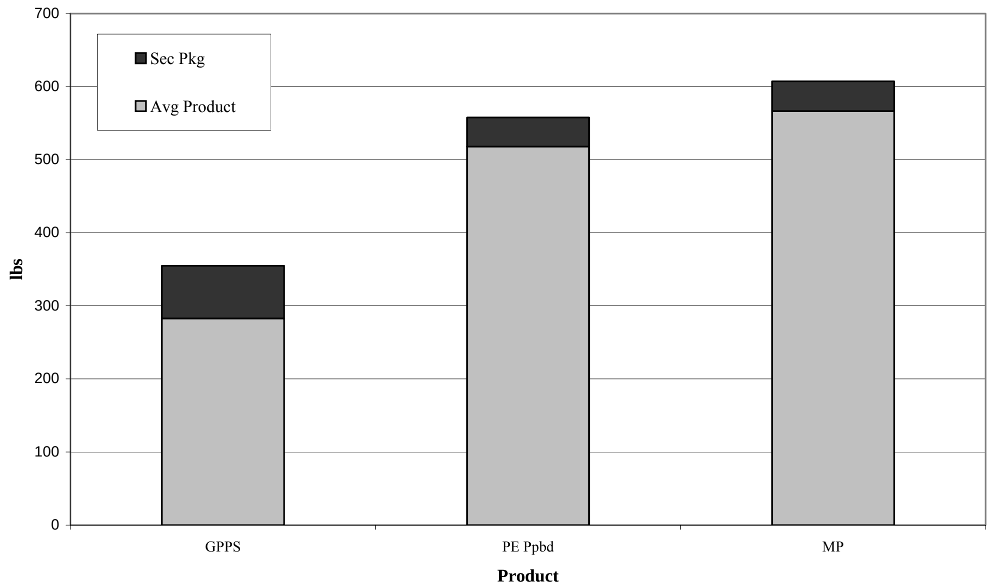
Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure ES-22. Solid Waste by Weight for 10,000 32-oz Cold Cups and Secondary Packaging (lbs)



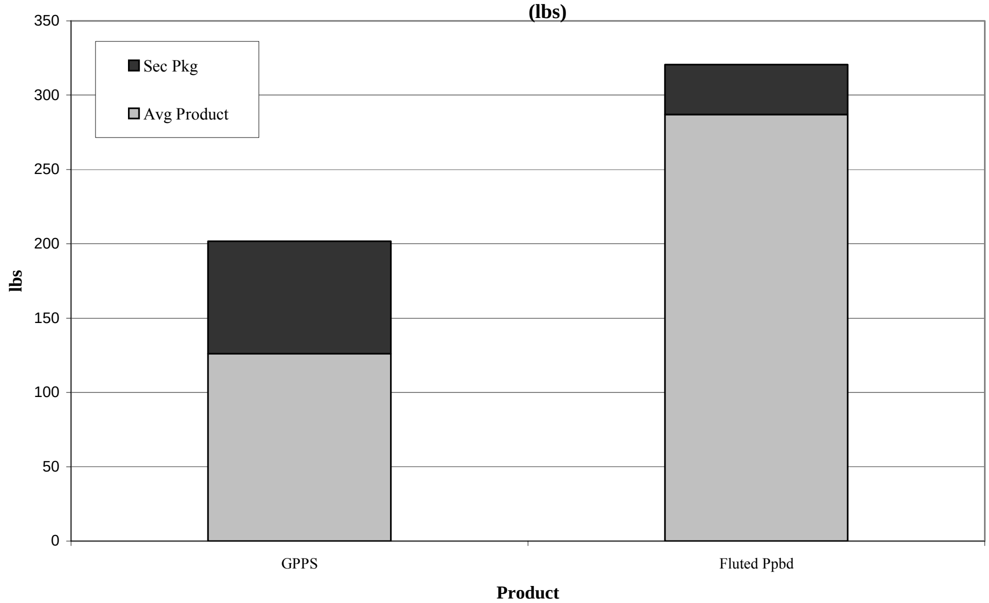
Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure ES-23. Solid Waste by Weight for 10,000 9-inch High-Grade Plates and Secondary Packaging (lbs)



Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure ES-24. Solid Waste by Weight for 10,000 5-inch Sandwich-Size Clamshells and Secondary Packaging (lbs)



Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

CHAPTER 1

STUDY APPROACH AND METHODOLOGY

OVERVIEW

The resource and environmental profile analysis presented in this study quantifies the total energy requirements, energy sources, atmospheric pollutants, waterborne pollutants, and solid waste resulting from the production, secondary packaging, and disposal of polystyrene and paperboard foodservice products. The methodology used for this inventory is consistent with the methodology for Life Cycle Inventory (LCI)[1] as described by the Society of Environmental Toxicology and Chemistry (SETAC) and in the ISO 14040 Standard documents.

This analysis is not an impact assessment. It does not attempt to determine the fate of emissions, or the relative risk to humans or to the environment due to emissions from the systems. In addition, no judgments are made as to the merit of obtaining natural resources from various sources.

A life cycle inventory quantifies the energy consumption and environmental emissions (i.e., atmospheric emissions, waterborne wastes, and solid wastes) for a given product based upon the study boundaries established. The unique feature of this type of analysis is its focus on the entire life cycle of a product, from raw material acquisition to final disposition, rather than on a single manufacturing step or environmental emission. Figure 1-1 illustrates the general approach used in an LCI analysis.

The information from this type of analysis can be used as the basis for further study of the potential improvement of resource use and environmental emissions associated with a given product. It can also pinpoint areas in the life cycle of a product or process where changes would be most beneficial in terms of reduced energy use or environmental emissions.

Study Goal and Intended Audience

This LCI of selected polystyrene foam and paperboard foodservice products is an expanded update of a 1990 LCI on foam polystyrene and bleached paperboard foodservice items. The study is being updated to incorporate the following changes that have occurred since the original study:

- Additional products/materials evaluated
- Improvements in manufacturing processes and energy usage

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1 SETAC. 1991. **A Technical Framework for Life-Cycle Assessment.** Workshop report from the Smugglers Notch, Vermont, USA, workshop held August 18-23, 1990.

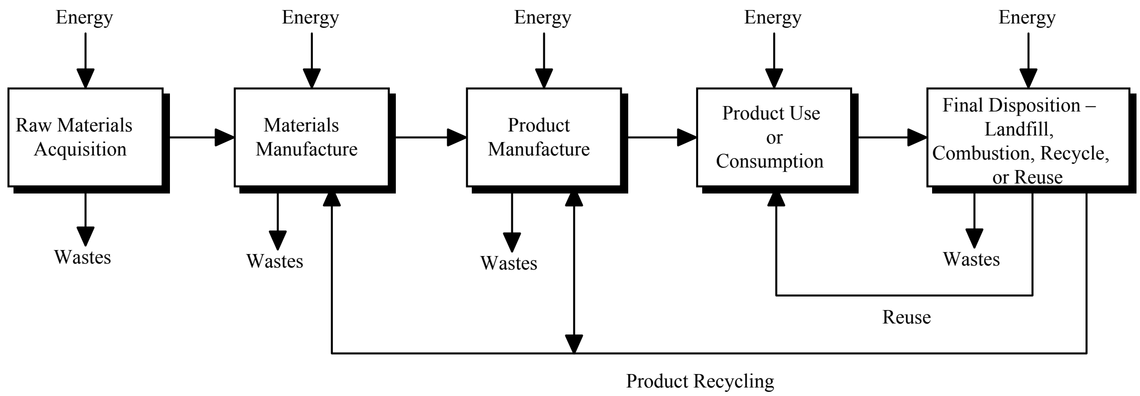

Figure 1-1. General materials flow for "cradle-to-grave" analysis of a product system.

- Development of ISO standards for conducting life cycle inventory studies and making comparative assessments or claims in the marketplace.

The goal of the analysis is to provide foodservice industry stakeholders with the information needed to better understand the current environmental profiles of the foodservice products studied. This type of information can be used to target efforts to improve the environmental profiles of foodservice products.

The intent of the study was to develop life cycle profiles for the product systems using the most up-to-date data available from the representative industries producing each type of foodservice product. However, industry participation in the study was very limited despite extensive and repeated efforts to secure participation of all stakeholder industries. Environmental profiles presented in this report for participating industries were developed using the data those companies provided for this study. For non-participating industries, the environmental profiles presented in this report were developed using the best and most current data available from Franklin Associates' U.S. life cycle database, updated to the extent possible to represent current technology using the data resources available.

Although the original study goal also included consideration of newly developed materials, as the study progressed it became necessary to change this goal. The original intent of the study was to include biobased foodservice products, but samples were only available from one producer. Since biobased products tend to have unique proprietary formulations, no individual biobased product can be considered representative of biobased products in general. Thus, the decision was made to change the original goal by dropping biobased products from the study.

The primary intended audience for the report is foodservice industry stakeholders; however, the final report will be publicly available upon request to any interested party.

Study Scope and Boundaries

An LCI encompasses the entire life cycle of a product, from raw material acquisition to final disposition, rather than a single manufacturing step or environmental emission. Accordingly, the study boundaries of this LCI of foodservice products includes the following elements:

- Raw materials acquisition
- Production of intermediate materials for foodservice products and secondary packaging.
- Fabrication of foodservice products and secondary packaging.
- Disposal of foodservice products and secondary packaging, including a scenario for a low level of recycling and composting of foodservice products at end of life.

Detailed process flow diagrams, along with brief descriptions of processes for each foodservice product system can be found in the Appendices (separate document). The LCI quantifies energy and resource use, solid waste, and individual atmospheric and waterborne emissions for all stages listed above in the life cycle of each foodservice product system. Transportation of the packaged product to customers and use by consumers is not included in the study.

The weights and compositions of the foodservice products and secondary packaging are representative of the full range of product samples obtained and weighed by Franklin Associates from January 2003 through July 2003.

This study was conducted to analyze those types of foodservice products that would most closely compete with polystyrene foam products. The LCI analyzes polystyrene foam and paperboard foodservice items that are available in each of the following categories: cups for hot and cold beverage, plates, and sandwich clamshells.

The scope of the analysis reflects a modification from the scope originally defined for the study, which included hot and cold cups, plates, clamshells, and meat/poultry trays. In addition, the study goal changed to remove consideration of newly developed materials (i.e., biobased products). There are two principal reasons for the change in goal and scope:

- Meat/poultry trays were excluded from the study since few non-polystyrene foam alternate material trays exist in the marketplace; and

- No biobased foodservice products were included in the analysis. While there are various biobased foodservice products available in the marketplace today, samples comparable to polystyrene foam were available from only one producer and in only two of the four product categories (plates, clamshells). It was decided that such a limited sample would not be acceptable as the basis for a viable ISO-compliant comparative analysis. In this case, the limited availability of biobased samples would result in comparison of a single specific biobased product weight and formulation with average generic weight and formulation data for the alternative material products in the plate and clamshell categories.

The scope of the project does not include testing products for strength, insulating properties, etc., nor developing data on consumer use practices. The scope of the study does not include forecasting lightweighting trends or future technology improvements for any of the foodservice products studied.

LIFE CYCLE INVENTORY METHODOLOGY

Key elements of the LCI methodology include the study boundaries, resource inventory (raw materials and energy), emissions inventory (atmospheric, waterborne, and solid waste), and disposal practices. Additional discussion on the methodology used to calculate product life cycle resource and environmental emissions is presented in the following section of this chapter. The LCI study boundaries for disposable foodservice products were discussed in the previous section of this chapter.

Franklin Associates developed a methodology for performing resource and environmental profile analyses (REPA), commonly called life cycle inventories. This methodology has been documented for the U.S. Environmental Protection Agency and is incorporated in the EPA report **Product Life-Cycle Assessment Inventory Guidelines and Principles.** The methodology is also consistent with the life cycle inventory methodology described in two workshop reports produced by the Society of Environmental Toxicology and Chemistry (SETAC): **A Technical Framework for Life-cycle Assessment, January 1991** and **Guidelines for Life-Cycle Assessment: 'A Code of Practice', 1993,** as well as the ISO 14040 standards. The data presented in this report were developed using this methodology, which has been in use for over 30 years.

Figure 1-2 illustrates the basic approach to data development for each major process in an LCI analysis. This approach provides the essential building blocks of data used to construct a complete resource and environmental emissions inventory profile for the entire life cycle of a product. Using this approach, each individual process included in the study is examined as a closed system, or "black box", by fully accounting for all resource inputs and process outputs associated with that particular process. Resource inputs accounted for in the LCI include raw materials and energy use, while process outputs accounted for include products manufactured and environmental emissions to land, air, and water.

For each process included in the study, resource requirements and environmental emissions are determined and expressed in terms of a standard unit of output. A standard unit of output is used as the basis for determining the total life cycle resource requirements and environmental emissions of a product.

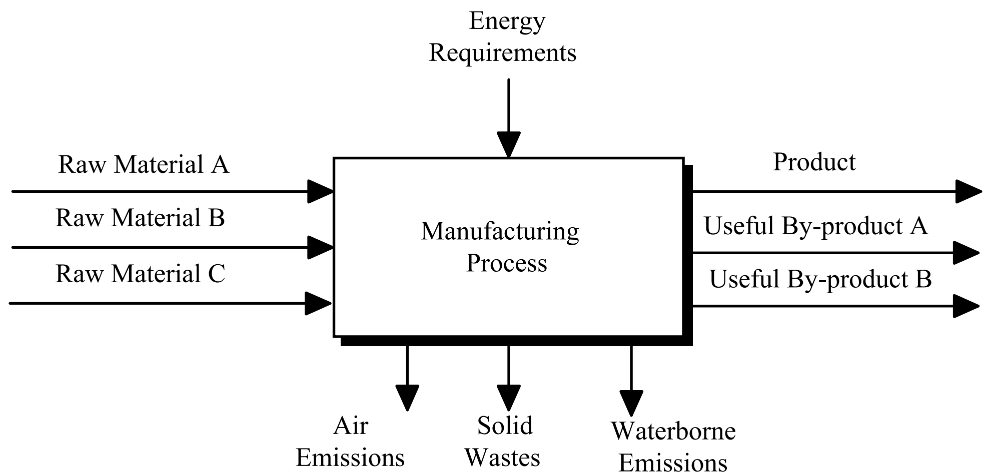

Figure 1-2. "Black box" concept for developing LCI data.

Material Requirements

Once the LCI study boundaries have been defined and the individual processes identified, a material balance is performed for each individual process. This analysis identifies and quantifies the input raw materials required per standard unit of output, such as 1,000 pounds, for each individual process included in the LCI. The purpose of the material balance is to determine the appropriate weight factors used in calculating the total energy requirements and environmental emissions associated with the foodservice product systems. Energy requirements and environmental emissions are determined for each process and expressed in terms of the standard unit of output.

Once the detailed material balance has been established for a standard unit of output for each process included in the LCI, a comprehensive material balance for the entire life cycle of each product system is constructed. This analysis determines the quantity of materials required from each process to produce and dispose of the required quantity of each system component and is typically illustrated as a flow chart. Data must be gathered for each process shown in the flow diagram, and the weight relationships of inputs and outputs for the various processes must be developed.

Energy Requirements

The average energy requirements for each process identified in the LCI are first quantified in terms of fuel or electricity units, such as cubic feet of natural gas, gallons of diesel fuel, or kilowatt-hours (kWh) of electricity. The fuel used to transport raw materials to each process is included as a part of the LCI energy requirements. Transportation energy requirements for each step in the life cycle are developed in the conventional units of ton-miles by each transport mode (e.g. truck, rail, barge, etc.).

Government statistical data for the average efficiency of each transportation mode are used to convert from ton-miles to fuel consumption.

Once the fuel consumption for each industrial process and transportation step is quantified, the fuel units are converted from their original units to an equivalent Btu value based on standard conversion factors.

The conversion factors have been developed to account for the energy required to extract, transport, and process the fuels and to account for the energy content of the fuels. The energy to extract, transport, and process fuels into a usable form is labeled precombustion energy. For electricity, precombustion energy calculations include adjustments for the average efficiency of conversion of fuel to electricity and for transmission losses in power lines based on national averages.

The LCI methodology assigns a fuel-energy equivalent to raw materials that are derived from fossil fuels. Therefore, the total energy requirement for coal, natural gas, or petroleum based materials includes the fuel-energy of the raw material (called energy of material resource or inherent energy). In this study, this applies to the crude oil and natural gas used to produce plastics and wax coatings. No fuel-energy equivalent is assigned to combustible materials, such as wood, that are not major fuel sources in this country.

The Btu values for fuels and electricity consumed in each industrial process are summed and categorized into an energy profile according to the six basic energy sources listed below:

- Natural gas
- Petroleum
- Coal
- Nuclear
- Hydropower
- Other

The “other” category includes nonconventional sources, such as solar, biomass and geothermal energy. Also included in the LCI energy profile are the Btu values for all transportation steps and all fossil fuel-derived raw materials. Energy requirements for each foodservice product system examined in this LCI are presented in Chapter 2. Energy requirements for secondary packaging are addressed in Chapter 3.

Environmental Emissions

Environmental emissions are categorized as atmospheric emissions, waterborne wastes, and solid wastes and represent discharges into the environment after the effluents pass through existing emission control devices. Similar to energy, environmental emissions associated with processing fuels into usable forms are also included in the inventory. When efforts to obtain actual industry emissions data fail, published emissions standards are used as the basis for determining environmental emissions.

The different categories of atmospheric and waterborne emissions are not totaled in this LCI because it is widely recognized that various substances emitted to the air and water differ greatly in their effect on the environment. Individual environmental emissions for each foodservice product system are presented in Chapter 2.

Atmospheric Emissions. These emissions include substances classified by regulatory agencies as pollutants, as well as selected nonregulated emissions such as carbon dioxide. Atmospheric emissions associated with the combustion of fuel for process or transportation energy, as well as process emissions, is included in this LCI. Emissions are reported as pounds of pollutant per unit of product output. The amounts reported represent actual discharges into the atmosphere after the effluents pass through existing emission control devices. Some of the more commonly reported atmospheric emissions are: carbon dioxide, carbon monoxide, hydrocarbons, nitrogen oxides, particulates, and sulfur oxides.

Waterborne Wastes. As with atmospheric emissions, waterborne wastes include all substances classified as pollutants. Waterborne wastes are reported as pounds of pollutant per unit of product output. The values reported are the average quantity of pollutants still present in the wastewater stream after wastewater treatment and represent discharges into receiving waters. This includes both process-related and fuel-related waterborne wastes. Some of the most commonly reported waterborne wastes are: acid, ammonia, biochemical oxygen demand (BOD), chemical oxygen demand (COD), chromium, dissolved solids, iron, and suspended solids.

Solid Wastes. This category includes solid wastes generated from all sources that are landfilled or disposed of in some other way, including ash from postconsumer waste that is incinerated. It does not include materials that are recovered for reuse or recycling.

When performing an LCI, typically both postconsumer and industrial wastes are considered. Postconsumer solid wastes are the foodservice products that are not recycled. Examples of industrial solid wastes are wastewater treatment sludge, solids collected in air pollution control devices, trim or waste materials from manufacturing operations that are not recycled, and fuel combustion residues such as the ash generated by burning coal or wood.

LCI PRACTITIONER METHODOLOGY VARIATION

There is general consensus among life cycle practitioners on the fundamental methodology for performing LCIs.[2] However, for some specific aspects of life cycle inventory, there is some minor variation in methodology used by experienced

[2] SETAC. 1993. **Guidelines for Life-Cycle Assessment: A “Code of Practice.”** 1st ed. Workshop report from the Sesimbra, Portugal, workshop held March 31 through April 3, 1993.

practitioners. These areas include the method used to allocate energy requirements and environmental releases among more than one useful product produced by a process and the method used to account for the energy contained in material feedstocks. LCI practitioners vary to some extent in their approaches to these issues. The following sections describe the approach to each issue used in this study.

Coproduct Credit

One unique feature of life cycle inventories is that the quantification of inputs and outputs are related to a specific amount of product from a process. However, controversy in LCI studies often occurs because it is sometimes difficult or impossible to identify which inputs and outputs are associated with one of multiple products from a process. The practice of allocating inputs and outputs among multiple products from a process is often referred to as "coproduct credit"[3] or "partitioning"[4].

Coproduct 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 coproduct credit is less desirable than being able to identify which inputs lead to particular outputs.

The method of allocating energy and emissions among multiple products is subject to much discussion among LCI researchers, and various methods of calculating this ratio are discussed in literature.[5,6,7,8,9] In the ISO 14040 series of standards on life cycle inventory, 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. In this study, when allocation cannot be avoided, allocation of flows is based on the relative **mass** outputs of products.

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3 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.

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

5 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.

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

7 SETAC. 1993. **Guidelines for Life-Cycle Assessment: A "Code of Practice."** 1st ed. Workshop report from the Sesimbra, Portugal, workshop held March 31 through April 3, 1993.

8 **Life-Cycle Assessment: Inventory Guidelines and Principles.** Risk Reduction Engineering Laboratory, Office of Research and Development, United States Environmental Protection Agency. EPA/600/R-92/245. February, 1993.

9 **Product Life Cycle Assessment–Principles and Methodology.** NORD 1992:9. Nordic Council of Ministers, Copenhagen. ISBN 92 9120 012 3.

Energy of Material Resource

For some raw materials, such as petroleum, natural gas, and coal, the amount consumed in all applications as fuel far exceeds the amount consumed as raw materials (feedstock) for products. The primary use of these materials is for energy. The total amount of these materials can be viewed as an energy pool or reserve. This concept is illustrated in Figure 1-3.

The use of a certain amount of these materials as feedstocks for products, rather than as fuels, removes that amount of material from the energy pool, thereby reducing the amount of energy available for consumption. This use of available energy as feedstock is called the “energy of material resource” and is included in the inventory. The energy of material resource represents the amount the energy pool is reduced by the consumption of fuel materials as raw materials in products and is quantified in energy units.

The energy of material resource is the energy content of the fuel materials *input* as raw materials or feedstocks. The energy of material resource assigned to a material is *not* the energy value of the final product, but is the energy value of the raw material at the point of extraction from its natural environment. For fossil fuels, this definition is straightforward. For instance, petroleum is extracted in the form of crude oil. Therefore, the energy of material resource for petroleum is the higher heating value of crude oil.

Once the feedstock is converted to a product, there is energy content that could be recovered, for instance through combustion in a waste-to-energy waste disposal facility. The energy that can be recovered in this manner is always somewhat less than the feedstock energy because the steps to convert from a gas or liquid to a solid material reduces the amount of energy left in the product itself.

The materials which are primarily used as fuels can change over time and with location. In the industrially developed countries included in this analysis, these materials are petroleum, natural gas, coal, and nuclear material. While some wood is burned for energy, the primary uses for wood are for products such as paper and lumber. Similarly, some oleochemical oils such as palm oils are burned for fuels, often referred to as “bio-diesel.” However, as in the case of wood, their primary consumption is as raw materials for products such as soaps, surfactants, cosmetics, etc.

DATA

The accuracy of the study is only as good as the quality of input data. The development of methodology for the collection of data is essential to obtaining quality data. Careful adherence to that methodology determines not only data quality but also objectivity. Methods for quantifying and communicating data quality including data uncertainty are being established. Franklin Associates has developed a methodology for incorporating data quality and uncertainty into LCI calculations. Data quality and uncertainty are discussed in more detail at the end of this section.

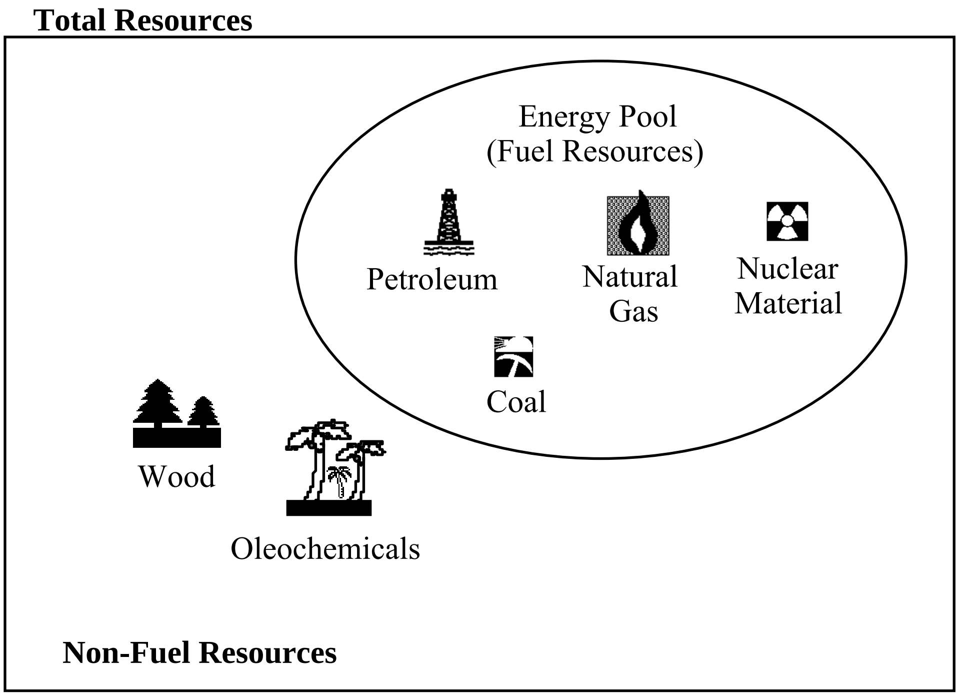

Figure 1-3. Illustration of the Energy of Material Resource Concept.

Data necessary for conducting this analysis are separated into two categories: process-related data and fuel-related data.

Process Data

Methodology for Collection/Verification. The process of gathering data is an iterative one. The data-gathering process for each system begins with a literature search to identify raw materials and processes necessary to produce the final product. The search is then extended to identify the raw materials and processes used to produce these raw materials. In this way, a flow diagram is systematically constructed to represent the production pathway of each system.

Each process identified during the construction of the flow diagram is then researched to identify potential industry sources for data. Sources for process data are contacted, and worksheets are provided to assist in gathering the necessary process data for their product.

Upon receipt of the completed worksheets, the data are evaluated for completeness and reviewed for any material inputs that are additions or changes to the flow diagram. In this way, the flow diagram is revised to represent current industrial practices. Data suppliers are then contacted again to discuss the data, process technology, waste treatment, identify coproducts, and any assumptions necessary to understand the data and boundaries.

After each data set has been completed and verified, the data sets for each process are aggregated into a single set of data for that process. The method of aggregation for each process is determined on a case-by-case basis. For example, if more than one process technology is involved, market shares for these processes are used to create a weighted average. In this way, a representative set of data can be estimated from a limited number of data sources. Process technologies and assumptions are then documented and returned with the aggregated data to each data supplier for their review. The data and documentation may also be provided to other industry and academic experts for comment. This provides an opportunity for experts on each process to review the completed data for accuracy, reasonableness of assumptions, and representativeness.

Confidentiality. The data requested in the worksheets are often considered proprietary by potential suppliers of data. The method used to collect and review data provides each supplier the opportunity to review the aggregated average data calculated from all data supplied by industry. This allows each supplier to verify that their company's data are not being published and that the averaged data are not aggregated in such a way that individual company data can be calculated or identified.

Objectivity. Each process is researched independently of all other processes. No calculations are performed to link processes together with the production of their raw materials until after data gathering and review are complete. The procedure of providing the aggregated data and documentation to suppliers and other industry experts provides several opportunities to review the individual data sets without affecting the objectivity of the research. This process serves as an external expert review of each process. Also, because these data are reviewed individually, assumptions are reviewed based on their relevance to the process rather than their effect on the overall outcome of the study.

Data Sources. As stated in the **Study Goal** section, the intended purpose of the study was to develop life cycle profiles for the product systems using the most up-to-date primary data collected from the industries producing each type of foodservice product. All foodservice product industries represented in the study were given the opportunity to participate in the study and provide state-of-the-art, U.S.-specific data on their products and materials.

Data collected specifically for this study include data on the production of polystyrene resins (provided by resin producers) and data on the fabrication and secondary packaging of polystyrene foodservice products (provided by producers of polystyrene foodservice products). Data on the weights of foodservice products and weights of secondary packaging were developed based on sample measurements, published weight data, and data reported by producers. Fabrication data for paperboard plates were estimated from equipment specifications for paper plate converting equipment. Data for production of coated paperboard were developed based on the properties of the coating materials.

Other than the data sets provided by industry for this study, or data developed for this study using secondary data sources, data sets for all other unit processes in this study were taken from Franklin Associates' U.S. industry average database. This database has been developed over a period of years through research for many LCI projects encompassing a wide variety of products and materials.

One advantage of this database is that Franklin Associates' research has been conducted for many products and processes, so that the database has a broad range of expertise, rather than being focused on a single product type at the expense of other types of products. Because of the large number and wide variety of studies which have contributed to the database, better data quality can be achieved for all products and processes in the database. Using Franklin Associates' life cycle database, gaps in fabrication data for molded pulp plates and corrugated cup sleeves could be filled using estimates based on data sets for fabrication of similar molded pulp and corrugated paperboard products.

Another advantage of the database is that it is continually updated. For each ongoing LCI project, verification and updating is carried out for the portions of the database that are accessed by that project. Although the paperboard industry declined to participate in the study, it is known that paperboard bleaching technology has changed significantly since the original study was conducted. Franklin Associates' bleached paperboard data set was updated for this study to reflect the shift from chlorine-based bleaching technologies to elemental chlorine free bleaching.

Fuel Data

When fuels are used for process or transportation energy, there are energy and emissions associated with the production and delivery of the fuels as well as the energy and emissions released when the fuels are burned. Before each fuel is usable, it must be mined, as in the case of coal or uranium, or extracted from the earth in some manner. Further processing is often necessary before the fuel is usable. For example, coal is crushed or pulverized and sometimes cleaned. Crude oil is refined to produce fuel oils, and "wet" natural gas is processed to produce natural gas liquids for fuel or feedstock.

To distinguish between environmental emissions from the combustion of fuels and emissions associated with the production of fuels, different terms are used to describe the different emissions. The combustion products of fuels are defined as "combustion data." Energy consumption and emissions which result from the mining, refining, and transportation of fuels are defined as "precombustion data." Precombustion data and combustion data together are referred to as "fuel-related data."

Fuel-related data are developed for fuels that are burned directly in industrial furnaces, boilers, and transport vehicles. Fuel-related data are also developed for the production of electricity. These data are assembled into a database from which the energy requirements and environmental emissions for the production and combustion of process fuels are calculated.

Energy data are developed in the form of measured units of each primary fuel required per measured unit of each fuel type. For electricity production, federal government statistical records provided data for the amount of fuel required to produce electricity from each fuel source, and the total amount of electricity generated from petroleum, natural gas, coal, nuclear, hydropower, and other (solar, geothermal, etc.). Literature sources and federal government statistical records provided data for the emissions resulting from the combustion of fuels in utility boilers, industrial boilers, stationary equipment such as pumps and compressors, and transportation equipment. Because electricity is required to produce primary fuels, which are in turn used to generate electricity, a circular loop is created. Iteration techniques are utilized to resolve this loop.

Data Accuracy

An important issue to consider when using LCI 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 study conclusions are correct. A specific conclusion depends on the accuracy of the numbers that are combined to arrive at that conclusion. Because of the many processes required to produce foodservice product systems, 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. In many cases, plant personnel reported actual plant data. 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. Taking into consideration budget constraints and limited industry participation, the data used in this report are believed to be the best which can be currently obtained.

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. It is assumed that with careful scrutiny of the data, any errors will be random. That is, some numbers will be a little high due to errors, and some will be slightly low, but in the summing process these random high and low errors will offset each other to some extent.

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 a raw 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 a polystyrene cup changes the quantity of polystyrene resin required, which changes the amounts of styrene and ethylbenzene required, and so on back to the quantities of crude oil and natural gas.

In summary, for the particular data sources used and for the specific methodology described in this report, the results of this report are believed to be as accurate and reasonable as possible.

Data Quality Indicators and Uncertainty Analysis

ISO standards 14040, 14041 and 14043 each detail various aspects of data quality and data quality analysis. These items are essential to give a study credibility. In particular, when comparative assertions are made, the estimates of uncertainty in the results are essential to determine if two numbers are most likely the same or different. No standard methods have been adopted for this activity, but Franklin Associates has developed methods that have been peer reviewed in technical journals and are described in part in the SETAC documents "Life Cycle Assessment Data Quality: A Conceptual Framework," 1992, and "Life Cycle Impact Assessment: The State of the Art," 1997.

Life cycle inventories attempt to determine all of the inputs (in terms of energy and natural resource use) and all of the outputs (in terms of products, coproducts, and environmental emissions to the air, water, and soil) over the entire life of a product or service, within the boundaries of the study. Thousands of data points are needed in a typical LCI, including values for the extraction of raw materials, the manufacturing of intermediate materials, the fabrication of the product, the use/reuse/maintenance of the product (not included in this study), and the ultimate disposal or recycling of the product.

In the best of possible worlds, classical statistics could be used to determine the uncertainties in LCIs. Classical statistics, however, requires that the data conform to several restrictive assumptions such as independence, randomness, and representativeness.

In LCIs, as in many areas of complex assessments, data often do not meet the stringent requirements of classical statistics. There may be no option to control the representativeness of samples, the number of data points, or the randomness of the data collected. In that case, expert judgment becomes important.

Recent research has shown that expert judgment can be translated into quantifiable statements about data quality and uncertainty with high reproducibility. While this introduces subjectivity into the uncertainty analysis, it is presently the best available methodology. It brings to LCI assessments valuable information that has historically been missing. It has the potential of greatly increasing the credibility of comparative LCI results, and making the database in a research project as sound as possible.

Franklin Associates has developed methodologies to deal with the issues of uncertainty and data quality in Life Cycle Analysis. In traditional LCIs, single point estimates of input variables (such as fuel requirements) are used to determine single point estimates for the output variables (such as total energy used or solid waste generated). These point estimates contain no information about the uncertainty of the data; therefore they give a false sense of precision. Analysis of meaningful differences in LCI results obtained using point value modeling thus relies upon the experience and expert judgment of the practitioner. Chapter 5 of this report provides an explanation of Franklin Associates' criteria for meaningful differences in LCI results, supported by statistical arguments with hypothetical, but similar, data.

The Franklin Associates methodology has been adapted to allow for the assignment of data quality indicators (DQIs) to the variables used as inputs to LCI computer models. These indicators can then be used as a basis for modeling input values as distributions rather than as single point estimates. This approach more accurately reflects the level of confidence in the values. The deterministic model is therefore changed into a stochastic model. This means that the output of the model is also a distribution of values, rather than a single point estimate. It is then easier to judge, for example, whether two values for total solid waste are the same or different. This stochastic approach requires considerable additional modeling time and expense, however, and is outside the scope of this project.

Data Quality Goals for This Study

As described earlier in this chapter, the data quality goal for this study was to use primary data collected from foodservice industry stakeholders to develop data for each type of foodservice product that were representative of the spectrum of currently available product in terms of time, geographic, and technology coverage.

Due to the very limited cooperation of foodservice companies, it was not possible to achieve the intended data quality goals of the study in terms of current primary data and geographic and technology coverage. Because of the lack of industry participation, it is not possible to guarantee equivalent data quality for different foodservice systems; however, all data used for this study were carefully evaluated and updated to the extent possible using Franklin Associates' life cycle database and secondary data sources to ensure that they provided the best data quality possible within the time and budget constraints for this study.

Data for polystyrene production and polystyrene foodservice product fabrication were provided for this study by members of the polystyrene industry. Data on the weights of foodservice products were also collected specifically for this study. These data are current primary data and are considered to be of the highest quality.

Data for most other processes and materials in this study were taken from Franklin Associates' LCI database or estimated based on secondary data sources. The quality of these data vary in terms of age, representativeness, measured values or estimates, etc.; however, all materials and process data sets used in this study were thoroughly reviewed for accuracy and currency and updated to the best of our capabilities in 1997 or later. All fuel data were reviewed and extensively updated in 1998. The report bibliography lists the published data sources that were used to develop the LCI models for each product system.

ISO Data Quality Requirements and Use of Study

PSPC is part of the American Chemistry Council (ACC), and it is the ACC policy to make publicly available final reports about environment, health, and safety. It is possible that the study results, when made publicly available, may be used inappropriately to make general comparative assertions. This is not an explicit goal of the study and is discouraged by the authors.

The authors provide the following guidelines and restrictions regarding appropriate use of the study results:

This report should not be used by sponsors or readers to make specific statements about product systems unless the statements are clearly supported by the Life Cycle Inventory (LCI) results and are accompanied by a reference to the publicly available full report. Use of the study results for advertising purposes (e.g., public assertions or comparative assertions) should comply with Federal Trade Commission (FTC) Guides for the Use of Environmental Marketing Claims (16 CFR Part 260) and ISO 14040 series guidelines.

Franklin Associates, the American Chemistry Council (ACC), the American Plastics Council (APC), PSPC and its members are not responsible for use of the study results by any party in a way that does not fully conform to the guidelines described herein.

In particular, this study does not meet all the ISO 14040 series data quality requirements for use in making general comparative assertions regarding the overall environmental superiority or preferability of one system relative to a competing system or systems. The authors discourage the use of this study as the sole basis for general comparative assertions of this nature.

PEER REVIEW

Critical review is specified in ISO standard 14040 as an optional component for LCI/LCA studies, although ISO 14040 goes on to say that "a critical review shall be conducted for LCA studies used to make a comparative assertion that is disclosed to the public…" This study is limited to an inventory rather than a full life cycle assessment; however, it will be made publicly available, and thus a peer review of the study was conducted. The purpose of the peer review is to verify that the study has met the requirements of the international standards for methodology, data and reporting. The review may be conducted by internal experts other than the persons performing the study, external experts, or by a review panel of interested parties.

This report was submitted to a peer review by a panel of three independent life cycle experts. At the beginning of the project, the panel was asked to review the following five areas: goal, target audience, scope, boundaries, and data collection approach. The panel's questions and comments were used to further refine and direct the process of conducting the analysis and preparing the draft report. Upon completion of the study, the final draft report was submitted to the panel for review.

The peer reviewers' comments on the draft report and Franklin Associates' responses to these comments are provided as a separate section of this final report. This final report incorporates revisions made in response to the peer review.

METHODOLOGY ISSUES

The following sections discuss how several key methodological issues are handled in this study.

Precombustion Energy and Emissions

The energy content of fuels has been adjusted to include the energy requirements for extracting, processing, and transporting fuels, in addition to the primary energy of a fuel resulting from its combustion. In this study, this additional energy is called precombustion energy. Precombustion energy refers to all the energy that must be expended to prepare and deliver the primary fuel. Adjustments for losses during transmission, spills, leaks, exploration, and drilling/mining operations are incorporated into the calculation of precombustion energy.

Precombustion environmental emissions (air, waterborne, and solid waste) are also associated with the acquisition, processing, and transportation of the primary fuel. These precombustion emissions are added to the emissions resulting from the burning of the fuels.

Electricity Fuel Profile

In general, detailed data do not exist on the fuels used to generate the electricity consumed by each industry. Electricity production and distribution systems in the United States are interlinked and are not easily separated. Users of electricity, in general, cannot specify the fuels used to produce their share of the electric power grid. Therefore, the national average fuel consumption by electrical utilities is assumed.

Electricity generated on-site at a manufacturing facility is represented in the process data by the fuels used to produce it. A portion of on-site generated electricity is sold to the electricity grid. This portion is accounted for in the calculations for the fuel mix in the grid.

Recycling and Composting

In this study, recycling and composting are evaluated as means by which products are diverted from the municipal solid waste stream.

Recycling. Products may be recycled in an open-loop or closed-loop system. In this study, open-loop recycling was evaluated for polystyrene foam foodservice products. The modeling of corrugated containers was based on national average percentages of open-loop and closed-loop recycling developed from paper industry statistics.

In a closed-loop system, material is diverted from disposal by its unlimited recycling or reuse. This typically occurs for materials that do not degrade with repeated reprocessing and reuse, such as glass and metals. Since recycling of the same material can occur over and over, it may be permanently diverted from disposal. Burdens for the virgin production of the material that is recycled are allocated over all the useful lives of the material. At the ideal 100 percent recycling rate, the energy requirements and environmental emissions from the virgin raw material acquisition/processing and disposal become negligible.

In an open-loop system, a product made from virgin material is manufactured, recovered for recycling, and manufactured into a new product which is generally not recycled. This extends the life of the initial material, but only for a limited time.

The significant difference between open-loop and closed-loop systems is the way recycling benefits are incorporated or credited to the product system under examination. In a closed-loop system, since the material is recycled many times, the energy and emissions of the initial virgin material manufacture are divided among the first product and all subsequent products made from that original material. Consequently, these initial impacts become insignificant. The only significant energy and emissions associated with closed-loop recycled material are those which result from the recycling process and any processes that follow, such as fabrication. Likewise, ultimate disposal of the recycled material becomes insignificant within the context of the numerous recycling loops that have occurred.

Material in an open-loop system is typically used to make two products. Initially, virgin material is used to make a product which is recycled into a second product that is not recycled. Thus, for open-loop recycling, the energy and emissions of virgin material manufacture, recycling, and eventual disposal of the recycled material are divided evenly between the first and second product. This analysis inherently assumes that the recycled material replaces virgin material when producing the second product.

Composting. In this study, composting was evaluated for paperboard foodservice items. The burdens for the production of the material that is composted are divided between the original use as a foodservice product and the second use as compost. Unlike recycling, where material must be reprocessed into resin and then refabricated into a second product, the composting step is the fabrication step for the second product, i.e., compost; thus, the burdens for composting are allocated entirely to the compost product. Because compost remains in place where it is applied and is not collected and disposed after use, the amount of material diverted from the solid waste stream for composting is assumed to be permanently diverted from landfill.

Postconsumer Waste Combustion

Except for materials that are recycled or reused, postconsumer waste in the United States is normally either landfilled or burned. In the U.S., approximately 20 percent of postconsumer municipal solid waste, after recycling and reuse, is burned in a combustion facility which recovers energy.[10] The energy released from the combustion of those postconsumer materials is considered an energy credit and is subtracted from the total energy requirements of the system. Postconsumer solid waste for the system is reduced by the quantity of materials burned in combustion facilities. The ash from combustion facilities then becomes part of the postconsumer solid waste for the system.

METHODOLOGICAL DECISIONS

Some general decisions are always necessary to limit a study such as this to a reasonable scope. It is important to understand these decisions. The key assumptions and limitations for this study are discussed in the following sections.

Geographic Scope

Data for foreign processes are generally not available. This is usually only a consideration for the production of oil that is obtained from overseas. In cases such as this, the energy requirements and emissions are assumed to be the same as if the materials originated in the United States. Since foreign standards and regulations vary from those of the United States, it is acknowledged that this assumption may introduce some error.

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[10] **Municipal Solid Waste in the United States: 2001 Facts and Figures.** U.S. Environmental Protection Agency Office of Solid Waste and Emergency Response. August 2003.

Fuel usage for transportation of materials from overseas locations is included in the study.

Recycling and Composting Rates

National average statistics on foodservice recycling and composting were researched for this study, but no reliable quantitative data could be found. Although individual programs with measurable levels of foodservice product recycling and/or composting may exist in some specific locations, national average rates for recycling and composting of foodservice products are generally acknowledged to be very low. However, it was decided that it would give useful perspective in this study to model the effects of a low national average level of recycling for polystyrene foodservice products and composting of paperboard foodservice products. Two percent was selected as the level to be evaluated.

Landfill Density

Landfill density factors are used to convert the weight of postconsumer containers to volume. Measured landfill densities for all types of containers in the analysis were taken from **Estimates of the Volume of MSW and Selected Components in Trash Cans and Landfills** (Franklin Associates, Ltd. and The Garbage Project, University of Arizona, February 1990).

System Components Not Included

The following components of each system are not included in this LCI study:

Emissions from Combustion and Landfilling of Postconsumer Waste. It is recognized that the combustion of postconsumer products in waste-to-energy facilities produces atmospheric and waterborne emissions; however, these emissions are not included in this study. Allocating atmospheric and waterborne wastes from municipal combustion facilities to specific product systems is not feasible, due to the variety of materials present in combusted municipal solid waste. Theoretical carbon dioxide emissions from incinerated containers could be calculated based on their carbon content and assuming complete oxidation; however, this may not be an accurate representation of the results of mixed MSW combustion. Therefore, emissions from incineration of foodservice products in mixed MSW are not included in the analysis.

Similarly, emissions of methane and carbon dioxide from aerobic and anaerobic decomposition of landfilled paperboard foodservice products are not estimated for this analysis, nor are estimates of leachate from landfilled foodservice product included.

Historically, LCI studies have not included emissions from landfilled materials because of a lack of data of suitable quality. Some foodservice items in this study contain paperboard that may degrade in a landfill, although some of these potentially degradable items are coated or laminated with materials such as plastic resins or wax, which would inhibit degradation.

The fate of degradable materials in a landfill is a very complex subject. A large number of variables come into play, such as moisture, permeability of cover, temperature, pH of surroundings and time. Landfill decomposition generally is strongly affected by moisture content, which is highly variable from landfill to landfill, and even more so from place to place within a landfill. Anaerobic decomposition proceeds only under a narrow range of environmental conditions, including appropriate temperature, pH and moisture level.

Decomposition in a landfill proceeds by some combination of aerobic and anaerobic processes. At first, there is air entrapped in the landfill, but with time, probably within a few weeks or months, the conditions become anaerobic. Time is also an element to consider. It may take a century or more for degradable material to decompose completely in a landfill, although many products are suspected to partially decompose rapidly at first.

The coated and laminated paperboard foodservice items in this study present even greater resistance to degradation. The degradable material must come into contact with the moisture and chemicals present in the landfill. The coatings and laminates are designed to prevent that, so the products must be broken open or torn during the landfilling action to expose the degradable material. Even at that, the material will be exposed only at the edges of the tear, with most of the material remaining protected.

For biomass-derived products such as paperboard, the issue of decomposition emissions is further complicated by the fact that CO2 from aerobic decomposition of biomass-derived products is considered part of the natural carbon cycle and not counted as a net contribution to global warming potential, but the more potent methane emissions from anaerobic decomposition are a result of human intervention (landfilling) and are counted as a net contribution to global warming potential. Thus, to estimate net greenhouse gas emissions for biomass-derived products, a methodology is needed to determine the relative percentages that decompose aerobically and anaerobically. This is an area in which further research is required in order to better address the issue of GHG for biomass-derived product systems such as paperboard.

Even when degradable materials decompose, not all gas produced by the decomposition enters the atmosphere. Some methane reacts with other chemicals in a landfill, some is oxidized in the soil, and some is recovered and flared or burned as a fuel. Possibly an even greater fraction of CO_2 generated never makes it through the landfill cover because it is soluble in water and may exit the landfill as leachate.

In summary, emissions from landfills (particularly greenhouse gas emissions) are potentially important to consider in LCI calculations, but it is premature to report them along with other LCI emissions data until there is general agreement among experts on an acceptable methodology for estimating actual releases.

Water Use, Land Use, and Farming. Because of the lack of availability of good data on water use for unit processes, Franklin Associates' LCI database does not include water use, nor does Franklin Associates' database include data on land use and erosion.

The quantities and compositions of pesticides, herbicides, and other chemical agents used in farming vary widely, and data on the production of specialized agricultural chemicals are largely unavailable. Thus, production and use of these materials is not included in the analysis, although the LCI does include the production of basic fertilizer inputs used in farming.

Capital Equipment. The energy and wastes associated with the manufacture of capital equipment are not included. This includes equipment to manufacture buildings, motor vehicles, and industrial machinery. The energy and emissions associated with such capital equipment generally, for 1,000 pounds of materials, become negligible when averaged over the millions of pounds of product which the capital equipment manufactures.

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. Energy consumed for space conditioning is usually less than one percent of the total energy consumption for the manufacturing process. This assumption has been checked in the past by Franklin Associates staff using confidential data from manufacturing plants. This assumption may not be true, however, for assembly plants or other locations that require large amounts of floor space but do not consume large amounts of process energy.

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.

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 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.

STUDY LIMITATIONS

Participation by some industry stakeholders in this study was limited despite extensive and repeated efforts to secure participation of all stakeholder industries. In particular, the paperboard industry, which is represented in every foodservice product category studied, declined to participate in any way. Thus, the data quality goals of the study could not be realized as originally intended. However, the environmental profiles presented in this report for non-participating industries were developed using the best and most current data available from Franklin Associates' U.S. life cycle database, updated to the extent possible to represent current technology.

Although the methodology for this study is compliant with ISO standards, it was not possible to meet some of the ISO data quality requirements due to the limited participation by some industries. In particular, this study does not meet all the stringent data quality requirements set out in the ISO 14040 standards for life cycle studies used to make general comparative assertions regarding the overall environmental superiority or preferability of one system relative to a competing system or systems. The authors discourage the use of this study to make general comparative assertions about overall environmental performance of the systems studied.

The use of this study to make public comparative assertions is limited to specific statements that are supported by the study results. Guidelines and restrictions regarding appropriate use of this study have been provided in the preface to this study and in this chapter in the section "**ISO Data Quality Requirements and Use of Study.**"

CHAPTER 2

LCI RESULTS FOR FOODSERVICE PRODUCTS FOR THE RANGE OF AVAILABLE PRODUCT WEIGHTS

INTRODUCTION

A life cycle inventory, such as this study, quantifies the energy use and environmental emissions associated with the life cycle of specific products. In this case, the specific products evaluated are polystyrene and paperboard foodservice products.

For the overall study, the goal and intended audience, functional unit, and scope and boundaries are presented in the Executive Summary and Chapter 1 and are not repeated here, except as they relate to the results presented in this chapter.

Purpose of Chapter 2

This chapter presents LCI results for the range of product weights in each foodservice product category.

Functional Unit

Within each foodservice product category, the functional unit for this study is an equivalent number of product units of the defined size or capacity and corresponding general level of functionality, based on available information. In some cases, different material products within a defined category were not available in exactly equivalent sizes and capacities. In these cases, the product configuration that most closely corresponded with the defined product category was evaluated. For example, in the "5-inch sandwich-size clamshell" category there were no containers available that were exactly 5 inches by 5 inches. The actual sizes of containers available varied from 4 ¾ inches x 5 inches to 5 1/8 inches x 5 3/8 inches. However, their functional use, i.e., to hold one sandwich, would be equivalent, at least for all sandwiches 4 ¾ inches or less in length or diameter. All foodservice product systems in this study are evaluated on the basis of 10,000 product units.

It is recognized that the different product samples available within a defined product category vary in certain properties (e.g., insulating properties of cups and clamshells, load strength and moisture resistance of plates). However, no information on individual product samples was available to quantify these functional differences. In order to evaluate differences in functional use of products due to incremental differences in product properties, it would be necessary to define specific use applications in which to evaluate individual samples' performance (e.g., for hot cups, to contain a certain temperature beverage not to exceed a defined cooling rate, or for plates, to support a load of food with a defined weight and moisture content). Such functional analysis is beyond the scope of this study.

Some provisions were made in this presentation of LCI results in this report to facilitate the analysis of consumer practices that may vary based on actual or perceived differences in product functionality. For example, because it is common practice at coffeeshops and other carry-out establishments for insulating sleeves to be used with paper cups for hot beverages, the 16-oz hot cup analysis includes coated paper cups used alone and with corrugated cup sleeves. “Double-cupping” (the use of two nested cups, a fairly common practice with paper cups) to provide consumers’ hands with additional protection from extremely hot or cold beverage can be evaluated by doubling the LCI results for the cup (and the packaging used to deliver the cup). Double or even triple use of plates by consumers may also occur (e.g., to provide additional strength under very heavy or wet loads) and can be evaluated in the same manner.

Systems Studied

The four general foodservice product categories evaluated and the types of product evaluated in each category are:

- 16-oz cups used for hot beverages (EPS, PE-coated paper, PE-coated paper with corrugated cup sleeve)
- 32-oz cups used for cold beverages (EPS, PE-coated paper, wax-coated paper)
- 9-inch high-grade plates (GPPS foam, PE-coated paper, bleached molded pulp)
- 5-inch sandwich-size clamshells (GPPS foam, corrugated paperboard)

The methodology for determining the range of product weights and average product weight in each product category is described below. The number of product samples and weight ranges for each product in each category are shown in Table 2-1.

Guidance on using this LCI to estimate environmental burdens for products of the same materials but different weights is provided in the section **Estimating Results for Other Product Weights** beginning on page 2-58.

Determining Range of Product Weights. A variety of methods was used to obtain weight data for the range of foodservice products available in each category. First, PSPC member companies were contacted for data on their products. Samples of cup sleeves were collected from local coffee shops. An internet search was conducted for each type of foodservice product listed above, and samples of all relevant products were requested from all domestic producers identified in the search. Finally, in a few categories where less than two sample weights had been obtained by the preceding steps, additional samples were purchased or acquired from local restaurants. In some cases it was not possible to obtain more than one sample. Sample weight data are summarized in Table 2-1.

Table 2-1

FOODSERVICE PRODUCT WEIGHT DATA

	No. of Mfrs	No. of Samples	Low Wt (g)	High Wt (g)	Avg Wt (g)	Avg Wt in lb per 10,000 units
16 oz Hot Cups						
EPS Foam	2	3	4.40	5.00	4.70	104
PE-coated Paperboard	3	6	12.3	15.0	13.3	294
Unbleached Corrugated Cup Sleeves	1	4	4.10	7.50	5.76	127
32 oz Cold Cups						
EPS Foam	2	3	8.10	10.0	8.83	195
PE-coated Paperboard	3	4	19.8	23.3	21.9	483
Wax-coated Paperboard (1)	1	1	31.3	31.3	31.3	690
9 inch Plates - High Grade						
GPPS Foam - Laminated	2	3	10.4	11.1	10.8	238
Uncoated Molded Pulp	2	4	16.2	17.4	16.6	367
Coated Paperboard	2	2	18.2	18.5	18.4	405
Sandwich-size Clamshells						
5 inch Corrugated Paperboard (1, 2)	1	2	10.2	10.3	10.2	225
5 inch GPPS Foam	4	4	4.40	5.00	4.80	106

(1) Only one producer located.
(2) Bleached outer layer, unbleached inner layer and fluting.

Source: Franklin Associates

Product samples collected and weighed by Franklin Associates from January 2003 through July 2003.

It was difficult to obtain samples in certain product categories. Large (32-ounce) EPS cold cups and wax-coated paper cups were difficult to find. Our sample search found that institutional foam cups tend to be smaller than 32 ounces, large fast food cups are usually PE-coated paperboard, and large convenience store cups are generally PE-coated paperboard or rigid plastic. Only one producer of wax-coated 32-ounce cold cups provided samples for this study.

Cup sleeves, sometimes used with coated paper cups for hot drinks, were available in too many configurations to characterize consistently. Sleeves were available in bleached and unbleached paperboard, preassembled (glued) or unassembled (tab in slot), corrugated or embossed texture, and a range of surface areas. However, most of the variety in samples was obtained from manufacturers promoting cup sleeves as an advertising medium. It was decided to model the cup sleeves based on an average of the sleeve samples collected from large coffee shop chains, which tend to use unbleached corrugated paperboard.

The greatest variety of samples was found in the category of plates. Plates are available in many configurations with widely varying weights; however, plates are generally classified by their manufacturer as low-, medium-, or high-grade. These classifications, described below, were found to correspond closely with the weights of the plates.

Low-grade plates. Plates categorized as low-grade weigh less than 10 grams per plate and consist of a single layer of bleached kraft paperboard with no coating. They are manufactured by unwinding rolls of paperboard and cutting and mechanically forming them into the proper shape.

Mid-grade plates. Mid-grade plates weigh between 10 and 16 grams per plate and consist of a thick layer of bleached kraft paperboard. All the mid-grade plate samples obtained for this study had some type of coating. Many of these coatings are proprietary, but the most common is polyethylene, which is the coating modeled in this analysis. These plates are manufactured by unwinding rolls of paperboard and then cutting and mechanically forming them into the proper shape. Some mid-grade plates have decorative patterns.

High-grade plates. High-grade plates weigh between 16 and 20 grams per plate. This weight range includes two types of plates: coated paperboard plates and uncoated molded pulp plates.

For this analysis, only high-grade plates were evaluated, because this is the only category that includes plates of all the materials studied, namely GPPS foam, coated paperboard, and molded pulp.

GPPS foam clamshells were readily available; however, it appears that GPPS has largely taken over this product market, as only one producer of insulating (corrugated) paperboard clamshells could be found.

Paperboard Product Assumptions. As noted previously, the paperboard industry declined to participate in any way in this study, including providing information on the composition of paperboard products and their secondary packaging, process data for bleached and unbleached paperboard production, process data for fabrication of paperboard products, etc. In the absence of such information from the paperboard industry, the following approach was used to model paperboard foodservice products:

- All paper products with the potential to have direct contact with food were modeled with no postconsumer content. This includes the bleached paperboard used in cups, plates, and the inner and outer surfaces of the clamshell, and the unbleached corrugated medium layer of the clamshell. The recycled pulp used in molded pulp plate production is clean preconsumer scrap that does not require deinking.
- Composition of non-food-contact paperboard products (external cup sleeves and the corrugated boxes used for secondary packaging) was

modeled using paperboard industry statistics on recovered paper and paperboard inputs to corrugated linerboard and medium.

- Bleached paperboard production was modeled as using elemental chlorine free technology, based on recent paperboard industry publications.
- No data were available on quantities and composition of colorants, sizing, fillers or printing inks used in the various foodservice products, so no inputs of these materials were modeled. Previous studies of paperboard foodservice products have not indicated use of clay sizing. Previous studies of similar products also indicate that printing inks and colorants generally comprise a very small weight percent of the product with negligible effect on results.

Scope and Boundaries

The results in this chapter represent the manufacture of each foodservice product from raw material extraction through product fabrication, plus disposal of postconsumer product. The production of secondary packaging, delivery of products to stores and use by consumers are not included in the results in this chapter.

RESULTS

The results in this chapter are presented on the comparative basis of 10,000 product units of the same size or capacity (or the closest corresponding sizes of products available).

As noted in the Functional Unit section, variations in consumer use practices such as “double-cupping” for protection from hot beverages or use of multiple plates to support a heavy load of food can be evaluated by multiplying the LCI results for the individual product by the number of product units used by the consumer.

Energy Results

Based on the uncertainty in the energy data, energy differences between systems are not considered meaningful unless the percent difference between systems 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 and supported by sample statistical calculations (see Chapter 5).

Energy by Category. Tables 2-2 through 2-5 present energy results broken out into the categories of process energy, transportation energy, and energy of material resource. The category of **process energy** includes totals for all processes required to produce the packaging materials, from acquisition of raw materials through manufacture into packaging materials. **Transportation energy** is the energy used to move material from location to location during its journey from raw material to product. **Energy of material resource** is not an expended energy but the energy value of fuel resources withdrawn from the planet's finite fossil reserves and used as material inputs for materials such as plastic resins. Use of fuel resources as a material input is a depletion of fuel resources just as the combustion of fuels for energy. In this study, energy of material resource is reported for plastic products and coatings and wax coatings, which are produced using natural gas and petroleum as material feedstocks. No energy of material resource is assigned to energy derived from wood (in virgin pulp and paper mills) because wood's primary use is as a material input, not as a fuel resource.

It should be noted that energy of material resource is a methodological choice of the practitioner that is described in more detail in Chapter 1. The exclusion of energy of material resource from results for polystyrene systems or the addition of wood energy content to results for paperboard systems could significantly affect energy comparisons between polystyrene and paperboard systems. The energy results presented in Tables 2-2 through 2-5 present individual energy categories separately, so that the reader can make a comparison of system results excluding energy of material resource as it is applied in this study to polystyrene products and plastic and wax coatings on paperboard products.

Below the total energy is a line showing an energy credit for each system. The energy credit is for the energy recovered from waste-to-energy incineration of 20 percent of the solid waste that is not diverted for reuse or recycling, based on the national average percentage of municipal solid waste (MSW) that is disposed by waste-to-energy (WTE) combustion. The energy credit is based on the higher heating values of each material. Although some MSW incinerators are used to provide heat, most are used to produce electricity. However, the efficiency for generation and delivery of electricity from MSW is very low, so the actual usable energy obtained from the energy from MSW incineration is considerably lower than the higher heating value shown in the tables.

The lower section of Tables 2-2 through 2-5 show the percentage of the total energy contributed by each category of energy. Energy by category is shown graphically in Figures 2-1 through 2-4.

16-ounce Hot Cups. Within the category of hot cups, total energy for the highest weight EPS cups is 14 percent higher than the lowest weight sample. Total energy for the heaviest PE-coated paperboard cup is 22 percent higher than for the lightest cup. The heaviest PE-coated paperboard cup with the heaviest cup sleeve has total energy requirements 31 percent higher than the lightest cup/sleeve combination.

The difference in total energy requirements between two systems can be considered meaningful if the percent difference between the two is at least 10 percent. In comparing the EPS cup to the PE-coated paperboard cup, the percent difference in energy between the heaviest EPS cup and the lightest paperboard cup is less than 10 percent, so the comparison is inconclusive. When the paperboard cup is used together with a corrugated sleeve, however, the percent difference between the lowest weight cup and sleeve combination and the heaviest EPS cup is meaningful.

Table 2-2

Energy by Category for 10,000 16-ounce Hot Cups

	Polystyrene			Poly-Coated Paperboard			Corrugated Cup Sleeves			PE Ppbd Cup + Sleeve		
	Low	Avg	High	Low	Avg	High	Low	Avg	High	Low	Avg	High
Energy Category (Million Btu)												
Process	3.60	3.85	4.10	6.38	6.91	7.78	1.15	1.62	2.11	7.53	8.53	9.89
Transport	0.083	0.089	0.095	0.22	0.23	0.26	0.093	0.13	0.17	0.31	0.36	0.43
Energy of Material Resource	2.44	2.61	2.78	0.70	0.75	0.85	1.8E-04	2.6E-04	3.4E-04	0.70	0.75	0.85
Total Energy	**6.13**	**6.55**	**6.97**	**7.29**	**7.89**	**8.89**	**1.25**	**1.75**	**2.28**	**8.54**	**9.64**	**11.2**
Energy Credit from 20% WTE	0.35	0.37	0.39	0.46	0.50	0.56	0.14	0.20	0.26	0.61	0.70	0.83
Net Energy	5.79	6.18	6.57	6.83	7.39	8.33	1.10	1.55	2.02	7.93	8.94	10.3
Energy Category (Percent)												
Process	59%	59%	59%	87%	87%	87%	93%	93%	93%	88%	88%	89%
Transport	1%	1%	1%	3%	3%	3%	7%	7%	7%	4%	4%	4%
Energy of Material Resource	40%	40%	40%	10%	10%	10%	0%	0%	0%	8%	8%	8%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Source: Franklin Associates

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 10%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-35 at the end of this chapter for a summary of meaningful differences in results.

Table 2-3

Energy by Category for 10,000 32-ounce Cold Cups

	Polystyrene			Poly-Coated Paperboard			Wax-Coated Paperboard
	Low	Avg	High	Low	Avg	High	Avg
Energy Category (Million Btu)							
Process	6.34	6.92	7.83	9.89	10.9	11.6	19.7
Transport	0.15	0.17	0.19	0.35	0.39	0.41	0.70
Energy of Material Resource	4.43	4.83	5.47	0.92	1.02	1.08	1.83
Total Energy	**10.9**	**11.9**	**13.5**	**11.2**	**12.3**	**13.1**	**22.2**
Energy Credit from 20% WTE	0.64	0.69	0.79	0.74	0.82	0.88	1.18
Net Energy	10.3	11.2	12.7	10.4	11.5	12.3	21.0
Energy Category (Percent)							
Process	58%	58%	58%	89%	89%	89%	89%
Transport	1%	1%	1%	3%	3%	3%	3%
Energy of Material Resource	41%	41%	41%	8%	8%	8%	8%
Total	100%	100%	100%	100%	100%	100%	100%

Source: Franklin Associates

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 10%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-36 at the end of this chapter for a summary of meaningful differences in results.

Table 2-4

Energy by Category for 10,000 9-inch High-grade Plates

	Polystyrene			Poly-Coated Paperboard			Molded Pulp		
	Low	Avg	High	Low	Avg	High	Low	Avg	High
Energy Category (Million Btu)									
Process	5.59	5.80	5.96	8.73	8.80	8.88	11.2	11.5	12.1
Transport	0.20	0.20	0.21	0.32	0.32	0.33	0.32	0.32	0.34
Energy of Material Resource	5.47	5.68	5.84	0.93	0.94	0.94	0.0028	0.0029	0.0030
Total Energy	**11.3**	**11.7**	**12.0**	**9.98**	**10.1**	**10.1**	**11.6**	**11.9**	**12.4**
Energy Credit from 20% WTE	0.82	0.85	0.87	0.68	0.69	0.70	0.52	0.53	0.56
Net Energy	10.4	10.8	11.1	9.30	9.37	9.45	11.0	11.3	11.9
Energy Category (Percent)									
Process	50%	50%	50%	87%	87%	87%	97%	97%	97%
Transport	2%	2%	2%	3%	3%	3%	3%	3%	3%
Energy of Material Resource	49%	49%	49%	9%	9%	9%	0%	0%	0%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%

Source: Franklin Associates

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Results in this table apply only to high-grade plates, which are the strongest and heaviest plates available in each material category. Lighter weight polystyrene and paper plates are available but are not included in these results.
Due to the uncertainties in LCI data, differences in results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 10%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-37 at the end of this chapter for a summary of meaningful differences in results.

Table 2-5

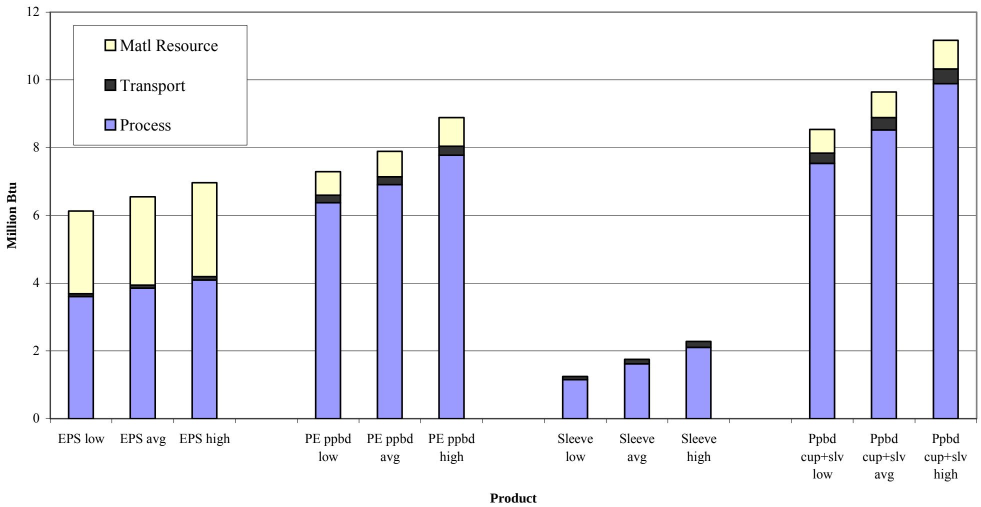
Energy by Category for 10,000 5-inch Sandwich-size Clamshells

	Polystyrene			Fluted Paperboard		
	Low	Avg	High	Low	Avg	High
Energy Category (Million Btu)						
Process	2.39	2.61	2.72	5.00	5.04	5.08
Transport	0.083	0.091	0.095	0.30	0.30	0.31
Energy of Material Resource	2.31	2.53	2.63	0.0014	0.0014	0.0014
Total Energy	**4.79**	**5.22**	**5.44**	**5.31**	**5.35**	**5.38**
Energy Credit from 20% WTE	0.35	0.38	0.39	0.35	0.35	0.35
Net Energy	4.44	4.85	5.05	4.96	5.00	5.03
Energy Category (Percent)						
Process	50%	50%	50%	94%	94%	94%
Transport	2%	2%	2%	6%	6%	6%
Energy of Material Resource	48%	48%	48%	0%	0%	0%
Total	100%	100%	100%	100%	100%	100%

Source: Franklin Associates

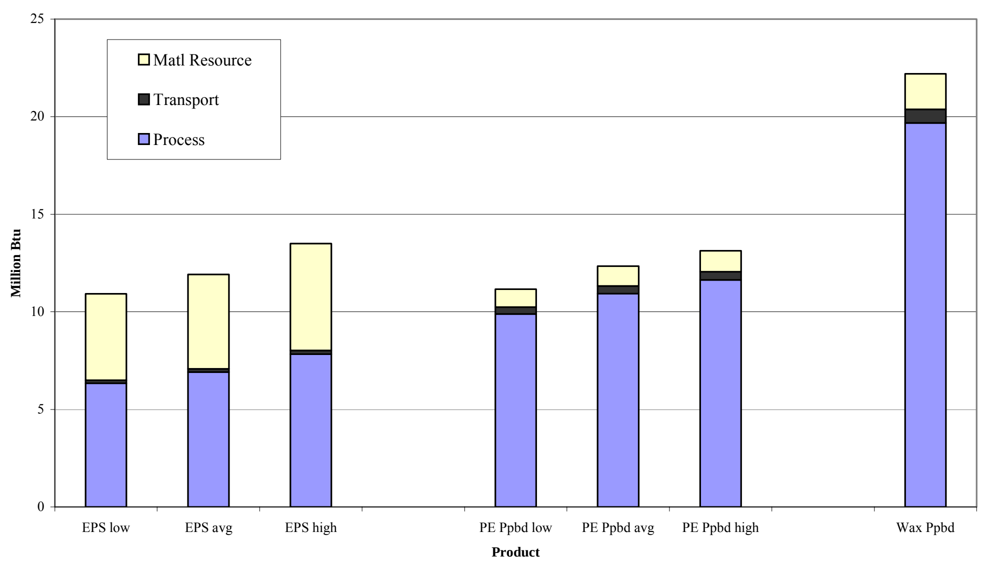
Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 10%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-38 at the end of this chapter for a summary of meaningful differences in results.

Figure 2-1. Energy by Category for 10,000 16-oz Hot Cups (Million Btu)



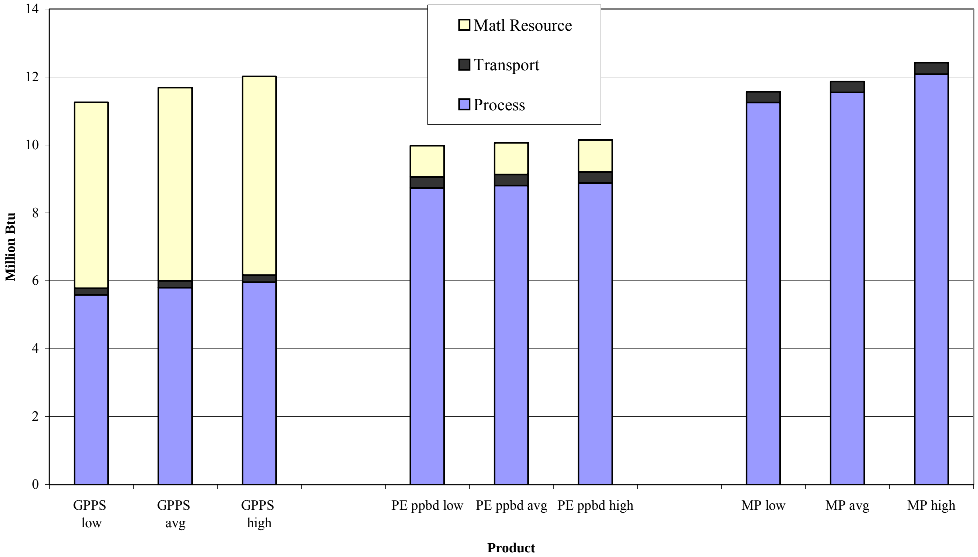
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in energy results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 10%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-35 for a summary of meaningful differences between products.

Figure 2-2. Energy by Category for 10,000 32-oz Cold Cups (Million Btu)



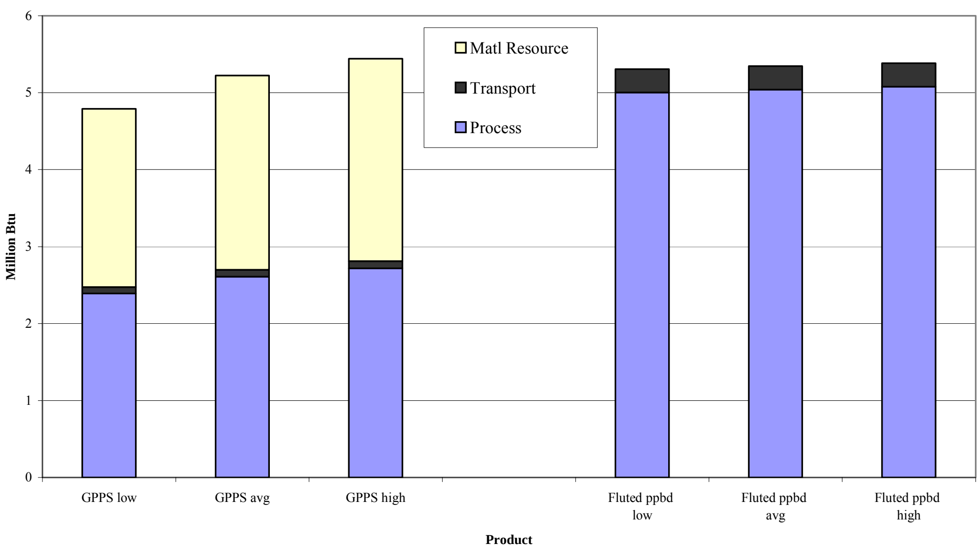
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in energy results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 10%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-36 for a summary of meaningful differences between products.

Figure 2-3. Energy by Category for 10,000 9-inch High-Grade Plates (Million Btu)



Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in energy results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 10%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-37 for a summary of meaningful differences between products.

Figure 2-4. Energy by Category for 10,000 5-inch Sandwich-Size Clamshells (Million Btu)



Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in energy results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 10%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-38 for a summary of meaningful differences between products.

For the EPS cup, energy of material resource accounts for 40 percent of the total energy, since fuel resources are the predominant raw materials for the cups. Energy of material resource for the PE coating on the paperboard cup accounts for 10 percent of the total energy. Process energy requirements for the coated paperboard cup are nearly twice as high as process energy for the EPS cups.

Energy credit for WTE incineration of 20 percent of disposed cups is about 6 to 7 percent of the total energy requirements, based on the higher heating value of the materials.

32-ounce Cold Cups. For EPS cold cups, total energy for the highest weight cup is 23 percent higher than the lowest weight sample, while the spread is 18 percent for the weight range of PE-coated paperboard cups. Only one wax-coated cup sample could be obtained, so there are no ranges of results to report.

Energy requirements for the EPS and PE-coated cup are very similar and there is no meaningful difference across the range of product weights of the two types of cups. When total energy for wax-coated cups is compared to both EPS and PE-coated cups, the energy differences are meaningful, with higher energy for wax-coated cups. The main reason for this is that there is a fairly high scrap rate in the production of paper cups. PE-coated paperboard is recyclable, but wax-coated scrap is not. Thus, all the energy (cradle-to-production) used to produce the wax-coated paperboard that ends up as fabrication waste must be assigned to the cup, while the energy to produce the PE-coated fabrication scrap is allocated to the product system that uses the scrap. In addition, the wax-coated cup is about 30 percent heavier than the PE-coated cup and thus requires production of more paperboard and coating for the finished cup.

Although the total energy requirements are very similar for EPS and PE-coated paperboard cups, the breakdown by energy category is very different. For the EPS cup, energy of material resource accounts for 40 percent of the total energy, since fuel resources are the predominant raw materials for the cups. Energy of material resource for the PE and wax coatings account for 8 percent of the total energy for the coated cups. Process energy accounts for 58 percent of total energy for EPS and almost 90 percent of total energy for coated paperboard cups. Process energy requirements for EPS cups are about 2/3 of the process energy for PE-coated paperboard cups and 1/3 of the process energy for wax-coated cups.

Energy credit for WTE incineration of 20 percent of disposed cups is about 6 percent of total energy for EPS cups, 7 percent for PE-coated cups, and 5 percent for wax-coated cups.

9-inch High-grade Plates. Disposable foodservice plates come in a wide range of weights and configurations. There can be large weight variations between the lightest and heaviest plates available within a single material category, but also substantial differences in strength. In order to make the product comparisons as equivalent as possible, only plates of the same general grade were analyzed. The LCI results for plates include only those plates classified by their manufacturers as high-grade.

In the category of high-grade plates, there is little variation in the weights of plates within each material, so there is also little variation in total energy. The heaviest GPPS and molded pulp plates have total energy requirements 7 percent higher than for the lightest product samples in their respective material categories, while energy for the heaviest PE-coated paperboard plate is only 2 percent higher than the lightest plate.

There is a 10 percent difference between total energy for the lowest weight GPPS plate and the heaviest PE-coated paperboard plate, so the energy difference between these systems can be considered meaningful, in favor of the paperboard plate. Results for the GPPS and molded pulp plates overlap, rendering the comparison inconclusive.

Total energy requirements for the polystyrene plates are divided evenly between energy of material resource and process energy, with a small percentage of transportation energy. Process energy dominates total energy for coated paperboard and molded pulp plates, at 87 percent and 97 percent of the total for the respective plate systems. Process energy for the PE-coated plates is about 50 percent higher than process energy for the GPPS plates, and process energy for the molded pulp plates is almost twice as high as process energy for GPPS plates. The molded pulp plates are made from bleached paper industrial scrap, so the plate material not only undergoes a chemical pulping process to produce the initial paper stock but also must be repulped, formed, and dried to produce the molded pulp plates.

Energy recovery from WTE incineration of 20 percent of postconsumer discards is equivalent to about 7 percent of total energy for all plates except molded pulp, with 4 percent energy credit. This is because the total energy requirements for the molded pulp plates include both chemical pulping and repulping, which increases the total energy but does not increase the recoverable energy in the material.

5-inch Sandwich-size Clamshells. As with plates, foodservice clamshells come in a wide variety of sizes and dimensions. Foodservice clamshells include foamed and corrugated products that provide some additional insulation properties, as well as single-layer paperboard and crystal resin containers that do not provide extra insulation. Sandwiches, particularly sandwiches served hot such as hamburgers, are typically provided to customers in clamshells that provide additional insulation properties. The clamshells analyzed here include only sandwich-size foamed or corrugated clamshells.

For GPPS foam clamshells, total energy requirements for the heaviest clamshell are 14 percent higher than for the lightest clamshell. There was very little difference in weights of the two fluted paperboard clamshells; as a result the difference in total energy is 1 percent. Total energy results for the GPPS and fluted paperboard clamshells overlap so that the comparison is inconclusive.

As with the GPPS foam plates, the total energy requirements for the GPPS foam clamshells are divided evenly between energy of material resource and process energy, with only 2 percent of total energy for transportation. The fluted paperboard clamshell has no coatings and thus no energy of material resource to report. Process energy for the fluted paperboard clamshell is 94 percent of total energy.

Energy recovery from WTE incineration of 20 percent of postconsumer discards is equivalent to about 7 percent of total energy for GPPS and paperboard clamshells.

Energy Profiles. Tables 2-6 through 2-9 show total energy broken out by the sources of energy by fuel, including the fuels used to generate electricity. Energy by fuel source is shown graphically in Figures 2-5 through 2-8.

Precombustion energy (the energy used to extract and process fuels used for process energy and transportation energy) is included in the results shown in the table. The fossil fuels–natural gas, petroleum and coal–are used for direct combustion for process fuels and generation of purchased electricity. Natural gas and petroleum use as raw material inputs for the production of plastics, reported as energy of material resource in Tables 2-2 through 2-5, is included in the totals for natural gas and petroleum energy. Petroleum is the dominant energy source for transportation. Non-fossil sources, such as hydropower, nuclear and other (geothermal, wind, etc.) shown in the table are used to generate purchased electricity along with the fossil fuels. Use of wood for energy occurs at integrated forest product manufacturing sites, particularly those that produce virgin pulp and paper.

The energy tables and figures show that wood is a significant source of process energy for paperboard foodservice products, providing nearly half of the total energy requirements. Integrated pulp and paper mills that produce virgin paper products use wood wastes (e.g., bark) and black liquor from the kraft pulping process to provide a significant part of their operating energy.

Over 90 percent of the total energy for polystyrene foodservice products is from fossil fuels. This includes not only the use of fossil fuels for process and transportation energy, but also the energy content of the crude oil and natural gas used as material feedstocks for production of polystyrene resin.

Table 2-6

Energy Profile for 10,000 16-ounce Hot Cups

	Polystyrene			Poly-Coated Paperboard			Corrugated Cup Sleeves			PE Ppbd Cup + Sleeve		
	Low	Avg	High	Low	Avg	High	Low	Avg	High	Low	Avg	High
Energy Source (Million Btu)												
Nat. Gas	2.76	2.95	3.14	1.83	1.98	2.23	0.18	0.25	0.33	2.01	2.23	2.56
Petroleum	2.13	2.28	2.42	0.51	0.55	0.62	0.12	0.17	0.22	0.63	0.72	0.85
Coal	0.83	0.89	0.94	1.20	1.29	1.46	0.36	0.51	0.66	1.56	1.80	2.12
Hydropower	0.050	0.054	0.057	0.061	0.066	0.074	0.0098	0.014	0.018	0.071	0.080	0.092
Nuclear	0.31	0.34	0.36	0.38	0.41	0.46	0.061	0.086	0.11	0.44	0.50	0.58
Wood	0	0	0	3.26	3.53	3.98	0.50	0.71	0.92	3.77	4.24	4.90
Other	0.043	0.046	0.049	0.052	0.056	0.063	0.0083	0.012	0.015	0.060	0.068	0.078
Total Energy	**6.13**	**6.55**	**6.97**	**7.29**	**7.89**	**8.89**	**1.25**	**1.75**	**2.28**	**8.54**	**9.64**	**11.2**
Energy Source (Percent)												
Nat. Gas	45%	45%	45%	25%	25%	25%	14%	14%	14%	24%	23%	23%
Petroleum	35%	35%	35%	7%	7%	7%	10%	10%	10%	7%	8%	8%
Coal	14%	14%	14%	16%	16%	16%	29%	29%	29%	18%	19%	19%
Hydropower	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Nuclear	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Wood	0%	0%	0%	45%	45%	45%	40%	40%	40%	44%	44%	44%
Other	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Source: Franklin Associates

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 10%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-35 at the end of this chapter for a summary of meaningful differences in results.

Table 2-7

Energy Profile for 10,000 32-ounce Cold Cups

	Polystyrene			Poly-Coated Paperboard			Wax-Coated Paperboard
	Low	Avg	High	Low	Avg	High	Avg
Energy Source (Million Btu)							
Nat. Gas	4.96	5.41	6.12	2.66	2.94	3.13	3.52
Petroleum	3.86	4.21	4.76	0.77	0.85	0.90	2.98
Coal	1.41	1.54	1.75	1.69	1.87	1.99	3.37
Hydropower	0.086	0.094	0.11	0.083	0.092	0.098	0.17
Nuclear	0.54	0.59	0.66	0.52	0.58	0.61	1.03
Wood	0	0	0	5.37	5.94	6.32	11.0
Other	0.073	0.079	0.090	0.071	0.078	0.083	0.14
Total Energy	**10.9**	**11.9**	**13.5**	**11.2**	**12.3**	**13.1**	**22.2**
Energy Source (Percent)							
Nat. Gas	45%	45%	45%	24%	24%	24%	16%
Petroleum	35%	35%	35%	7%	7%	7%	13%
Coal	13%	13%	13%	15%	15%	15%	15%
Hydropower	1%	1%	1%	1%	1%	1%	1%
Nuclear	5%	5%	5%	5%	5%	5%	5%
Wood	0%	0%	0%	48%	48%	48%	50%
Other	1%	1%	1%	1%	1%	1%	1%
Total	100%	100%	100%	100%	100%	100%	100%

Source: Franklin Associates

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 10%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-36 at the end of this chapter for a summary of meaningful differences in results.

Table 2-8

Energy Profile for 10,000 9-inch High-grade Plates

	Polystyrene			Poly-Coated Paperboard			Molded Pulp		
	Low	Avg	High	Low	Avg	High	Low	Avg	High
Energy Source (Million Btu)									
Nat. Gas	4.36	4.53	4.65	2.47	2.49	2.52	2.48	2.54	2.66
Petroleum	4.61	4.79	4.92	0.71	0.71	0.72	0.57	0.58	0.61
Coal	1.53	1.59	1.64	1.38	1.39	1.40	2.73	2.80	2.93
Hydropower	0.093	0.097	0.10	0.066	0.067	0.067	0.088	0.090	0.094
Nuclear	0.58	0.60	0.62	0.41	0.42	0.42	0.55	0.56	0.59
Wood	0	0	0	4.89	4.93	4.97	5.09	5.22	5.47
Other	0.079	0.082	0.084	0.056	0.057	0.057	0.074	0.076	0.080
Total Energy	**11.3**	**11.7**	**12.0**	**9.98**	**10.1**	**10.1**	**11.6**	**11.9**	**12.4**
Energy Source (Percent)									
Nat. Gas	39%	39%	39%	25%	25%	25%	21%	21%	21%
Petroleum	41%	41%	41%	7%	7%	7%	5%	5%	5%
Coal	14%	14%	14%	14%	14%	14%	24%	24%	24%
Hydropower	1%	1%	1%	1%	1%	1%	1%	1%	1%
Nuclear	5%	5%	5%	4%	4%	4%	5%	5%	5%
Wood	0%	0%	0%	49%	49%	49%	44%	44%	44%
Other	1%	1%	1%	1%	1%	1%	1%	1%	1%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%

Source: Franklin Associates

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Results in this table apply only to high-grade plates, which are the strongest and heaviest plates available in each material category. Lighter weight polystyrene and paper plates are available but are not included in these results.
Due to the uncertainties in LCI data, differences in results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 10%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-37 at the end of this chapter for a summary of meaningful differences in results.

Table 2-9

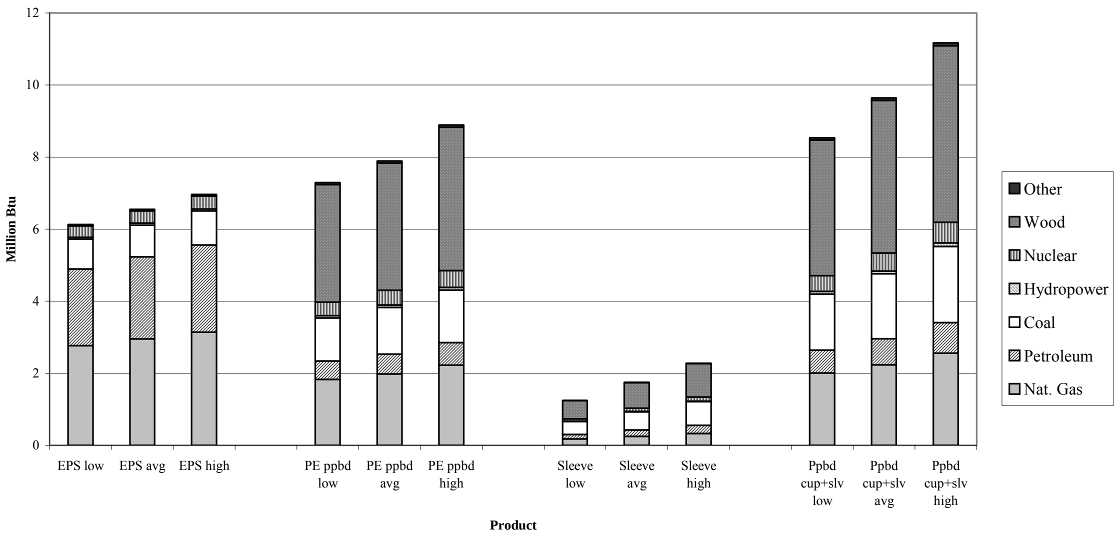
Energy Profile for 10,000 5-inch Sandwich-size Clamshells

	Polystyrene			Fluted Paperboard		
	Low	Avg	High	Low	Avg	High
Energy Source (Million Btu)						
Nat. Gas	1.85	2.01	2.10	0.65	0.65	0.66
Petroleum	1.96	2.14	2.23	0.65	0.65	0.66
Coal	0.66	0.72	0.75	1.32	1.33	1.34
Hydropower	0.040	0.044	0.045	0.035	0.036	0.036
Nuclear	0.25	0.27	0.28	0.22	0.22	0.22
Wood	0	0	0	2.40	2.42	2.44
Other	0.034	0.037	0.038	0.030	0.030	0.031
Total Energy	**4.79**	**5.22**	**5.44**	**5.31**	**5.35**	**5.38**
Energy Source (Percent)						
Nat. Gas	39%	39%	39%	12%	12%	12%
Petroleum	41%	41%	41%	12%	12%	12%
Coal	14%	14%	14%	25%	25%	25%
Hydropower	1%	1%	1%	1%	1%	1%
Nuclear	5%	5%	5%	4%	4%	4%
Wood	0%	0%	0%	45%	45%	45%
Other	1%	1%	1%	1%	1%	1%
Total	100%	100%	100%	100%	100%	100%

Source: Franklin Associates

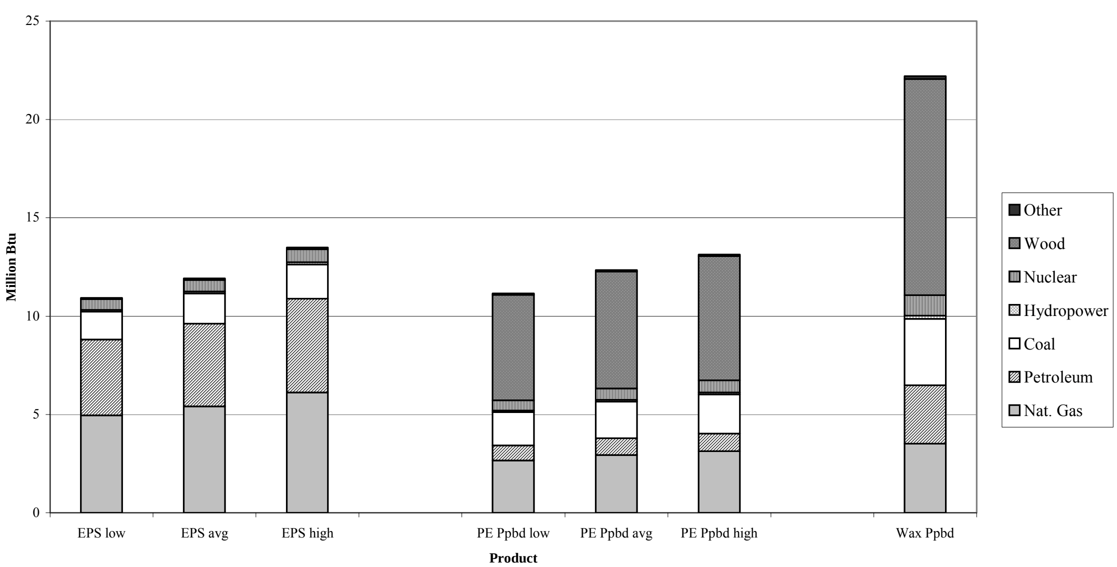
Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 10%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-38 at the end of this chapter for a summary of meaningful differences in results.

Figure 2-5. Energy Profile for 10,000 16-oz Hot Cups (Million Btu)



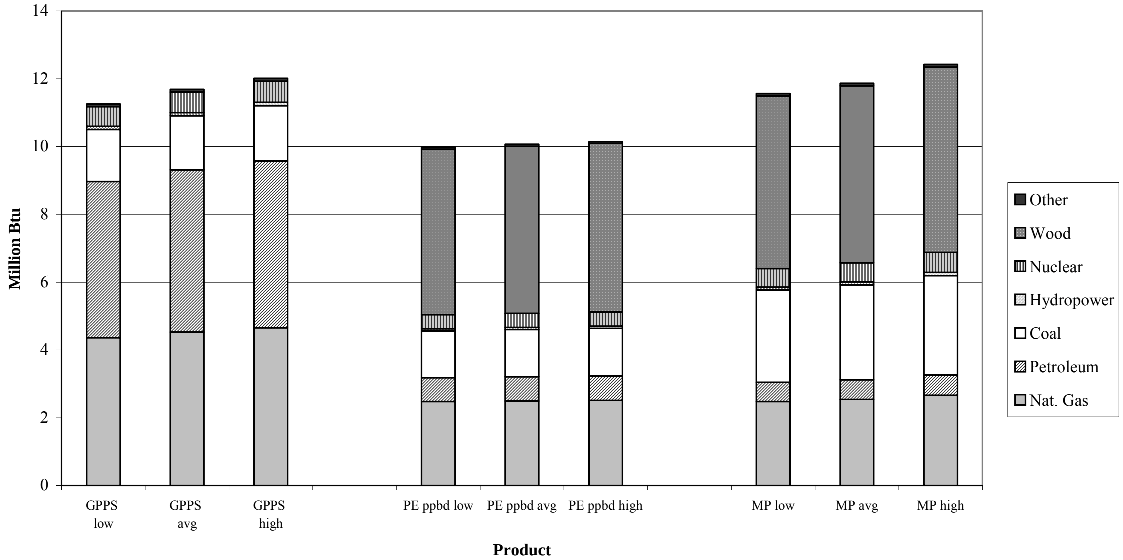
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in energy results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 10%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-35 for a summary of meaningful differences between products.

Figure 2-6. Energy Profile for 10,000 32-oz Cold Cups (Million Btu)



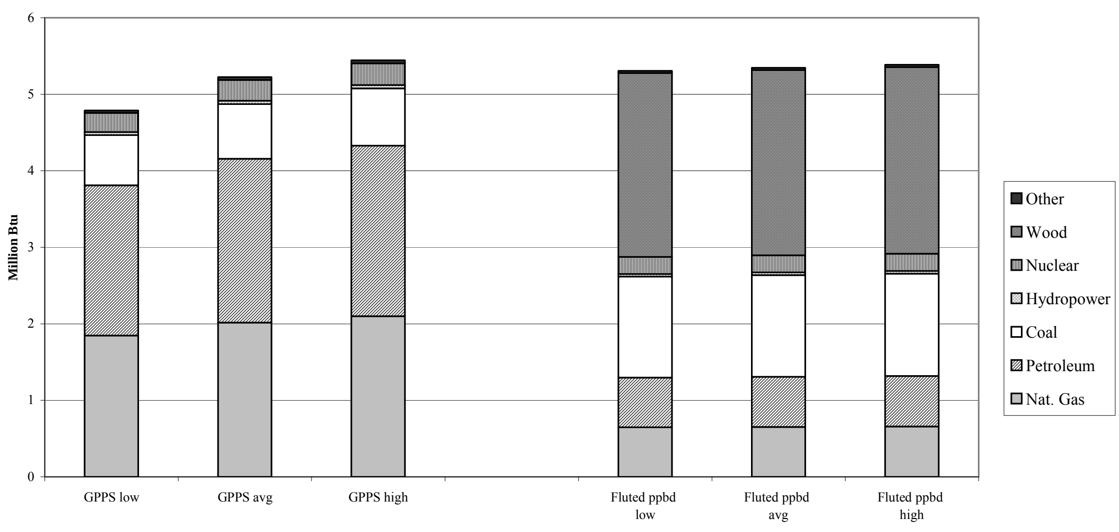
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in energy results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 10%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-36 for a summary of meaningful differences between products.

Figure 2-7. Energy Profile for 10,000 9-inch High-Grade Plates (Million Btu)



Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in energy results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 10%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-37 for a summary of meaningful differences between products.

Figure 2-8. Energy Profile for 10,000 5-inch Sandwich-Size Clamshells (Million Btu)



Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in energy results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 10%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-38 for a summary of meaningful differences between products.

Solid Waste

Solid waste is broadly categorized into process wastes, fuel-related wastes, and postconsumer wastes. **Process wastes** are the solid wastes generated by the various processes from raw material acquisition through material manufacture. **Fuel-related wastes** are the wastes from the production and combustion of fuels used for process energy and transportation energy. **Postconsumer wastes** are the wastes discarded by the end users of the product after diversion for reuse and recycling.

Solid waste results by weight and by volume are shown in Tables 2-10 through 2-13. As with energy results, the upper section of the results tables shows the quantity of solid waste, while the lower section shows the percentage of total solid waste by category.

It is helpful to understand how the results for **solid waste** by category relate to the results for **energy** by category. Solid wastes for a process include not only waste materials generated from the process itself, but also solid wastes from the production and combustion of fuels used for process energy. Thus, **fuel-related solid waste** includes the solid waste associated with process energy as well as transportation energy, while **process solid wastes** include wastes from material extraction or refining processes, wastes from chemical reactions, unrecyclable scrap from fabrication processes, etc.

Solid Waste by Weight. Solid waste by weight is shown graphically for each system in Figures 2-9 through 2-12. Based on the uncertainty in solid waste data, differences in solid waste results between systems are not considered meaningful unless the percent difference is greater than 25 percent for process and fuel-related wastes, or greater than 10 percent for postconsumer wastes. (Percent difference between systems is defined as the difference between solid waste 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 and supported by sample statistical calculations (see Chapter 5).

As with energy results, the heaviest products within each foodservice category have higher solid wastes than the lightest products. The percentage difference in the weights of solid waste from heaviest to lightest weights of each product track very closely with the percent difference in energy results for heaviest to lightest, presented in the **Energy by Category** discussions above. This makes sense when the relationship of energy results and solid waste results is considered.

Table 2-10

Solid Wastes by Weight and Volume for 10,000 16-ounce Hot Cups

	Polystyrene			Poly-Coated Paperboard			Corrugated Cup Sleeves			PE Ppbd Cup + Sleeve		
	Low	Avg	High	Low	Avg	High	Low	Avg	High	Low	Avg	High
Solid Wastes By Weight (lb)												
Process	4.97	5.31	5.64	51.2	55.4	62.4	10.9	15.3	20.0	62.1	70.8	82.4
Fuel	46.4	49.5	52.7	89.8	97.3	110	37.6	52.8	68.8	127	150	178
Postconsumer	77.5	82.8	88.1	217	235	265	146	205	267	363	440	532
Total lb	**129**	**138**	**146**	**358**	**388**	**437**	**195**	**273**	**356**	**553**	**661**	**793**
Weight Percent by Category												
Process	4%	4%	4%	14%	14%	14%	6%	6%	6%	11%	11%	10%
Fuel	36%	36%	36%	25%	25%	25%	19%	19%	19%	23%	23%	22%
Postconsumer	60%	60%	60%	61%	61%	61%	75%	75%	75%	66%	67%	67%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Solid Wastes By Volume (cu ft)												
Process	0.099	0.106	0.11	1.02	1.11	1.25	0.22	0.31	0.40	1.24	1.42	1.65
Fuel	0.93	0.99	1.05	1.80	1.95	2.19	0.75	1.06	1.38	2.55	3.00	3.57
Postconsumer	8.72	9.32	9.91	7.92	8.57	9.66	5.25	7.36	9.59	13.2	15.9	19.3
Total cu ft	**9.75**	**10.4**	**11.1**	**10.7**	**11.6**	**13.1**	**6.22**	**8.73**	**11.4**	**17.0**	**20.4**	**24.5**
Volume Percent by Category												
Process	1%	1%	1%	10%	10%	10%	4%	4%	4%	7%	7%	7%
Fuel	10%	10%	10%	17%	17%	17%	12%	12%	12%	15%	15%	15%
Postconsumer	89%	89%	89%	74%	74%	74%	84%	84%	84%	78%	78%	79%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Source: Franklin Associates

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-35 at the end of this chapter for a summary of meaningful differences in results.

Table 2-11

Solid Wastes by Weight and Volume for 10,000 32-ounce Cold Cups

	Polystyrene			Poly-Coated Paperboard			Wax-Coated Paperboard
	Low	Avg	High	Low	Avg	High	Avg
Solid Wastes By Weight (lb)							
Process	8.95	9.76	11.0	83.3	92.1	98.0	377
Fuel	80.0	87.3	98.8	135	149	159	270
Postconsumer	143	156	176	350	387	412	553
Total lb	**232**	**253**	**286**	**568**	**628**	**668**	**1,200**
Weight Percent by Category							
Process	4%	4%	4%	15%	15%	15%	31%
Fuel	35%	35%	35%	24%	24%	24%	23%
Postconsumer	62%	62%	62%	62%	62%	62%	46%
Total	100%	100%	100%	100%	100%	100%	100%
Solid Wastes By Volume (cu ft)							
Process	0.18	0.20	0.22	1.67	1.84	1.96	11.0
Fuel	1.60	1.75	1.98	2.70	2.99	3.18	5.41
Postconsumer	16.1	17.5	19.8	12.7	14.1	15.0	20.1
Total cu ft	**17.8**	**19.5**	**22.0**	**17.1**	**18.9**	**20.1**	**36.6**
Volume Percent by Category							
Process	1%	1%	1%	10%	10%	10%	30%
Fuel	9%	9%	9%	16%	16%	16%	15%
Postconsumer	90%	90%	90%	74%	74%	74%	55%
Total	100%	100%	100%	100%	100%	100%	100%

Source: Franklin Associates

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-36 at the end of this chapter for a summary of meaningful differences in results.

Table 2-12

Solid Wastes by Weight and Volume for 10,000 9-inch High-grade Plates

	Polystyrene			Poly-Coated Paperboard			Molded Pulp		
	Low	Avg	High	Low	Avg	High	Low	Avg	High
Solid Wastes By Weight (lb)									
Process	7.87	8.17	8.39	76.2	76.8	77.4	89.3	91.7	95.9
Fuel	81.2	84.3	86.7	116	117	118	177	181	190
Postconsumer	183	190	196	321	324	327	286	294	307
Total lb	**272**	**283**	**291**	**514**	**518**	**522**	**552**	**567**	**593**
Weight Percent by Category									
Process	3%	3%	3%	15%	15%	15%	16%	16%	16%
Fuel	30%	30%	30%	23%	23%	23%	32%	32%	32%
Postconsumer	67%	67%	67%	63%	63%	63%	52%	52%	52%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%
Solid Wastes By Volume (cu ft)									
Process	0.16	0.16	0.17	1.52	1.54	1.55	1.79	1.83	1.92
Fuel	1.62	1.69	1.73	2.32	2.34	2.36	3.53	3.62	3.79
Postconsumer	20.6	21.4	22.0	11.7	11.8	11.9	9.43	9.67	10.1
Total cu ft	**22.4**	**23.3**	**23.9**	**15.6**	**15.7**	**15.8**	**14.7**	**15.1**	**15.8**
Volume Percent by Category									
Process	1%	1%	1%	10%	10%	10%	12%	12%	12%
Fuel	7%	7%	7%	15%	15%	15%	24%	24%	24%
Postconsumer	92%	92%	92%	75%	75%	75%	64%	64%	64%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%

Source: Franklin Associates

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Results in this table apply only to high-grade plates, which are the strongest and heaviest plates available in each material category. Lighter weight polystyrene and paper plates are available but are not included in these results.

Due to the uncertainties in LCI data, differences in results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-37 at the end of this chapter for a summary of meaningful differences in results.

Table 2-13

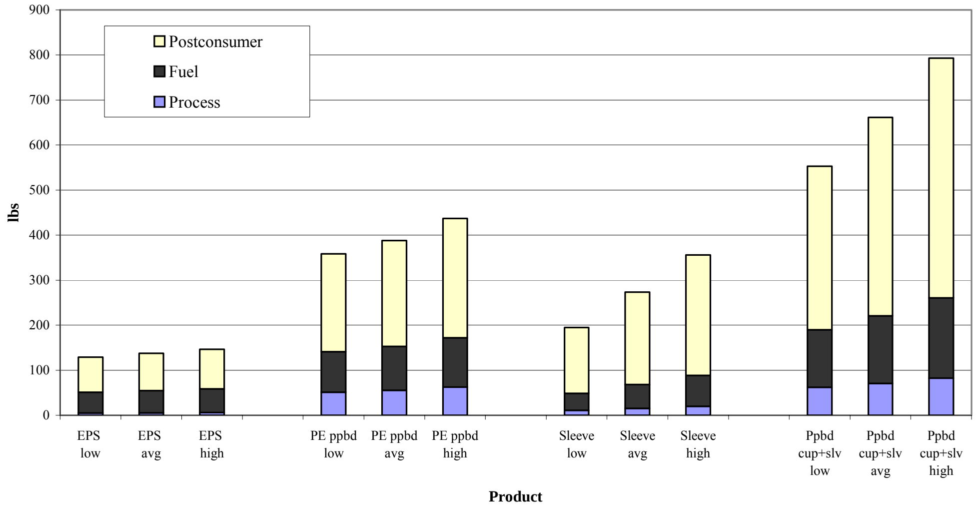
Solid Wastes by Weight and Volume for 10,000 5-inch Sandwich-size Clamshells

	Polystyrene			Fluted Paperboard		
	Low	Avg	High	Low	Avg	High
Solid Wastes By Weight (lb)						
Process	3.28	3.57	3.72	22.5	22.6	22.8
Fuel	34.8	37.9	39.5	82.0	82.6	83.2
Postconsumer	77.5	84.6	88.1	181	182	183
Total lb	**116**	**126**	**131**	**285**	**287**	**289**
Weight Percent by Category						
Process	3%	3%	3%	8%	8%	8%
Fuel	30%	30%	30%	29%	29%	29%
Postconsumer	67%	67%	67%	63%	63%	63%
Total	100%	100%	100%	100%	100%	100%
Solid Wastes By Volume (cu ft)						
Process	0.066	0.071	0.074	0.45	0.45	0.46
Fuel	0.70	0.76	0.79	1.64	1.65	1.66
Postconsumer	8.72	9.52	9.91	6.50	6.55	6.60
Total cu ft	**9.48**	**10.3**	**10.8**	**8.59**	**8.65**	**8.72**
Volume Percent by Category						
Process	1%	1%	1%	5%	5%	5%
Fuel	7%	7%	7%	19%	19%	19%
Postconsumer	92%	92%	92%	76%	76%	76%
Total	100%	100%	100%	100%	100%	100%

Source: Franklin Associates

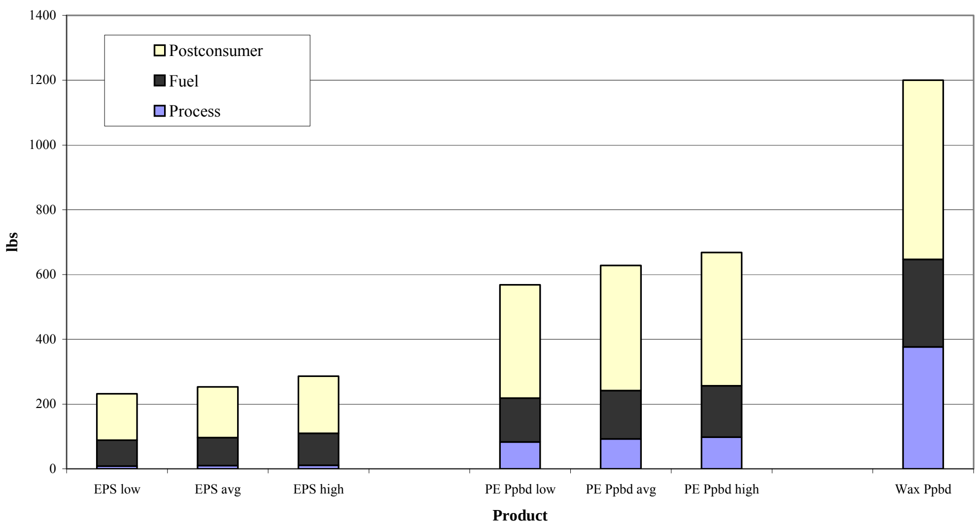
Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-38 at the end of this chapter for a summary of meaningful differences in results.

Figure 2-9. Solid Waste by Weight for 10,000 16-oz Hot Cups (Pounds)



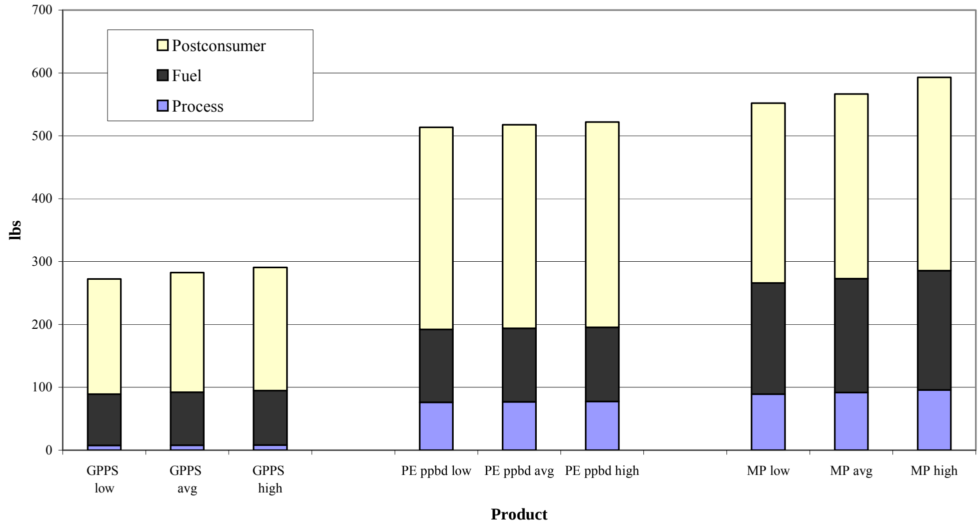
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-35 for a summary of meaningful differences between products.

Figure 2-10. Solid Waste by Weight for 10,000 32-oz Cold Cups (Pounds)



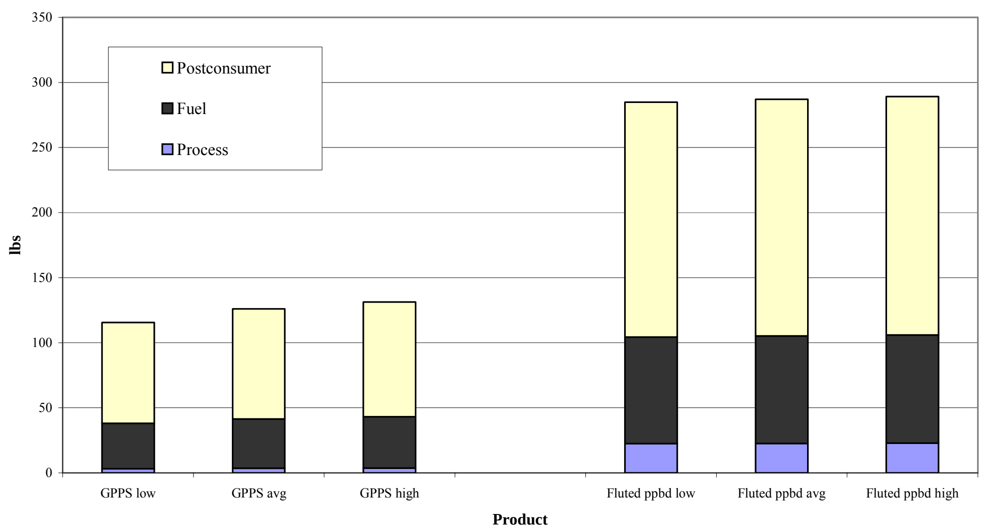
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-36 for a summary of meaningful differences between products.

Figure 2-11. Solid Waste by Weight for 10,000 9-inch High Grade Plates (Pounds)



Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-37 for a summary of meaningful differences between products.

Figure 2-12. Solid Waste by Weight for 10,000 5-inch Sandwich-Size Clamshells (Pounds)



Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-38 for a summary of meaningful differences between products.

Total energy for a product system depends on the quantity of material used in the product, multiplied by the energy requirements per pound of material. The solid waste tables and figures show that solid wastes for each system are dominated by postconsumer wastes and fuel-related wastes. Postconsumer solid waste is directly dependent on the quantity of material used in a product. Fuel-related solid waste is associated with the production and combustion of fuels used for process and transportation energy. Thus, it makes sense that solid waste results show the same variation as energy results when comparing the range of product weights for a given foodservice product.

16-ounce Hot Cups. The comparisons of weight of solid waste for EPS cups with PE-coated cups, with and without cup sleeves, are both meaningful in favor of EPS. Sixty percent or more of the total weight of solid waste for each hot cup is postconsumer waste. Fuel-related solid wastes account for 36 percent of the total weight of solid wastes for the EPS cup, 25 percent of the total for PE-coated cups, and 23 percent of the total for PE-coated cups with sleeves.

32-ounce Cold Cups. For cold cups, there is also a meaningful difference between the total weight of solid waste for EPS cups compared to both PE-coated paperboard and wax-coated paperboard cups, with EPS lower in solid waste. Postconsumer solid waste is 62 percent of the total for both EPS and PE-coated paperboard cups, and 46 percent of the total for wax-coated cups. Fuel-related wastes account for 35 percent of the total weight of solid waste for EPS cups and about 24 percent of the total for the two coated paperboard cups. Process solid wastes are much higher for the wax-coated paperboard cups because the trim scrap from cup fabrication is not recyclable.

9-inch High-grade Plates. GPPS plates are lower in total solid waste by weight when compared to the paper-based plates. Postconsumer solid waste accounts for similar percentages of total solid waste for the polystyrene and PE-coated paperboard systems, 67 percent and 63 percent respectively. For the molded pulp plates, postconsumer solid waste is similar in magnitude to the weight of postconsumer wastes for PE-coated plates, but postconsumer molded pulp plates account for only about half of the total weight of solid waste. Fuel-related solid waste is highest for the molded pulp system because of the two fabrication steps involved in producing plates from industrial scrap (chemical pulping to produce the original paper, then repulping of the industrial scrap and fabrication into molded pulp plates).

5-inch Sandwich-size Clamshells. The difference in total weight of solid waste for GPPS foam clamshells compared to fluted paperboard clamshells is meaningful, in favor of GPPS. As with plates, postconsumer solid waste accounts for 67 percent of the total weight of solid waste for polystyrene clamshells and 63 percent of the total for fluted paperboard. Fuel-related solid wastes for polystyrene and paperboard clamshells are about 30 percent of the total.

Solid Waste by Volume. Landfills fill up because of volume, not weight. While weight is the conventional measure of waste, landfill volume is more relevant to the environmental concerns of land use. The problem is the difficulty in deriving accurate landfill volume factors. However, Franklin Associates has developed a set of landfill density factors for different materials based upon an extensive sampling by the University of Arizona. While these factors are considered to be only estimates, their use helps add valuable perspective. Volume factors are estimated to be accurate to +/- 25%. This means that waste volume values must differ by at least 25% in order to be interpreted as a meaningful difference. (Percent difference is defined as the difference between two system totals divided by their average.)

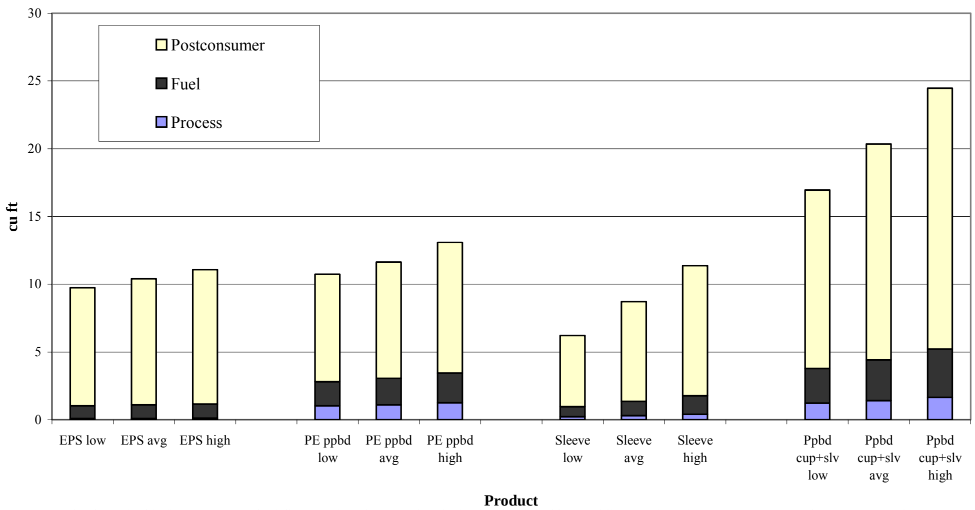
Weights of solid waste are converted into volumes using landfill density factors. Process and fuel-related solid waste are generally reported as totals without detail on the composition and densities of individual substances within these categories; thus, the weights of process and fuel-related waste are converted to volume using an average conversion factor for industrial solid waste. The weight to volume conversions for postconsumer solid waste, however, are based on the landfill densities for materials from the University of Arizona studies and reflect the volumes that specific materials are likely to take up in a landfill.

Solid waste by volume is shown graphically for each system in Figures 2-13 through 2-16. The density of postconsumer foodservice products is lower than the density of process and fuel-related solid wastes; thus, when the weights of solid waste by category are converted to volumes, postconsumer wastes account for a larger proportion of total solid waste by volume than by weight. For all foodservice product systems, postconsumer waste is the dominant contributor to both the total weight and total volume of solid waste.

When the figures for solid waste by weight are compared to the corresponding figures for solid waste by volume for each type of foodservice product, it is interesting to note that solid waste by weight for polystyrene products is generally lower than for alternative paper-based systems; however, by volume, the totals for polystyrene and paper-based products are comparable (or, in the case of plates, polystyrene has a higher solid waste volume). This is because of the very low density of polystyrene foam products.

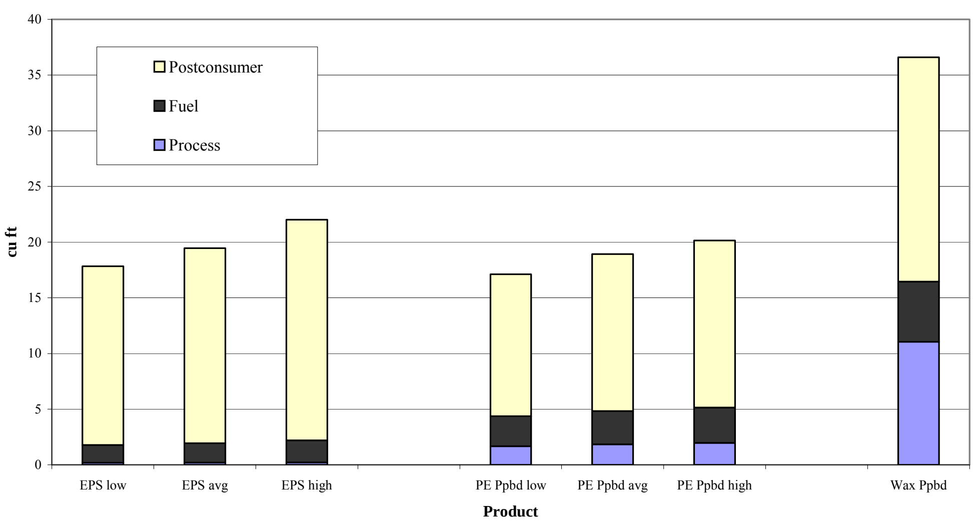
16-ounce Hot Cups. For hot cups, the comparison of the total volumes of solid wastes for EPS and PE-coated paperboard cups is inconclusive; however, there is a meaningful difference in the total volume of solid waste for PE-coated cups with sleeves compared to EPS cups, with EPS lower. Postconsumer solid waste accounts for 90 percent of the total solid waste volume for EPS cups, 74 percent for PE-coated cups, and 78 percent for PE-coated cups with sleeves.

Figure 2-13. Solid Waste by Volume for 10,000 16-oz Hot Cups (cubic feet)



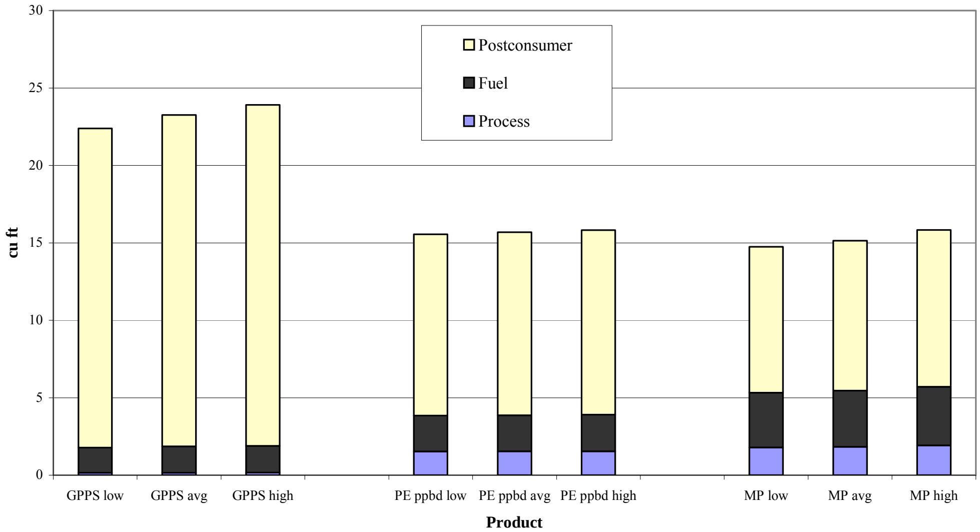
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-35 for a summary of meaningful differences between products.

Figure 2-14. Solid Waste by Volume for 10,000 32-oz Cold Cups (cubic feet)



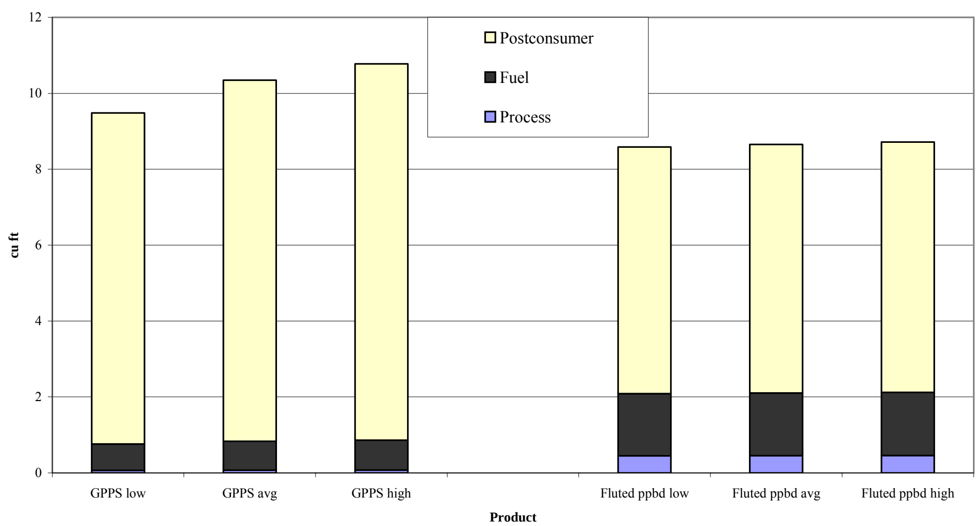
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-36 for a summary of meaningful differences between products.

Figure 2-15. Solid Waste by Volume for 10,000 9-inch High-Grade Plates (cubic feet)



Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-37 for a summary of meaningful differences between products.

Figure 2-16. Solid Waste by Volume for 10,000 5-inch Sandwich-Size Clamshell (cubic feet)



Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-38 for a summary of meaningful differences between products.

32-ounce Cold Cups. As with hot cups, the solid waste volume comparison of EPS and PE-coated paperboard cups is inconclusive. The percent difference in solid waste volumes for wax-coated paperboard cold cups compared to EPS and PE-coated cups is meaningful, with the wax-coated cup higher in both cases. Postconsumer solid waste is 90 percent of the total volume of solid waste for EPS cold cups, 74 percent of the total for PE-coated paperboard, and 55 percent of the total for waxed paperboard cups. The volume of process wastes for wax-coated cups is much higher than for other cups because the wax-coated fabrication scrap is not recyclable and is discarded as process waste.

9-inch High-grade Plates. Although the comparison of solid weight results for GPPS plates and PE-coated paperboard plates and molded pulp plates is meaningful in favor of GPPS, these results are reversed for solid waste volume because of the very low density of polystyrene foam products. As a result, the difference in total volume of solid waste for GPPS foam plates compared to both PE-coated paperboard plates and molded pulp plates is meaningful with GPPS higher in both cases.

For GPPS foam plates, postconsumer solid waste volume is 92 percent of the total solid waste volume. Postconsumer solid waste is 75 percent of the total solid waste volume for PE-coated plates and 64 percent of the total for molded pulp plates.

5-inch Sandwich-size Clamshells. Although the comparison of total weight of solid waste for GPPS foam clamshells and fluted paperboard clamshells is meaningful in favor of GPPS, the comparison of total solid waste volume for the two systems is inconclusive.

As in all other foodservice categories, postconsumer solid waste dominates the solid waste volume results, at 92 percent of the total for GPPS foam clamshells and 76 percent of the total for fluted paperboard.

Environmental Emissions

Atmospheric and waterborne emissions for each system include emissions from processes and those associated with the combustion of fuels. Atmospheric emissions are shown in 2-14 through 2-17, and waterborne emissions are shown in Tables 2-18 through 21.

The emissions tables in this section present emission quantities based upon the best data available. However, some of the data are reported from industrial sources, some are from standard emissions tables, and some have been calculated. This means there are significant uncertainties with regards to the application of the data to these particular foodservice product systems. Because of these uncertainties, the difference in two systems' emissions of a given substance is not considered meaningful unless the percent difference exceeds 25 percent. (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 and supported by sample statistical calculations (see Chapter 5).

Table 2-14

Atmospheric Emissions for 10,000 16-ounce Hot Cups

	Polystyrene			Poly-Coated Paperboard			Corrugated Cup Sleeves			PE Ppbd Cup + Sleeve		
	Low	Avg	High	Low	Avg	High	Low	Avg	High	Low	Avg	High
Atmospheric Emissions (lb)												
Particulates	0.32	0.34	0.37	1.55	1.67	1.88	0.53	0.75	0.97	2.08	2.42	2.86
Nitrogen Oxides	1.95	2.09	2.22	3.31	3.59	4.04	1.77	2.48	3.23	5.08	6.07	7.27
Hydrocarbons	2.16	2.31	2.46	1.28	1.38	1.56	0.27	0.37	0.49	1.55	1.76	2.05
Sulfur Oxides	6.03	6.44	6.85	6.13	6.64	7.47	2.70	3.80	4.95	8.83	10.4	12.4
Carbon Monoxide	1.05	1.12	1.20	5.76	6.24	7.03	2.95	4.14	5.40	8.71	10.4	12.4
Aldehydes	0.0086	0.0092	0.0097	0.024	0.026	0.030	0.011	0.015	0.020	0.035	0.041	0.049
Methane	1.31	1.39	1.48	1.15	1.24	1.40	0.36	0.51	0.66	1.51	1.75	2.06
Other Organics	0.068	0.073	0.077	0.23	0.25	0.28	0.15	0.22	0.28	0.38	0.46	0.56
Odorous Sulfur	0	0	0	0	0	0	6.0E-05	8.4E-05	1.1E-04	6.0E-05	8.4E-05	1.1E-04
Kerosene	7.0E-05	7.5E-05	8.0E-05	8.5E-05	9.2E-05	1.0E-04	1.7E-05	2.4E-05	3.1E-05	1.0E-04	1.2E-04	1.4E-04
Ammonia	0.0013	0.0013	0.0014	0.0011	0.0012	0.0014	0.010	0.014	0.018	0.011	0.015	0.020
Hydrogen Fluoride	0.0019	0.0020	0.0022	0.0023	0.0025	0.0028	4.7E-04	6.6E-04	8.5E-04	0.0028	0.0032	0.0037
Lead	1.5E-05	1.6E-05	1.7E-05	4.4E-04	4.7E-04	5.3E-04	1.5E-04	2.1E-04	2.8E-04	5.9E-04	6.9E-04	8.1E-04
Mercury	6.1E-06	6.5E-06	6.9E-06	1.1E-05	1.1E-05	1.3E-05	1.3E-05	1.8E-05	2.4E-05	2.4E-05	3.0E-05	3.7E-05
Chlorine	2.3E-05	2.4E-05	2.6E-05	0.0029	0.0031	0.0035	9.8E-04	0.0014	0.0018	0.0038	0.0045	0.0053
HCl	0.014	0.015	0.016	0.017	0.018	0.020	0.0034	0.0048	0.0062	0.020	0.023	0.027
CO2 (fossil)	470	502	534	455	493	555	198	278	362	653	770	917
CO2 (non-fossil)	0.13	0.14	0.15	760	823	927	262	368	480	1,023	1,191	1,407
Total Reduced Sulfur	0	0	0	0.079	0.086	0.097	0.0062	0.0087	0.011	0.086	0.095	0.11
Metals (unspecified)	5.3E-05	5.7E-05	6.0E-05	0.31	0.34	0.38	0.11	0.15	0.20	0.42	0.49	0.57
Antimony	3.0E-06	3.2E-06	3.4E-06	1.8E-06	1.9E-06	2.2E-06	5.9E-07	8.3E-07	1.1E-06	2.4E-06	2.8E-06	3.3E-06
Arsenic	1.3E-05	1.4E-05	1.5E-05	5.9E-05	6.4E-05	7.2E-05	4.5E-05	6.4E-05	8.3E-05	1.0E-04	1.3E-04	1.5E-04
Beryllium	1.4E-06	1.4E-06	1.5E-06	3.2E-06	3.4E-06	3.9E-06	4.0E-06	5.7E-06	7.4E-06	7.2E-06	9.1E-06	1.1E-05
Cadmium	7.8E-06	8.3E-06	8.8E-06	8.2E-06	8.8E-06	1.0E-05	1.1E-05	1.6E-05	2.1E-05	2.0E-05	2.5E-05	3.1E-05
Chromium	1.9E-05	2.1E-05	2.2E-05	6.7E-05	7.2E-05	8.1E-05	7.4E-05	1.0E-04	1.4E-04	1.4E-04	1.8E-04	2.2E-04
Cobalt	8.4E-06	9.0E-06	9.6E-06	5.0E-06	5.4E-06	6.1E-06	1.7E-06	2.3E-06	3.0E-06	6.7E-06	7.7E-06	9.1E-06
Manganese	3.3E-05	3.6E-05	3.8E-05	0.0034	0.0036	0.0041	0.0012	0.0017	0.0023	0.0046	0.0054	0.0064
Nickel	1.1E-04	1.2E-04	1.3E-04	2.7E-04	3.0E-04	3.4E-04	1.3E-04	1.8E-04	2.3E-04	4.0E-04	4.8E-04	5.7E-04
Selenium	2.1E-05	2.3E-05	2.4E-05	2.4E-05	2.6E-05	2.9E-05	5.1E-06	7.1E-06	9.3E-06	2.9E-05	3.3E-05	3.8E-05
Acreolin	2.7E-06	2.9E-06	3.1E-06	3.3E-06	3.6E-06	4.0E-06	6.7E-07	9.4E-07	1.2E-06	4.0E-06	4.5E-06	5.3E-06
Nitrous Oxide	0.0017	0.0018	0.0020	0.0028	0.0030	0.0034	0.0018	0.0026	0.0034	0.0046	0.0056	0.0067
Benzene	3.9E-06	4.2E-06	4.5E-06	0.0013	0.0014	0.0016	4.6E-04	6.5E-04	8.5E-04	0.0018	0.0021	0.0025
Perchloroethylene	2.6E-06	2.8E-06	3.0E-06	3.2E-06	3.4E-06	3.9E-06	6.4E-07	9.0E-07	1.2E-06	3.8E-06	4.3E-06	5.0E-06
Trichloroethylene	2.6E-06	2.8E-06	2.9E-06	3.1E-06	3.4E-06	3.8E-06	6.3E-07	8.9E-07	1.2E-06	3.8E-06	4.3E-06	5.0E-06
Methylene Chloride	1.2E-05	1.2E-05	1.3E-05	1.4E-05	1.5E-05	1.7E-05	2.8E-06	4.0E-06	5.2E-06	1.7E-05	1.9E-05	2.2E-05
Carbon Tetrachloride	4.4E-06	4.7E-06	5.0E-06	5.2E-06	5.6E-06	6.4E-06	1.1E-06	1.6E-06	2.1E-06	6.3E-06	7.2E-06	8.4E-06
Phenols	8.2E-06	8.7E-06	9.3E-06	0.014	0.015	0.017	0.0048	0.0068	0.0089	0.019	0.022	0.026
Naphthalene	2.1E-07	2.3E-07	2.4E-07	8.5E-04	9.2E-04	0.0010	2.9E-04	4.1E-04	5.4E-04	0.0011	0.0013	0.0016
Dioxins	1.5E-11	1.6E-11	1.7E-11	1.8E-11	2.0E-11	2.2E-11	3.7E-12	5.1E-12	6.7E-12	2.2E-11	2.5E-11	2.9E-11
n-nitrosodimethlamine	5.8E-07	6.2E-07	6.6E-07	7.0E-07	7.6E-07	8.5E-07	1.4E-07	2.0E-07	2.6E-07	8.4E-07	9.6E-07	1.1E-06
Radionuclides	4.7E-05	5.0E-05	5.3E-05	5.6E-05	6.1E-05	6.9E-05	1.1E-05	1.6E-05	2.1E-05	6.8E-05	7.7E-05	9.0E-05
Ethylene Glycol	0	0	0	0.0036	0.0039	0.0044	0	0	0	0.0036	0.0039	0.0044
Greenhouse Gas Summary (lb of Carbon Dioxide Equivalents)												
Fossil CO2	470	502	534	455	493	555	198	278	362	653	770	917
Methane	30.0	32.1	34.1	26.4	28.6	32.2	8.31	11.7	15.2	34.7	40.3	47.4
Nitrous oxide	0.51	0.55	0.58	0.82	0.88	1.00	0.54	0.76	0.99	1.36	1.65	1.99
Total	**500**	**534**	**569**	**482**	**522**	**588**	**207**	**290**	**378**	**689**	**812**	**966**

Source: Franklin Associates

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-35 at the end of this chapter for a summary of meaningful differences in results.

Table 2-15

Atmospheric Emissions for 10,000 32-ounce Cold Cups

	Polystyrene			Poly-Coated Paperboard			Wax-Coated Paperboard
	Low	Avg	High	Low	Avg	High	Avg
Atmospheric Emissions (lb)							
Particulates	0.56	0.61	0.69	2.45	2.71	2.88	4.98
Nitrogen Oxides	3.44	3.75	4.25	5.15	5.69	6.06	10.1
Hydrocarbons	3.94	4.30	4.86	1.89	2.09	2.22	3.18
Sulfur Oxides	10.7	11.7	13.3	9.14	10.1	10.8	15.4
Carbon Monoxide	1.88	2.05	2.32	9.39	10.4	11.1	18.8
Aldehydes	0.016	0.017	0.019	0.040	0.044	0.047	0.083
Methane	2.31	2.52	2.85	1.65	1.82	1.94	2.70
Other Organics	0.12	0.14	0.15	0.37	0.41	0.44	0.73
Kerosene	1.2E-04	1.3E-04	1.5E-04	1.2E-04	1.3E-04	1.4E-04	2.3E-04
Ammonia	0.0022	0.0024	0.0027	0.0016	0.0018	0.0019	0.0035
Hydrogen Fluoride	0.0033	0.0036	0.0040	0.0032	0.0035	0.0037	0.0063
Lead	2.6E-05	2.8E-05	3.2E-05	7.2E-04	7.9E-04	8.4E-04	0.0015
Mercury	1.0E-05	1.1E-05	1.3E-05	1.6E-05	1.7E-05	1.8E-05	3.1E-05
Chlorine	4.1E-05	4.5E-05	5.0E-05	0.0047	0.0052	0.0055	0.0097
HCl	0.024	0.026	0.029	0.023	0.025	0.027	0.045
CO2 (fossil)	826	901	1,020	668	739	786	1,295
CO2 (non-fossil)	0.23	0.25	0.28	1,251	1,384	1,472	2,564
Total Reduced Sulfur	0	0	0	0.13	0.14	0.15	0.27
Metals (unspecified)	9.3E-05	1.0E-04	1.1E-04	0.51	0.56	0.60	1.05
Antimony	5.3E-06	5.8E-06	6.5E-06	2.5E-06	2.8E-06	2.9E-06	5.3E-06
Arsenic	2.2E-05	2.4E-05	2.8E-05	9.4E-05	1.0E-04	1.1E-04	1.9E-04
Beryllium	2.3E-06	2.5E-06	2.9E-06	4.9E-06	5.4E-06	5.7E-06	9.9E-06
Cadmium	1.4E-05	1.5E-05	1.7E-05	1.3E-05	1.4E-05	1.5E-05	2.7E-05
Chromium	3.4E-05	3.7E-05	4.1E-05	1.0E-04	1.2E-04	1.2E-04	2.1E-04
Cobalt	1.5E-05	1.6E-05	1.8E-05	7.0E-06	7.8E-06	8.2E-06	1.5E-05
Manganese	5.7E-05	6.3E-05	7.1E-05	0.0055	0.0061	0.0065	0.011
Nickel	2.0E-04	2.2E-04	2.5E-04	4.4E-04	4.9E-04	5.2E-04	9.1E-04
Selenium	3.7E-05	4.0E-05	4.5E-05	3.3E-05	3.6E-05	3.8E-05	6.5E-05
Acreolin	4.7E-06	5.1E-06	5.8E-06	4.5E-06	5.0E-06	5.3E-06	9.0E-06
Nitrous Oxide	0.0030	0.0032	0.0036	0.0040	0.0044	0.0047	0.0079
Benzene	6.7E-06	7.4E-06	8.3E-06	0.0022	0.0024	0.0025	0.0044
Perchloroethylene	4.5E-06	4.9E-06	5.5E-06	4.3E-06	4.8E-06	5.1E-06	8.6E-06
Trichloroethylene	4.4E-06	4.8E-06	5.5E-06	4.3E-06	4.7E-06	5.0E-06	8.5E-06
Methylene Chloride	2.0E-05	2.2E-05	2.4E-05	1.9E-05	2.1E-05	2.3E-05	3.8E-05
Carbon Tetrachloride	7.5E-06	8.1E-06	9.2E-06	7.2E-06	7.9E-06	8.4E-06	1.4E-05
Phenols	1.4E-05	1.5E-05	1.7E-05	0.023	0.026	0.027	0.047
Naphthalene	3.7E-07	4.0E-07	4.5E-07	0.0014	0.0015	0.0016	0.0029
Dioxins	2.6E-11	2.8E-11	3.2E-11	2.5E-11	2.7E-11	2.9E-11	4.9E-11
n-nitrosodimethlamine	9.9E-07	1.1E-06	1.2E-06	9.6E-07	1.1E-06	1.1E-06	1.9E-06
Radionuclides	8.0E-05	8.7E-05	9.8E-05	7.7E-05	8.5E-05	9.1E-05	1.5E-04
Methyl Ethyl Ketone	0	0	0	0	0	0	0.023
Ethylene Glycol	0	0	0	0.0059	0.0066	0.0070	0.012
Greenhouse Gas Summary (lb of Carbon Dioxide Equivalents)							
Fossil CO2	826	901	1,020	668	739	786	1,295
Methane	53.1	57.9	65.6	37.9	41.9	44.6	62.0
Nitrous oxide	0.87	0.95	1.08	1.17	1.30	1.38	2.35
Total	**880**	**960**	**1,087**	**707**	**782**	**832**	**1,359**

Source: Franklin Associates

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-36 at the end of this chapter for a summary of meaningful differences in results.

Table 2-16

Atmospheric Emissions for 10,000 9-inch High-grade Plates

	Polystyrene			Poly-Coated Paperboard			Molded Pulp		
	Low	Avg	High	Low	Avg	High	Low	Avg	High
Atmospheric Emissions (lb)									
Particulates	0.59	0.61	0.63	2.17	2.19	2.21	2.87	2.95	3.09
Nitrogen Oxides	2.90	3.01	3.10	4.56	4.59	4.63	5.64	5.79	6.06
Hydrocarbons	4.49	4.66	4.79	1.76	1.77	1.79	1.63	1.67	1.75
Sulfur Oxides	9.74	10.1	10.4	8.21	8.28	8.35	10.3	10.5	11.0
Carbon Monoxide	1.44	1.50	1.54	8.55	8.62	8.69	9.00	9.23	9.66
Aldehydes	0.018	0.019	0.020	0.036	0.036	0.037	0.037	0.038	0.040
Methane	2.16	2.24	2.30	1.44	1.46	1.47	2.03	2.09	2.18
Other Organics	0.14	0.14	0.15	0.34	0.34	0.35	0.34	0.35	0.37
Kerosene	1.3E-04	1.4E-04	1.4E-04	9.3E-05	9.3E-05	9.4E-05	1.2E-04	1.3E-04	1.3E-04
Ammonia	0.0025	0.0026	0.0027	0.0013	0.0013	0.0013	0.0016	0.0016	0.0017
Hydrogen Fluoride	0.0035	0.0037	0.0038	0.0025	0.0025	0.0026	0.0033	0.0034	0.0036
Lead	2.1E-05	2.1E-05	2.2E-05	6.5E-04	6.6E-04	6.6E-04	6.9E-04	7.1E-04	7.4E-04
Mercury	1.0E-05	1.1E-05	1.1E-05	1.3E-05	1.3E-05	1.3E-05	1.8E-05	1.8E-05	1.9E-05
Chlorine	4.9E-05	5.1E-05	5.2E-05	0.0043	0.0043	0.0044	0.0045	0.0046	0.0048
HCl	0.026	0.027	0.027	0.018	0.018	0.018	0.024	0.025	0.026
CO2 (fossil)	746	775	796	571	575	580	948	973	1,018
CO2 (non-fossil)	0.21	0.22	0.23	1,139	1,148	1,158	1,186	1,217	1,274
Total Reduced Sulfur	0	0	0	0.12	0.12	0.12	0.12	0.13	0.13
Metals (unspecified)	8.7E-05	9.1E-05	9.3E-05	0.46	0.47	0.47	0.48	0.50	0.52
Antimony	3.4E-06	3.5E-06	3.6E-06	2.1E-06	2.1E-06	2.1E-06	3.1E-06	3.1E-06	3.3E-06
Arsenic	2.0E-05	2.1E-05	2.1E-05	8.4E-05	8.4E-05	8.5E-05	1.7E-04	1.7E-04	1.8E-04
Beryllium	2.2E-06	2.3E-06	2.4E-06	4.2E-06	4.2E-06	4.3E-06	1.4E-05	1.4E-05	1.5E-05
Cadmium	7.4E-06	7.6E-06	7.8E-06	1.1E-05	1.1E-05	1.1E-05	3.8E-05	3.9E-05	4.1E-05
Chromium	3.1E-05	3.2E-05	3.3E-05	9.2E-05	9.3E-05	9.4E-05	2.6E-04	2.7E-04	2.8E-04
Cobalt	9.5E-06	9.8E-06	1.0E-05	5.8E-06	5.8E-06	5.8E-06	8.6E-06	8.8E-06	9.2E-06
Manganese	5.9E-05	6.1E-05	6.3E-05	0.0050	0.0050	0.0051	0.0055	0.0056	0.0059
Nickel	1.1E-04	1.2E-04	1.2E-04	3.9E-04	4.0E-04	4.0E-04	5.3E-04	5.5E-04	5.7E-04
Selenium	3.7E-05	3.9E-05	4.0E-05	2.6E-05	2.6E-05	2.6E-05	3.5E-05	3.6E-05	3.7E-05
Acreolin	5.1E-06	5.3E-06	5.4E-06	3.6E-06	3.6E-06	3.7E-06	4.8E-06	4.9E-06	5.1E-06
Nitrous Oxide	0.0032	0.0033	0.0034	0.0033	0.0033	0.0033	0.0075	0.0077	0.0080
Benzene	7.3E-06	7.5E-06	7.8E-06	0.0020	0.0020	0.0020	0.0021	0.0021	0.0022
Perchloroethylene	4.8E-06	5.0E-06	5.2E-06	3.4E-06	3.5E-06	3.5E-06	4.5E-06	4.7E-06	4.9E-06
Trichloroethylene	4.8E-06	5.0E-06	5.1E-06	3.4E-06	3.4E-06	3.5E-06	4.5E-06	4.6E-06	4.8E-06
Methylene Chloride	2.1E-05	2.2E-05	2.3E-05	1.5E-05	1.5E-05	1.5E-05	2.0E-05	2.1E-05	2.2E-05
Carbon Tetrachloride	8.0E-06	8.3E-06	8.5E-06	5.7E-06	5.8E-06	5.8E-06	7.7E-06	7.9E-06	8.3E-06
Phenols	1.5E-05	1.5E-05	1.6E-05	0.021	0.021	0.021	0.022	0.022	0.024
Naphthalene	3.6E-07	3.8E-07	3.9E-07	0.0013	0.0013	0.0013	0.0013	0.0014	0.0014
Dioxins	2.8E-11	2.9E-11	3.0E-11	2.0E-11	2.0E-11	2.0E-11	2.6E-11	2.7E-11	2.8E-11
n-nitrosodimethlamine	1.1E-06	1.1E-06	1.1E-06	7.6E-07	7.7E-07	7.7E-07	1.0E-06	1.0E-06	1.1E-06
Radionuclides	8.6E-05	8.9E-05	9.2E-05	6.1E-05	6.2E-05	6.2E-05	8.1E-05	8.3E-05	8.7E-05
Ethylene Glycol	0	0	0	0.0054	0.0055	0.0055	0.0056	0.0058	0.0061
Greenhouse Gas Summary (lb of Carbon Dioxide Equivalents)									
Fossil CO2	746	775	796	571	575	580	948	973	1,018
Methane	49.6	51.5	53.0	33.2	33.5	33.8	46.8	48.0	50.3
Nitrous oxide	0.95	0.98	1.01	0.97	0.98	0.99	2.22	2.28	2.38
Total	**797**	**827**	**850**	**605**	**610**	**615**	**997**	**1,023**	**1,071**

Source: Franklin Associates

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Results in this table apply only to high-grade plates, which are the strongest and heaviest plates available in each material category. Lighter weight polystyrene and paper plates are available but are not included in these results.
Due to the uncertainties in LCI data, differences in results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-37 at the end of this chapter for a summary of meaningful differences in results.

Table 2-17

Atmospheric Emissions for 10,000 5-inch Sandwich-size Clamshells

	Polystyrene			Fluted Paperboard		
	Low	Avg	High	Low	Avg	High
Atmospheric Emissions (lb)						
Particulates	0.25	0.27	0.28	0.98	0.99	1.00
Nitrogen Oxides	1.24	1.35	1.41	3.85	3.87	3.90
Hydrocarbons	1.90	2.07	2.16	0.62	0.62	0.63
Sulfur Oxides	4.14	4.51	4.70	5.63	5.67	5.71
Carbon Monoxide	0.61	0.67	0.70	5.79	5.83	5.88
Aldehydes	0.0078	0.0085	0.0089	0.021	0.021	0.021
Methane	0.92	1.00	1.04	0.80	0.80	0.81
Other Organics	0.058	0.064	0.066	0.30	0.30	0.30
Odorous Sulfur	0	0	0	0.0016	0.0017	0.0017
Kerosene	5.6E-05	6.1E-05	6.3E-05	5.0E-05	5.0E-05	5.0E-05
Ammonia	0.0011	0.0012	0.0012	0.019	0.019	0.019
Hydrogen Fluoride	0.0015	0.0017	0.0017	0.0013	0.0014	0.0014
Lead	8.8E-06	9.6E-06	1.0E-05	3.4E-04	3.4E-04	3.4E-04
Mercury	4.4E-06	4.8E-06	5.0E-06	2.5E-05	2.5E-05	2.5E-05
Chlorine	2.1E-05	2.3E-05	2.4E-05	0.0033	0.0034	0.0034
HCl	0.011	0.012	0.012	0.0098	0.0098	0.0099
CO2 (fossil)	319	348	363	464	467	470
CO2 (non-fossil)	0.092	0.10	0.10	560	564	568
Total Reduced Sulfur	0	0	0	0.042	0.043	0.043
Metals (unspecified)	3.7E-05	4.1E-05	4.2E-05	0.23	0.23	0.23
Antimony	1.4E-06	1.6E-06	1.6E-06	5.4E-06	5.4E-06	5.5E-06
Arsenic	8.5E-06	9.2E-06	9.6E-06	9.6E-05	9.7E-05	9.8E-05
Beryllium	9.6E-07	1.0E-06	1.1E-06	8.1E-06	8.2E-06	8.2E-06
Cadmium	3.1E-06	3.4E-06	3.6E-06	3.4E-05	3.5E-05	3.5E-05
Chromium	1.3E-05	1.5E-05	1.5E-05	1.5E-04	1.5E-04	1.5E-04
Cobalt	4.0E-06	4.4E-06	4.6E-06	1.5E-05	1.5E-05	1.5E-05
Manganese	2.5E-05	2.8E-05	2.9E-05	0.0026	0.0026	0.0027
Nickel	4.8E-05	5.3E-05	5.5E-05	4.4E-04	4.5E-04	4.5E-04
Selenium	1.6E-05	1.7E-05	1.8E-05	1.9E-05	1.9E-05	1.9E-05
Acreolin	2.2E-06	2.4E-06	2.5E-06	1.9E-06	1.9E-06	2.0E-06
Nitrous Oxide	0.0014	0.0015	0.0016	0.0038	0.0038	0.0038
Benzene	3.1E-06	3.4E-06	3.5E-06	9.9E-04	0.0010	0.0010
Perchloroethylene	2.1E-06	2.3E-06	2.4E-06	1.8E-06	1.9E-06	1.9E-06
Trichloroethylene	2.1E-06	2.2E-06	2.3E-06	1.8E-06	1.8E-06	1.9E-06
Methylene Chloride	9.2E-06	1.0E-05	1.0E-05	8.2E-06	8.2E-06	8.3E-06
Carbon Tetrachloride	3.4E-06	3.7E-06	3.9E-06	3.2E-06	3.2E-06	3.2E-06
Phenols	6.3E-06	6.8E-06	7.1E-06	0.010	0.010	0.010
Naphthalene	1.5E-07	1.7E-07	1.8E-07	6.2E-04	6.3E-04	6.3E-04
Dioxins	1.2E-11	1.3E-11	1.3E-11	1.1E-11	1.1E-11	1.1E-11
n-nitrosodimethlamine	4.6E-07	5.0E-07	5.2E-07	4.1E-07	4.1E-07	4.1E-07
Radionuclides	3.7E-05	4.0E-05	4.2E-05	3.3E-05	3.3E-05	3.3E-05
Greenhouse Gas Summary (lb of Carbon Dioxide Equivalents)						
Fossil CO2	319	348	363	464	467	470
Methane	21.1	23.0	24.0	18.3	18.5	18.6
Nitrous oxide	0.41	0.44	0.46	1.12	1.13	1.14
Total	**341**	**372**	**387**	**483**	**487**	**490**

Source: Franklin Associates

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-38 at the end of this chapter for a summary of meaningful differences in results.

Table 2-18

Waterborne Emissions for 10,000 16-ounce Hot Cups

	Polystyrene			Poly-Coated Paperboard			Corrugated Cup Sleeves			PE Ppbd Cup + Sleeve		
	Low	Avg	High	Low	Avg	High	Low	Avg	High	Low	Avg	High
Waterborne Wastes (lb)												
Acid	0.0035	0.0038	0.0040	0.0047	0.0050	0.0057	0.0027	0.0037	0.0049	0.0073	0.0088	0.011
Metal Ion (unspecified)	0.0025	0.0027	0.0029	6.1E-04	6.6E-04	7.4E-04	2.6E-04	3.7E-04	4.8E-04	8.7E-04	0.0010	0.0012
Fluorides	3.1E-04	3.3E-04	3.5E-04	3.4E-04	3.7E-04	4.1E-04	6.9E-05	9.6E-05	1.3E-04	4.1E-04	4.6E-04	5.4E-04
Dissolved Solids	7.98	8.53	9.07	26.3	28.5	32.1	0.82	1.15	1.50	27.1	29.6	33.6
Suspended Solids	0.25	0.26	0.28	1.43	1.54	1.74	0.52	0.73	0.95	1.95	2.27	2.69
BOD	0.065	0.069	0.074	1.09	1.18	1.33	0.34	0.48	0.62	1.43	1.66	1.95
COD	0.19	0.20	0.21	1.74	1.89	2.12	1.71	2.40	3.12	3.45	4.28	5.25
Phenol	8.2E-06	8.8E-06	9.4E-06	4.1E-06	4.5E-06	5.1E-06	7.5E-05	1.0E-04	1.4E-04	7.9E-05	1.1E-04	1.4E-04
Sulfides	0.0019	0.0020	0.0021	0.0018	0.0019	0.0022	0.0061	0.0086	0.011	0.0079	0.011	0.013
Oil	0.14	0.15	0.16	0.088	0.095	0.11	0.021	0.029	0.038	0.11	0.12	0.14
Sulfuric Acid	0.0020	0.0022	0.0023	0.0026	0.0029	0.0032	0.0013	0.0018	0.0023	0.0039	0.0047	0.0056
Iron	0.011	0.012	0.013	0.015	0.017	0.019	0.013	0.018	0.024	0.028	0.035	0.043
Cyanide	5.0E-07	5.3E-07	5.7E-07	3.6E-07	3.8E-07	4.3E-07	6.0E-08	8.4E-08	1.1E-07	4.2E-07	4.7E-07	5.4E-07
Chromium	3.4E-04	3.6E-04	3.9E-04	2.2E-04	2.4E-04	2.7E-04	3.6E-05	5.1E-05	6.6E-05	2.6E-04	2.9E-04	3.4E-04
Aluminum	2.0E-04	2.1E-04	2.3E-04	0	0	0	0.015	0.021	0.027	0.015	0.021	0.027
Nickel	0	0	0	7.3E-09	7.9E-09	8.9E-09	2.5E-10	3.4E-10	4.5E-10	7.5E-09	8.2E-09	9.3E-09
Mercury	2.6E-08	2.8E-08	3.0E-08	2.8E-08	3.0E-08	3.4E-08	3.1E-09	4.4E-09	5.7E-09	3.1E-08	3.4E-08	3.9E-08
Lead	2.1E-07	2.3E-07	2.4E-07	9.7E-06	1.0E-05	1.2E-05	2.2E-08	3.1E-08	4.0E-08	9.7E-06	1.1E-05	1.2E-05
Phosphates	0.0015	0.0016	0.0017	0.0036	0.0040	0.0045	0.013	0.018	0.023	0.016	0.022	0.028
Phosphorus	0	0	0	0	0	0	0.0069	0.0097	0.013	0.0069	0.0097	0.013
Nitrogen	0	0	0	0.0093	0.010	0.011	0.0025	0.0035	0.0045	0.012	0.014	0.016
Zinc	1.5E-04	1.6E-04	1.7E-04	0.0013	0.0014	0.0016	9.9E-05	1.4E-04	1.8E-04	0.0014	0.0016	0.0018
Ammonia	8.0E-04	8.6E-04	9.1E-04	2.5E-04	2.7E-04	3.0E-04	0.0048	0.0067	0.0088	0.0050	0.0070	0.0091
Hydrocarbons	0.0095	0.010	0.011	0	0	0	0	0	0	0	0	0
Chlorides	0.34	0.37	0.39	0.23	0.24	0.28	0.037	0.051	0.067	0.26	0.30	0.34
Cadmium	3.4E-04	3.6E-04	3.9E-04	2.2E-04	2.4E-04	2.7E-04	3.6E-05	5.1E-05	6.6E-05	2.6E-04	2.9E-04	3.4E-04
Organic Carbon	0.0045	0.0048	0.0051	0.0042	0.0045	0.0051	0	0	0	0.0042	0.0045	0.0051
Sulfates	0.30	0.32	0.34	0.22	0.23	0.26	0.037	0.051	0.067	0.25	0.28	0.33
Sodium	1.1E-04	1.2E-04	1.3E-04	1.4E-04	1.5E-04	1.6E-04	2.7E-05	3.8E-05	5.0E-05	1.6E-04	1.8E-04	2.1E-04
Calcium	6.1E-05	6.5E-05	6.9E-05	7.3E-05	7.9E-05	8.9E-05	1.5E-05	2.1E-05	2.7E-05	8.8E-05	1.0E-04	1.2E-04
Manganese	0.0063	0.0068	0.0072	0.0090	0.0097	0.011	0.0044	0.0061	0.0080	0.013	0.016	0.019
Nitrates	2.6E-05	2.8E-05	3.0E-05	3.2E-05	3.5E-05	3.9E-05	6.5E-06	9.1E-06	1.2E-05	3.8E-05	4.4E-05	5.1E-05
Boron	0.0081	0.0087	0.0092	0.011	0.011	0.013	0.0051	0.0072	0.0093	0.016	0.019	0.022
Other Organics	0.018	0.020	0.021	0.012	0.013	0.015	0.0032	0.0046	0.0059	0.015	0.017	0.021
Chromates	6.4E-06	6.9E-06	7.3E-06	2.9E-06	3.2E-06	3.6E-06	1.2E-06	1.7E-06	2.2E-06	4.2E-06	4.9E-06	5.8E-06
Sodium Dichromate	0	0	0	6.0E-06	6.5E-06	7.3E-06	0	0	0	6.0E-06	6.5E-06	7.3E-06

Source: Franklin Associates

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-35 at the end of this chapter for a summary of meaningful differences in results.

Table 2-19

Waterborne Emissions for 10,000 32-ounce Cold Cups

	Polystyrene			Poly-Coated Paperboard			Wax-Coated Paperboard
	Low	Avg	High	Low	Avg	High	Avg
Waterborne Wastes (lb)							
Acid	0.0064	0.0070	0.0079	0.0064	0.0071	0.0075	0.0025
Metal Ion (unspecified)	0.0046	0.0050	0.0057	9.1E-04	0.0010	0.0011	0.0035
Fluorides	5.3E-04	5.8E-04	6.6E-04	4.6E-04	5.1E-04	5.5E-04	9.2E-04
Dissolved Solids	14.3	15.6	17.7	42.4	46.8	49.8	81.7
Suspended Solids	0.43	0.47	0.53	2.29	2.54	2.70	4.64
BOD	0.12	0.13	0.14	1.79	1.98	2.11	3.65
COD	0.33	0.36	0.41	2.85	3.15	3.35	5.74
Phenol	1.5E-05	1.6E-05	1.8E-05	6.5E-06	7.2E-06	7.7E-06	9.7E-05
Sulfides	0.0034	0.0037	0.0042	0.0024	0.0026	0.0028	3.3E-06
Oil	0.25	0.27	0.30	0.13	0.14	0.15	0.17
Sulfuric Acid	0.0035	0.0038	0.0043	0.0037	0.0041	0.0044	0.0075
Iron	0.020	0.021	0.024	0.022	0.024	0.025	0.043
Cyanide	8.9E-07	9.7E-07	1.1E-06	5.2E-07	5.8E-07	6.2E-07	7.3E-07
Chromium	6.1E-04	6.7E-04	7.5E-04	3.3E-04	3.6E-04	3.8E-04	4.4E-04
Aluminum	3.6E-04	3.9E-04	4.4E-04	0	0	0	0
Nickel	0	0	0	1.2E-08	1.3E-08	1.4E-08	2.5E-08
Mercury	4.7E-08	5.1E-08	5.8E-08	4.2E-08	4.7E-08	5.0E-08	6.8E-08
Lead	3.8E-07	4.2E-07	4.7E-07	1.6E-05	1.8E-05	1.9E-05	3.3E-05
Phosphates	0.0026	0.0028	0.0032	0.0056	0.0062	0.0066	0.011
Nitrogen	0	0	0	0.015	0.017	0.018	0.031
Zinc	2.7E-04	2.9E-04	3.3E-04	0.0021	0.0024	0.0025	0.0042
Ammonia	0.0014	0.0016	0.0018	3.5E-04	3.9E-04	4.2E-04	8.2E-04
Hydrocarbons	0.017	0.019	0.021	0	0	0	0
Chlorides	0.61	0.67	0.76	0.33	0.36	0.39	0.44
Cadmium	6.1E-04	6.7E-04	7.5E-04	3.3E-04	3.6E-04	3.8E-04	4.4E-04
Organic Carbon	0.0081	0.0089	0.0100	0.0055	0.0061	0.0065	0
Sulfates	0.53	0.58	0.65	0.31	0.34	0.36	0.45
Sodium	1.9E-04	2.1E-04	2.4E-04	1.8E-04	2.0E-04	2.2E-04	3.7E-04
Calcium	1.0E-04	1.1E-04	1.3E-04	1.0E-04	1.1E-04	1.2E-04	2.0E-04
Manganese	0.011	0.012	0.013	0.013	0.014	0.015	0.025
Nitrates	4.5E-05	4.9E-05	5.6E-05	4.4E-05	4.8E-05	5.2E-05	8.7E-05
Boron	0.014	0.015	0.017	0.015	0.016	0.018	0.030
Other Organics	0.033	0.036	0.041	0.018	0.020	0.021	0.033
Chromates	1.1E-05	1.3E-05	1.4E-05	4.2E-06	4.6E-06	4.9E-06	9.2E-06
Sodium Dichromate	0	0	0	9.8E-06	1.1E-05	1.2E-05	2.0E-05

Source: Franklin Associates

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-36 at the end of this chapter for a summary of meaningful differences in results.

Table 2-20

Waterborne Emissions for 10,000 9-inch High-grade Plates

	Polystyrene			Poly-Coated Paperboard			Molded Pulp		
	Low	Avg	High	Low	Avg	High	Low	Avg	High
Waterborne Wastes (lb)									
Acid	0.0081	0.0084	0.0086	0.0063	0.0064	0.0064	0.0011	0.0012	0.0012
Metal Ion (unspecified)	0.0055	0.0057	0.0059	8.4E-04	8.5E-04	8.6E-04	6.6E-04	6.8E-04	7.1E-04
Fluorides	5.2E-04	5.4E-04	5.5E-04	3.7E-04	3.7E-04	3.7E-04	4.9E-04	5.0E-04	5.2E-04
Dissolved Solids	11.9	12.4	12.7	38.7	39.0	39.3	40.1	41.1	43.0
Suspended Solids	0.41	0.42	0.43	2.06	2.08	2.10	3.06	3.14	3.29
BOD	0.14	0.14	0.15	1.63	1.65	1.66	2.05	2.10	2.20
COD	0.35	0.36	0.37	2.60	2.62	2.64	2.68	2.75	2.88
Phenol	1.8E-05	1.9E-05	1.9E-05	6.0E-06	6.0E-06	6.1E-06	5.5E-06	5.7E-06	5.9E-06
Sulfides	0.0042	0.0044	0.0045	0.0024	0.0024	0.0024	1.5E-06	1.6E-06	1.7E-06
Oil	0.22	0.23	0.24	0.12	0.12	0.12	0.12	0.12	0.13
Sulfuric Acid	0.0035	0.0037	0.0038	0.0030	0.0031	0.0031	0.0058	0.0060	0.0063
Iron	0.020	0.021	0.022	0.017	0.018	0.018	0.033	0.034	0.035
Cyanide	7.8E-07	8.1E-07	8.4E-07	4.8E-07	4.9E-07	4.9E-07	4.9E-07	5.0E-07	5.3E-07
Chromium	5.4E-04	5.6E-04	5.7E-04	3.0E-04	3.1E-04	3.1E-04	3.1E-04	3.1E-04	3.3E-04
Nickel	0	0	0	1.1E-08	1.1E-08	1.1E-08	1.1E-08	1.2E-08	1.2E-08
Mercury	4.1E-08	4.3E-08	4.4E-08	3.9E-08	3.9E-08	3.9E-08	4.0E-08	4.1E-08	4.2E-08
Lead	4.6E-07	4.7E-07	4.9E-07	1.5E-05	1.5E-05	1.5E-05	1.5E-05	1.5E-05	1.6E-05
Phosphates	0.0022	0.0023	0.0023	0.0050	0.0050	0.0051	0.0062	0.0064	0.0067
Nitrogen	0	0	0	0.014	0.014	0.014	0.015	0.015	0.016
Zinc	2.6E-04	2.7E-04	2.7E-04	0.0020	0.0020	0.0020	0.0020	0.0020	0.0021
Ammonia	7.6E-04	7.9E-04	8.1E-04	3.0E-04	3.0E-04	3.1E-04	3.7E-04	3.8E-04	4.0E-04
Hydrocarbons	0.022	0.022	0.023	0	0	0	0	0	0
Chlorides	0.54	0.56	0.57	0.31	0.31	0.31	0.31	0.32	0.33
Cadmium	5.4E-04	5.6E-04	5.7E-04	3.0E-04	3.1E-04	3.1E-04	3.1E-04	3.1E-04	3.3E-04
Organic Carbon	0.0097	0.010	0.010	0.0056	0.0056	0.0057	0	0	0
Sulfates	0.48	0.50	0.51	0.28	0.28	0.28	0.30	0.30	0.32
Sodium	2.1E-04	2.1E-04	2.2E-04	1.5E-04	1.5E-04	1.5E-04	1.9E-04	2.0E-04	2.1E-04
Calcium	1.1E-04	1.2E-04	1.2E-04	8.0E-05	8.0E-05	8.1E-05	1.1E-04	1.1E-04	1.1E-04
Manganese	0.012	0.012	0.012	0.010	0.010	0.010	0.020	0.021	0.021
Nitrates	4.9E-05	5.1E-05	5.2E-05	3.5E-05	3.5E-05	3.5E-05	4.6E-05	4.7E-05	5.0E-05
Boron	0.014	0.015	0.015	0.012	0.012	0.012	0.023	0.024	0.025
Other Organics	0.027	0.028	0.028	0.016	0.016	0.016	0.024	0.024	0.025
Chromates	6.2E-06	6.5E-06	6.6E-06	3.5E-06	3.5E-06	3.6E-06	5.6E-06	5.7E-06	6.0E-06
Sodium Dichromate	0	0	0	9.0E-06	9.0E-06	9.1E-06	9.3E-06	9.6E-06	1.0E-05

Source: Franklin Associates

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Results in this table apply only to high-grade plates, which are the strongest and heaviest plates available in each material category. Lighter weight polystyrene and paper plates are available but are not included in these results.
Due to the uncertainties in LCI data, differences in results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-37 at the end of this chapter for a summary of meaningful differences in results.

Table 2-21

Waterborne Emissions for 10,000 5-inch Sandwich-size Clamshells

	Polystyrene			Fluted Paperboard		
	Low	Avg	High	Low	Avg	High
Waterborne Wastes (lb)						
Acid	0.0035	0.0038	0.0039	0.0043	0.0044	0.0044
Metal Ion (unspecified)	0.0023	0.0025	0.0027	7.9E-04	7.9E-04	8.0E-04
Fluorides	2.2E-04	2.4E-04	2.5E-04	2.0E-04	2.0E-04	2.0E-04
Dissolved Solids	5.06	5.52	5.75	1.82	1.83	1.85
Suspended Solids	0.17	0.19	0.20	1.05	1.06	1.07
BOD	0.059	0.064	0.067	0.45	0.45	0.46
COD	0.15	0.16	0.17	2.52	2.54	2.56
Phenol	7.6E-06	8.3E-06	8.6E-06	2.6E-06	2.6E-06	2.6E-06
Sulfides	0.0018	0.0020	0.0021	3.6E-07	3.7E-07	3.7E-07
Oil	0.093	0.10	0.11	0.032	0.033	0.033
Sulfuric Acid	0.0015	0.0016	0.0017	0.0032	0.0033	0.0033
Iron	0.0087	0.0095	0.0099	0.016	0.016	0.016
Cyanide	3.3E-07	3.6E-07	3.8E-07	1.4E-07	1.4E-07	1.4E-07
Chromium	2.3E-04	2.5E-04	2.6E-04	8.1E-05	8.1E-05	8.2E-05
Aluminum	0	0	0	0.018	0.018	0.018
Nickel	0	0	0	2.7E-09	2.7E-09	2.7E-09
Mercury	1.8E-08	1.9E-08	2.0E-08	9.9E-09	1.0E-08	1.0E-08
Lead	1.9E-07	2.1E-07	2.2E-07	6.8E-08	6.9E-08	6.9E-08
Phosphates	9.3E-04	0.0010	0.0011	0.022	0.022	0.022
Phosphorus	0	0	0	0.019	0.019	0.019
Nitrogen	0	0	0	0.0070	0.0070	0.0071
Zinc	1.1E-04	1.2E-04	1.2E-04	2.8E-05	2.8E-05	2.9E-05
Ammonia	3.3E-04	3.5E-04	3.7E-04	0.030	0.030	0.031
Hydrocarbons	0.0093	0.010	0.011	0	0	0
Chlorides	0.23	0.25	0.26	0.082	0.082	0.083
Cadmium	2.3E-04	2.5E-04	2.6E-04	8.0E-05	8.1E-05	8.2E-05
Organic Carbon	0.0040	0.0044	0.0046	0	0	0
Sulfates	0.20	0.22	0.23	0.087	0.088	0.088
Sodium	8.8E-05	9.6E-05	1.0E-04	7.9E-05	7.9E-05	8.0E-05
Calcium	4.8E-05	5.2E-05	5.5E-05	4.3E-05	4.3E-05	4.3E-05
Manganese	0.0050	0.0055	0.0057	0.0096	0.0097	0.0097
Nitrates	2.1E-05	2.3E-05	2.4E-05	1.9E-05	1.9E-05	1.9E-05
Boron	0.0060	0.0066	0.0069	0.013	0.013	0.013
Other Organics	0.011	0.012	0.013	0.0075	0.0076	0.0076
Chromates	2.7E-06	2.9E-06	3.0E-06	1.3E-05	1.3E-05	1.3E-05
Sodium Dichromate	0	0	0	2.0E-06	2.0E-06	2.1E-06

Source: Franklin Associates

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-38 at the end of this chapter for a summary of meaningful differences in results.

It is important to realize that interpretation of air and water emission data requires great care. The effects of the various emissions on humans and on the environment are not fully known. The degree of potential environmental disruption due to environmental releases is not related to the weight of the releases in a simple way. Research on this evaluation problem is ongoing, but no valid impact assessment methodology currently exists for a life cycle study.

The analysis does not include emissions from the combustion of 20% of postconsumer products discarded after diversion for reuse and recycling or from the decomposition of product in landfills. (See discussion in Chapter 1.) As a result, carbon dioxide and methane emissions, as well as other products of incomplete combustion or decomposition, are understated by an unknown amount.

Process and Fuel-related Emissions. The total emissions of each substance shown in Tables 2-14 through 2-21 include both process and fuel-related emissions. As defined in the report glossary, process emissions are those released directly from the sequence of processes that are used to extract, transform, fabricate, or otherwise effect changes on a material or product during its life cycle, while fuel-related emissions are those associated with the combustion of fuels used for process energy and transportation energy.

Tables 2-22 through 2-25 show the relative percentages of process and fuel-related emissions for each substance released over the life cycle of average weight foodservice products in each product category. The tables show that the majority of atmospheric emissions are fuel-related. Waterborne emissions also tend to be dominated by fuel-related emissions in many cases, but not to the same extent as atmospheric emissions.

It is not practical to attempt to discuss individually all the emission categories listed in the tables (over 40 different atmospheric substances and over 30 waterborne substances); therefore, matrices are presented at the end of this section summarizing the comparison of the full list of emissions for each polystyrene foam product and alternative products.

Greenhouse Gas Emissions. The following discussion focuses on the high priority atmospheric issue of greenhouse gas emissions.

The primary three atmospheric emissions reported in this analysis that contribute to global warming are fossil fuel-derived carbon dioxide, methane, and nitrous oxide. (Non-fossil carbon dioxide emissions, such as those from the burning of wood, are considered part of the natural carbon cycle and are not considered a net contributor to global warming.) The 100-year global warming potential for each of these substances as reported in the Intergovernmental Panel on Climate Change (IPCC) 2001 report are: carbon dioxide 1, methane 23, and nitrous oxide 296. The global warming potential represents the relative global warming contribution of a pound of a particular greenhouse

Table 2-22 (page 1 of 2)

Process and Fuel-Related Emissions for 10,000 Average Weight 16-ounce Hot Cups (lb/10,000 product units)

	Polystyrene			Poly-Coated Paperboard			Corrugated Cup Sleeves		
	Total	**% Process**	**% Fuel**	**Total**	**% Process**	**% Fuel**	**Total**	**% Process**	**% Fuel**
Atmospheric Emissions									
Particulates	0.34	9%	91%	1.67	68%	32%	0.75	54%	46%
Nitrogen Oxides	2.09	14%	86%	3.59	25%	75%	2.48	43%	57%
Hydrocarbons	2.31	47%	53%	1.38	36%	64%	0.37	1%	99%
Sulfur Oxides	6.44	17%	83%	6.64	36%	64%	3.80	47%	53%
Carbon Monoxide	1.12	19%	81%	6.24	0%	100%	4.14	30%	70%
Aldehydes	0.0092	44%	56%	0.026	35%	65%	0.015	12%	88%
Methane	1.39	15%	85%	1.24	15%	85%	0.51	0%	100%
Other Organics	0.073	0%	100%	0.25	0%	100%	0.22	0%	100%
Odorous Sulfur	0			0			8.4E-05	100%	0%
Kerosene	7.5E-05	0%	100%	9.2E-05	0%	100%	2.4E-05	0%	100%
Ammonia	0.0013	39%	61%	0.0012	16%	84%	0.014	98%	2%
Hydrogen Fluoride	0.0020	0%	100%	0.0025	0%	100%	6.6E-04	0%	100%
Lead	1.6E-05	1%	99%	4.7E-04	0%	100%	2.1E-04	0%	100%
Mercury	6.5E-06	0%	100%	1.1E-05	35%	65%	1.8E-05	83%	17%
Chlorine	2.4E-05	86%	14%	0.0031	1%	99%	0.0014	0%	100%
HCl	0.015	0%	100%	0.018	0%	100%	0.0048	0%	100%
CO2 (fossil)	502	1%	99%	493	0%	100%	278	0%	100%
CO2 (non-fossil)	0.14	0%	100%	823	0%	100%	368	0%	100%
Total Reduced Sulfur	0			0.086	100%	0%	0.0087	100%	0%
Metals (unspecified)	5.7E-05	0%	100%	0.34	0%	100%	0.15	0%	100%
Antimony	3.2E-06	0%	100%	1.9E-06	0%	100%	8.3E-07	0%	100%
Arsenic	1.4E-05	0%	100%	6.4E-05	0%	100%	6.4E-05	0%	100%
Beryllium	1.4E-06	0%	100%	3.4E-06	0%	100%	5.7E-06	0%	100%
Cadmium	8.3E-06	0%	100%	8.8E-06	0%	100%	1.6E-05	0%	100%
Chromium	2.1E-05	0%	100%	7.2E-05	0%	100%	1.0E-04	0%	100%
Cobalt	9.0E-06	0%	100%	5.4E-06	0%	100%	2.3E-06	0%	100%
Manganese	3.6E-05	0%	100%	0.0036	0%	100%	0.0017	0%	100%
Nickel	1.2E-04	0%	100%	3.0E-04	0%	100%	1.8E-04	0%	100%
Selenium	2.3E-05	0%	100%	2.6E-05	0%	100%	7.1E-06	0%	100%
Acreolin	2.9E-06	0%	100%	3.6E-06	0%	100%	9.4E-07	0%	100%
Nitrous Oxide	0.0018	0%	100%	0.0030	0%	100%	0.0026	0%	100%
Benzene	4.2E-06	0%	100%	0.0014	0%	100%	6.5E-04	0%	100%
Perchloroethylene	2.8E-06	0%	100%	3.4E-06	0%	100%	9.0E-07	0%	100%
Trichloroethylene	2.8E-06	0%	100%	3.4E-06	0%	100%	8.9E-07	0%	100%
Methylene Chloride	1.2E-05	0%	100%	1.5E-05	0%	100%	4.0E-06	0%	100%
Carbon Tetrachloride	4.7E-06	0%	100%	5.6E-06	0%	100%	1.6E-06	0%	100%
Phenols	8.7E-06	0%	100%	0.015	0%	100%	0.0068	0%	100%
Naphthalene	2.3E-07	0%	100%	9.2E-04	0%	100%	4.1E-04	0%	100%
Dioxins	1.6E-11	0%	100%	2.0E-11	0%	100%	5.1E-12	0%	100%
n-nitrosodimethlamine	6.2E-07	0%	100%	7.6E-07	0%	100%	2.0E-07	0%	100%
Radionuclides	5.0E-05	0%	100%	6.1E-05	0%	100%	1.6E-05	0%	100%
Ethylene Glycol	0			0.0039	100%	0%	0		
Greenhouse Gas Summary									
Fossil CO2	502	1%	99%	493	0%	100%	278	0%	100%
Methane	32.1	15%	85%	28.6	15%	85%	11.7	0%	100%
Nitrous oxide	0.55	0%	100%	0.88	0%	100%	0.76	0%	100%
Total	**534**	2%	98%	**522**	1%	99%	**290**	0%	100%

Source: Franklin Associates

Results shown in this table represent average weight product based on the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. The purpose of this table is to illustrate the relative shares of total emissions that are released from processes and from the production and combustion of fuels, respectively. Conclusions regarding the relative performance of competing products cannot be drawn from this table because the full range of product weights for each material are not shown.

Table 2-22 (page 2 of 2)

Process and Fuel-Related Emissions for 10,000 Average Weight 16-ounce Hot Cups
(lb/10,000 product units)

	Polystyrene			Poly-Coated Paperboard			Corrugated Cup Sleeves		
	Total	**% Process**	**% Fuel**	**Total**	**% Process**	**% Fuel**	**Total**	**% Process**	**% Fuel**
Waterborne Wastes									
Acid	0.0038	100%	0%	0.0050	100%	0%	0.0037	100%	0%
Metal Ion (unspecified)	0.0027	88%	12%	6.6E-04	30%	70%	3.7E-04	1%	99%
Fluorides	3.3E-04	10%	90%	3.7E-04	0%	100%	9.6E-05	0%	100%
Dissolved Solids	8.53	26%	74%	28.5	87%	13%	1.15	2%	98%
Suspended Solids	0.26	7%	93%	1.54	83%	17%	0.73	81%	19%
BOD	0.069	91%	9%	1.18	100%	0%	0.48	100%	0%
COD	0.20	55%	45%	1.89	97%	3%	2.40	99%	1%
Phenol	8.8E-06	88%	12%	4.5E-06	67%	33%	1.0E-04	99%	1%
Sulfides	0.0020	100%	0%	0.0019	100%	0%	0.0086	100%	0%
Oil	0.15	24%	76%	0.095	30%	70%	0.029	30%	70%
Sulfuric Acid	0.0022	0%	100%	0.0029	0%	100%	0.0018	0%	100%
Iron	0.012	5%	95%	0.017	0%	100%	0.018	47%	53%
Cyanide	5.3E-07	21%	79%	3.8E-07	35%	65%	8.4E-08	12%	88%
Chromium	3.6E-04	21%	79%	2.4E-04	29%	71%	5.1E-05	0%	100%
Aluminum	2.1E-04	100%	0%	0			0.021	100%	0%
Nickel	0			7.9E-09	100%	0%	3.4E-10	100%	0%
Mercury	2.8E-08	21%	79%	3.0E-08	56%	44%	4.4E-09	11%	89%
Lead	2.3E-07	88%	12%	1.0E-05	100%	0%	3.1E-08	2%	98%
Phosphates	0.0016	32%	68%	0.0040	64%	36%	0.018	95%	5%
Phosphorus	0			0			0.0097	100%	0%
Nitrogen	0			0.010	100%	0%	0.0035	100%	0%
Zinc	1.6E-04	38%	62%	0.0014	96%	4%	1.4E-04	87%	13%
Ammonia	8.6E-04	70%	30%	2.7E-04	9%	91%	0.0067	99%	1%
Hydrocarbons	0.010	100%	0%	0			0		
Chlorides	0.37	21%	79%	0.24	29%	71%	0.051	0%	100%
Cadmium	3.6E-04	20%	80%	2.4E-04	29%	71%	5.1E-05	0%	100%
Organic Carbon	0.0048	100%	0%	0.0045	100%	0%	0		
Sulfates	0.32	18%	82%	0.23	23%	77%	0.051	1%	99%
Sodium	1.2E-04	0%	100%	1.5E-04	0%	100%	3.8E-05	0%	100%
Calcium	6.5E-05	0%	100%	7.9E-05	0%	100%	2.1E-05	0%	100%
Manganese	0.0068	0%	100%	0.0097	0%	100%	0.0061	0%	100%
Nitrates	2.8E-05	0%	100%	3.5E-05	0%	100%	9.1E-06	0%	100%
Boron	0.0087	0%	100%	0.011	0%	100%	0.0072	0%	100%
Other Organics	0.020	0%	100%	0.013	0%	100%	0.0046	0%	100%
Chromates	6.9E-06	0%	100%	3.2E-06	0%	100%	1.7E-06	0%	100%
Sodium Dichromate	0			6.5E-06	100%	0%	0		

Source: Franklin Associates

Results shown in this table represent average weight product based on the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. The purpose of this table is to illustrate the relative shares of total emissions that are released from processes and from the production and combustion of fuels, respectively. Conclusions regarding the relative performance of competing products cannot be drawn from this table because the full range of product weights for each material are not shown.

Table 2-23 (page 1 of 2)

Process and Fuel-Related Emissions for 10,000 Average Weight 32-ounce Cold Cups
(lb/10,000 product units)

	Polystyrene			Poly-Coated Paperboard			Wax-Coated Paperboard		
	Total	**% Process**	**% Fuel**	**Total**	**% Process**	**% Fuel**	**Total**	**% Process**	**% Fuel**
Atmospheric Emissions									
Particulates	0.61	10%	90%	2.71	70%	30%	4.98	71%	29%
Nitrogen Oxides	3.75	14%	86%	5.69	26%	74%	10.1	27%	73%
Hydrocarbons	4.30	48%	52%	2.09	34%	66%	3.18	27%	73%
Sulfur Oxides	11.7	17%	83%	10.1	37%	63%	15.4	29%	71%
Carbon Monoxide	2.05	19%	81%	10.4	0%	100%	18.8	0%	100%
Aldehydes	0.017	44%	56%	0.044	35%	65%	0.083	38%	62%
Methane	2.52	15%	85%	1.82	14%	86%	2.70	0%	100%
Other Organics	0.14	0%	100%	0.41	0%	100%	0.73	0%	100%
Kerosene	1.3E-04	0%	100%	1.3E-04	0%	100%	2.3E-04	0%	100%
Ammonia	0.0024	40%	60%	0.0018	18%	82%	0.0035	27%	73%
Hydrogen Fluoride	0.0036	0%	100%	0.0035	0%	100%	0.0063	0%	100%
Lead	2.8E-05	1%	99%	7.9E-04	0%	100%	0.0015	0%	100%
Mercury	1.1E-05	0%	100%	1.7E-05	39%	61%	3.1E-05	39%	61%
Chlorine	4.5E-05	86%	14%	0.0052	1%	99%	0.0097	1%	99%
HCl	0.026	0%	100%	0.025	0%	100%	0.045	0%	100%
CO2 (fossil)	901	1%	99%	739	0%	100%	1,295	0%	100%
CO2 (non-fossil)	0.25	0%	100%	1,384	0%	100%	2,564	0%	100%
Total Reduced Sulfur	0			0.14	100%	0%	0.27	100%	0%
Metals (unspecified)	1.0E-04	0%	100%	0.56	0%	100%	1.05	0%	100%
Antimony	5.8E-06	0%	100%	2.8E-06	0%	100%	5.3E-06	0%	100%
Arsenic	2.4E-05	0%	100%	1.0E-04	0%	100%	1.9E-04	0%	100%
Beryllium	2.5E-06	0%	100%	5.4E-06	0%	100%	9.9E-06	0%	100%
Cadmium	1.5E-05	0%	100%	1.4E-05	0%	100%	2.7E-05	0%	100%
Chromium	3.7E-05	0%	100%	1.2E-04	0%	100%	2.1E-04	0%	100%
Cobalt	1.6E-05	0%	100%	7.8E-06	0%	100%	1.5E-05	0%	100%
Manganese	6.3E-05	0%	100%	0.0061	0%	100%	0.011	0%	100%
Nickel	2.2E-04	0%	100%	4.9E-04	0%	100%	9.1E-04	0%	100%
Selenium	4.0E-05	0%	100%	3.6E-05	0%	100%	6.5E-05	0%	100%
Acreolin	5.1E-06	0%	100%	5.0E-06	0%	100%	9.0E-06	0%	100%
Nitrous Oxide	0.0032	0%	100%	0.0044	0%	100%	0.0079	0%	100%
Benzene	7.4E-06	0%	100%	0.0024	0%	100%	0.0044	0%	100%
Perchloroethylene	4.9E-06	0%	100%	4.8E-06	0%	100%	8.6E-06	0%	100%
Trichloroethylene	4.8E-06	0%	100%	4.7E-06	0%	100%	8.5E-06	0%	100%
Methylene Chloride	2.2E-05	0%	100%	2.1E-05	0%	100%	3.8E-05	0%	100%
Carbon Tetrachloride	8.1E-06	0%	100%	7.9E-06	0%	100%	1.4E-05	0%	100%
Phenols	1.5E-05	0%	100%	0.026	0%	100%	0.047	0%	100%
Naphthalene	4.0E-07	0%	100%	0.0015	0%	100%	0.0029	0%	100%
Dioxins	2.8E-11	0%	100%	2.7E-11	0%	100%	4.9E-11	0%	100%
n-nitrosodimethlamine	1.1E-06	0%	100%	1.1E-06	0%	100%	1.9E-06	0%	100%
Radionuclides	8.7E-05	0%	100%	8.5E-05	0%	100%	1.5E-04	0%	100%
Methyl Ethyl Ketone	0			0			0.023	100%	0%
Ethylene Glycol	0			0.0066	100%	0%	0.012	100%	0%
Greenhouse Gas Summary									
Fossil CO2	901	1%	99%	739	0%	100%	1,295	0%	100%
Methane	57.9	15%	85%	41.9	14%	86%	62.0	0%	100%
Nitrous oxide	0.95	0%	100%	1.30	0%	100%	2.35	0%	100%
Total	**960**	2%	98%	**782**	1%	99%	**1,359**	0%	100%

Source: Franklin Associates

Results shown in this table represent average weight product based on the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. The purpose of this table is to illustrate the relative shares of total emissions that are released from processes and from the production and combustion of fuels, respectively. Conclusions regarding the relative performance of competing products cannot be drawn from this table because the full range of product weights for each material are not shown.

Table 2-23 (page 2 of 2)

Process and Fuel-Related Emissions for 10,000 Average Weight 32-ounce Cold Cups (lb/10,000 product units)

	Polystyrene			Poly-Coated Paperboard			Wax-Coated Paperboard		
	Total	**% Process**	**% Fuel**	**Total**	**% Process**	**% Fuel**	**Total**	**% Process**	**% Fuel**
Waterborne Wastes (lb/10,000 product units)									
Acid	0.0070	100%	0%	0.0071	100%	0%	0.0025	100%	0%
Metal Ion (unspecified)	0.0050	88%	12%	0.0010	26%	74%	0.0035	61%	39%
Fluorides	5.8E-04	10%	90%	5.1E-04	0%	100%	9.2E-04	0%	100%
Dissolved Solids	15.6	26%	74%	46.8	87%	13%	81.7	88%	12%
Suspended Solids	0.47	7%	93%	2.54	85%	15%	4.64	86%	14%
BOD	0.13	91%	9%	1.98	100%	0%	3.65	100%	0%
COD	0.36	56%	44%	3.15	97%	3%	5.74	98%	2%
Phenol	1.6E-05	88%	12%	7.2E-06	67%	33%	9.7E-05	95%	5%
Sulfides	0.0037	100%	0%	0.0026	100%	0%	3.3E-06	100%	0%
Oil	0.27	24%	76%	0.14	27%	73%	0.17	2%	98%
Sulfuric Acid	0.0038	0%	100%	0.0041	0%	100%	0.0075	0%	100%
Iron	0.021	5%	95%	0.024	0%	100%	0.043	0%	100%
Cyanide	9.7E-07	21%	79%	5.8E-07	33%	67%	7.3E-07	13%	87%
Chromium	6.7E-04	21%	79%	3.6E-04	26%	74%	4.4E-04	2%	98%
Aluminum	3.9E-04	100%	0%	0			0		
Nickel	0			1.3E-08	100%	0%	2.5E-08	100%	0%
Mercury	5.1E-08	21%	79%	4.7E-08	56%	44%	6.8E-08	51%	49%
Lead	4.2E-07	88%	12%	1.8E-05	100%	0%	3.3E-05	100%	0%
Phosphates	0.0028	33%	67%	0.0062	67%	33%	0.011	66%	34%
Nitrogen	0			0.017	100%	0%	0.031	100%	0%
Zinc	2.9E-04	38%	62%	0.0024	96%	4%	0.0042	96%	4%
Ammonia	0.0016	71%	29%	3.9E-04	9%	91%	8.2E-04	23%	77%
Hydrocarbons	0.019	100%	0%	0			0		
Chlorides	0.67	21%	79%	0.36	26%	74%	0.44	0%	100%
Cadmium	6.7E-04	21%	79%	3.6E-04	26%	74%	4.4E-04	0%	100%
Organic Carbon	0.0089	100%	0%	0.0061	100%	0%	0		
Sulfates	0.58	18%	82%	0.34	21%	79%	0.45	0%	100%
Sodium	2.1E-04	0%	100%	2.0E-04	0%	100%	3.7E-04	0%	100%
Calcium	1.1E-04	0%	100%	1.1E-04	0%	100%	2.0E-04	0%	100%
Manganese	0.012	0%	100%	0.014	0%	100%	0.025	0%	100%
Nitrates	4.9E-05	0%	100%	4.8E-05	0%	100%	8.7E-05	0%	100%
Boron	0.015	0%	100%	0.016	0%	100%	0.030	0%	100%
Other Organics	0.036	0%	100%	0.020	0%	100%	0.033	0%	100%
Chromates	1.3E-05	0%	100%	4.6E-06	0%	100%	9.2E-06	0%	100%
Sodium Dichromate	0			1.1E-05	100%	0%	2.0E-05	100%	0%

Source: Franklin Associates

Results shown in this table represent average weight product based on the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. The purpose of this table is to illustrate the relative shares of total emissions that are released from processes and from the production and combustion of fuels, respectively. Conclusions regarding the relative performance of competing products cannot be drawn from this table because the full range of product weights for each material are not shown.

Table 2-24 (page 1 of 2)

Process and Fuel-Related Emissions for 10,000 Average Weight 9-inch High-grade Plates (lb/10,000 product units)

	Polystyrene			Poly-Coated Paperboard			Molded Pulp		
	Total	**% Process**	**% Fuel**	**Total**	**% Process**	**% Fuel**	**Total**	**% Process**	**% Fuel**
Atmospheric Emissions									
Particulates	0.61	5%	95%	2.19	71%	29%	2.95	65%	35%
Nitrogen Oxides	3.01	3%	97%	4.59	27%	73%	5.79	22%	78%
Hydrocarbons	4.66	62%	38%	1.77	36%	64%	1.67	9%	91%
Sulfur Oxides	10.1	23%	77%	8.28	39%	61%	10.5	20%	80%
Carbon Monoxide	1.50	2%	98%	8.62	0%	100%	9.23	0%	100%
Aldehydes	0.019	46%	54%	0.036	35%	65%	0.038	34%	66%
Methane	2.24	19%	81%	1.46	16%	84%	2.09	0%	100%
Other Organics	0.14	4%	96%	0.34	0%	100%	0.35	0%	100%
Kerosene	1.4E-04	0%	100%	9.3E-05	0%	100%	1.3E-04	0%	100%
Ammonia	0.0026	44%	56%	0.0013	20%	80%	0.0016	14%	86%
Hydrogen Fluoride	0.0037	0%	100%	0.0025	0%	100%	0.0034	0%	100%
Lead	2.1E-05	1%	99%	6.6E-04	0%	100%	7.1E-04	0%	100%
Mercury	1.1E-05	0%	100%	1.3E-05	42%	58%	1.8E-05	32%	68%
Chlorine	5.1E-05	90%	10%	0.0043	1%	99%	0.0046	1%	99%
HCl	0.027	0%	100%	0.018	0%	100%	0.025	0%	100%
CO2 (fossil)	775	1%	99%	575	0%	100%	973	0%	100%
CO2 (non-fossil)	0.22	0%	100%	1,148	0%	100%	1,217	0%	100%
Total Reduced Sulfur	0			0.12	100%	0%	0.13	100%	0%
Metals (unspecified)	9.1E-05	0%	100%	0.47	0%	100%	0.50	0%	100%
Antimony	3.5E-06	0%	100%	2.1E-06	0%	100%	3.1E-06	0%	100%
Arsenic	2.1E-05	0%	100%	8.4E-05	0%	100%	1.7E-04	0%	100%
Beryllium	2.3E-06	0%	100%	4.2E-06	0%	100%	1.4E-05	0%	100%
Cadmium	7.6E-06	0%	100%	1.1E-05	0%	100%	3.9E-05	0%	100%
Chromium	3.2E-05	0%	100%	9.3E-05	0%	100%	2.7E-04	0%	100%
Cobalt	9.8E-06	0%	100%	5.8E-06	0%	100%	8.8E-06	0%	100%
Manganese	6.1E-05	0%	100%	0.0050	0%	100%	0.0056	0%	100%
Nickel	1.2E-04	0%	100%	4.0E-04	0%	100%	5.5E-04	0%	100%
Selenium	3.9E-05	0%	100%	2.6E-05	0%	100%	3.6E-05	0%	100%
Acreolin	5.3E-06	0%	100%	3.6E-06	0%	100%	4.9E-06	0%	100%
Nitrous Oxide	0.0033	0%	100%	0.0033	0%	100%	0.0077	0%	100%
Benzene	7.5E-06	0%	100%	0.0020	0%	100%	0.0021	0%	100%
Perchloroethylene	5.0E-06	0%	100%	3.5E-06	0%	100%	4.7E-06	0%	100%
Trichloroethylene	5.0E-06	0%	100%	3.4E-06	0%	100%	4.6E-06	0%	100%
Methylene Chloride	2.2E-05	0%	100%	1.5E-05	0%	100%	2.1E-05	0%	100%
Carbon Tetrachloride	8.3E-06	0%	100%	5.8E-06	0%	100%	7.9E-06	0%	100%
Phenols	1.5E-05	0%	100%	0.021	0%	100%	0.022	0%	100%
Naphthalene	3.8E-07	0%	100%	0.0013	0%	100%	0.0014	0%	100%
Dioxins	2.9E-11	0%	100%	2.0E-11	0%	100%	2.7E-11	0%	100%
n-nitrosodimethlamine	1.1E-06	0%	100%	7.7E-07	0%	100%	1.0E-06	0%	100%
Radionuclides	8.9E-05	0%	100%	6.2E-05	0%	100%	8.3E-05	0%	100%
Ethylene Glycol	0			0.0055	100%	0%	0.0058	100%	0%
Greenhouse Gas Summary									
Fossil CO2	775	1%	99%	575	0%	100%	973	0%	100%
Methane	51.5	19%	81%	33.5	16%	84%	48.0	0%	100%
Nitrous oxide	0.98	0%	100%	0.98	0%	100%	2.28	0%	100%
Total	**827**	2%	98%	**610**	1%	99%	**1,023**	0%	100%

Source: Franklin Associates

Results shown in this table represent average weight product based on the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Results in this table apply only to average weight high-grade plates, which are the strongest and heaviest plates available in each material category. Lighterweight polystyrene and paper plates are available but are not included in these results. The purpose of this table is to illustrate the relative shares of total emissions that are released from processes and from the production and combustion of fuels, respectively. Conclusions regarding the relative performance of competing products cannot be drawn from this table because the full range of product weights for each material are not shown.

Table 2-24 (page 2 of 2)

Process and Fuel-Related Emissions for 10,000 Average Weight 9-inch High-grade Plates
(lb/10,000 product units)

	Polystyrene			Poly-Coated Paperboard			Molded Pulp		
	Total	**% Process**	**% Fuel**	**Total**	**% Process**	**% Fuel**	**Total**	**% Process**	**% Fuel**
Waterborne Wastes									
Acid	0.0084	100%	0%	0.0064	100%	0%	0.0012	100%	0%
Metal Ion (unspecified)	0.0057	92%	8%	8.5E-04	29%	71%	6.8E-04	0%	100%
Fluorides	5.4E-04	0%	100%	3.7E-04	0%	100%	5.0E-04	0%	100%
Dissolved Solids	12.4	29%	71%	39.0	88%	12%	41.1	83%	17%
Suspended Solids	0.42	7%	93%	2.08	86%	14%	3.14	83%	17%
BOD	0.14	94%	6%	1.65	100%	0%	2.10	100%	0%
COD	0.36	66%	34%	2.62	97%	3%	2.75	96%	4%
Phenol	1.9E-05	92%	8%	6.0E-06	68%	32%	5.7E-06	61%	39%
Sulfides	0.0044	100%	0%	0.0024	100%	0%	1.6E-06	100%	0%
Oil	0.23	33%	67%	0.12	29%	71%	0.12	0%	100%
Sulfuric Acid	0.0037	0%	100%	0.0031	0%	100%	0.0060	0%	100%
Iron	0.021	0%	100%	0.018	0%	100%	0.034	0%	100%
Cyanide	8.1E-07	28%	72%	4.9E-07	35%	65%	5.0E-07	9%	91%
Chromium	5.6E-04	28%	72%	3.1E-04	29%	71%	3.1E-04	0%	100%
Nickel	0			1.1E-08	100%	0%	1.2E-08	100%	0%
Mercury	4.3E-08	29%	71%	3.9E-08	57%	43%	4.1E-08	40%	60%
Lead	4.7E-07	92%	8%	1.5E-05	100%	0%	1.5E-05	100%	0%
Phosphates	0.0023	19%	81%	0.0050	69%	31%	0.0064	53%	47%
Nitrogen	0			0.014	100%	0%	0.015	100%	0%
Zinc	2.7E-04	49%	51%	0.0020	96%	4%	0.0020	95%	5%
Ammonia	7.9E-04	49%	51%	3.0E-04	10%	90%	3.8E-04	4%	96%
Hydrocarbons	0.022	100%	0%	0			0		
Chlorides	0.56	28%	72%	0.31	29%	71%	0.32	0%	100%
Cadmium	5.6E-04	28%	72%	3.1E-04	29%	71%	3.1E-04	0%	100%
Organic Carbon	0.010	100%	0%	0.0056	100%	0%	0		
Sulfates	0.50	25%	75%	0.28	24%	76%	0.30	0%	100%
Sodium	2.1E-04	0%	100%	1.5E-04	0%	100%	2.0E-04	0%	100%
Calcium	1.2E-04	0%	100%	8.0E-05	0%	100%	1.1E-04	0%	100%
Manganese	0.012	0%	100%	0.010	0%	100%	0.021	0%	100%
Nitrates	5.1E-05	0%	100%	3.5E-05	0%	100%	4.7E-05	0%	100%
Boron	0.015	0%	100%	0.012	0%	100%	0.024	0%	100%
Other Organics	0.028	0%	100%	0.016	0%	100%	0.024	0%	100%
Chromates	6.5E-06	0%	100%	3.5E-06	0%	100%	5.7E-06	0%	100%
Sodium Dichromate	0			9.0E-06	100%	0%	9.6E-06	100%	0%

Source: Franklin Associates

Results shown in this table represent average weight product based on the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Results in this table apply only to average weight high-grade plates, which are the strongest and heaviest plates available in each material category. Lighterweight polystyrene and paper plates are available but are not included in these results. The purpose of this table is to illustrate the relative shares of total emissions that are released from processes and from the production and combustion of fuels, respectively. Conclusions regarding the relative performance of competing products cannot be drawn from this table because the full range of product weights for each material are not shown.

Table 2-25 (page 1 of 2)

Process and Fuel-Related Emissions for 10,000 Average Weight 5-inch Clamshells (lb/10,000 product units)

	Polystyrene			Fluted Paperboard		
	Total	**% Process**	**% Fuel**	**Total**	**% Process**	**% Fuel**
Atmospheric Emissions						
Particulates	0.27	5%	95%	0.99	47%	53%
Nitrogen Oxides	1.35	3%	97%	3.87	42%	58%
Hydrocarbons	2.07	62%	38%	0.62	1%	99%
Sulfur Oxides	4.51	22%	78%	5.67	43%	57%
Carbon Monoxide	0.67	2%	98%	5.83	25%	75%
Aldehydes	0.0085	46%	54%	0.021	10%	90%
Methane	1.00	19%	81%	0.80	0%	100%
Other Organics	0.064	4%	96%	0.30	3%	97%
Odorous Sulfur	0			0.0017	100%	0%
Kerosene	6.1E-05	0%	100%	5.0E-05	0%	100%
Ammonia	0.0012	44%	56%	0.019	96%	4%
Hydrogen Fluoride	0.0017	0%	100%	0.0014	0%	100%
Lead	9.6E-06	1%	99%	3.4E-04	0%	100%
Mercury	4.8E-06	0%	100%	2.5E-05	71%	29%
Chlorine	2.3E-05	90%	10%	0.0034	37%	63%
HCl	0.012	0%	100%	0.0098	0%	100%
CO2 (fossil)	348	1%	99%	467	1%	99%
CO2 (non-fossil)	0.10	0%	100%	564	0%	100%
Total Reduced Sulfur	0			0.043	100%	0%
Metals (unspecified)	4.1E-05	0%	100%	0.23	0%	100%
Antimony	1.6E-06	0%	100%	5.4E-06	0%	100%
Arsenic	9.2E-06	0%	100%	9.7E-05	0%	100%
Beryllium	1.0E-06	0%	100%	8.2E-06	0%	100%
Cadmium	3.4E-06	0%	100%	3.5E-05	0%	100%
Chromium	1.5E-05	0%	100%	1.5E-04	0%	100%
Cobalt	4.4E-06	0%	100%	1.5E-05	0%	100%
Manganese	2.8E-05	0%	100%	0.0026	0%	100%
Nickel	5.3E-05	0%	100%	4.5E-04	0%	100%
Selenium	1.7E-05	0%	100%	1.9E-05	0%	100%
Acreolin	2.4E-06	0%	100%	1.9E-06	0%	100%
Nitrous Oxide	0.0015	0%	100%	0.0038	0%	100%
Benzene	3.4E-06	0%	100%	0.0010	0%	100%
Perchloroethylene	2.3E-06	0%	100%	1.9E-06	0%	100%
Trichloroethylene	2.2E-06	0%	100%	1.8E-06	0%	100%
Methylene Chloride	1.0E-05	0%	100%	8.2E-06	0%	100%
Carbon Tetrachloride	3.7E-06	0%	100%	3.2E-06	0%	100%
Phenols	6.8E-06	0%	100%	0.010	0%	100%
Naphthalene	1.7E-07	0%	100%	6.3E-04	0%	100%
Dioxins	1.3E-11	0%	100%	1.1E-11	0%	100%
n-nitrosodimethlamine	5.0E-07	0%	100%	4.1E-07	0%	100%
Radionuclides	4.0E-05	0%	100%	3.3E-05	0%	100%
Greenhouse Gas Summary						
Fossil CO2	348	1%	99%	467	1%	99%
Methane	23.0	19%	81%	18.5	0%	100%
Nitrous oxide	0.44	0%	100%	1.13	0%	100%
Total	**372**	2%	98%	**487**	1%	99%

Source: Franklin Associates

Results shown in this table represent average weight product based on the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. The purpose of this table is to illustrate the relative shares of total emissions that are released from processes and from the production and combustion of fuels, respectively. Conclusions regarding the relative performance of competing products cannot be drawn from this table because the full range of product weights for each material are not shown.

Table 2-25 (page 2 of 2)

Process and Fuel-Related Emissions for 10,000 Average Weight 5-inch Clamshells (lb/10,000 product units)

	Polystyrene			Fluted Paperboard		
	Total	**% Process**	**% Fuel**	**Total**	**% Process**	**% Fuel**
Waterborne Wastes						
Acid	0.0038	100%	0%	0.0044	100%	0%
Metal Ion (unspecified)	0.0025	92%	8%	7.9E-04	0%	100%
Fluorides	2.4E-04	0%	100%	2.0E-04	0%	100%
Dissolved Solids	5.52	29%	71%	1.83	2%	98%
Suspended Solids	0.19	7%	93%	1.06	79%	21%
BOD	0.064	94%	6%	0.45	100%	0%
COD	0.16	66%	34%	2.54	99%	1%
Phenol	8.3E-06	92%	8%	2.6E-06	1%	99%
Sulfides	0.0020	100%	0%	3.7E-07	100%	0%
Oil	0.10	32%	68%	0.033	0%	100%
Sulfuric Acid	0.0016	0%	100%	0.0033	0%	100%
Iron	0.0095	0%	100%	0.016	0%	100%
Cyanide	3.6E-07	28%	72%	1.4E-07	15%	85%
Chromium	2.5E-04	28%	72%	8.1E-05	0%	100%
Aluminum	0			0.018	100%	0%
Nickel	0			2.7E-09	100%	0%
Mercury	1.9E-08	28%	72%	1.0E-08	38%	62%
Lead	2.1E-07	92%	8%	6.9E-08	4%	96%
Phosphates	0.0010	19%	81%	0.022	93%	7%
Phosphorus	0			0.019	100%	0%
Nitrogen	0			0.0070	100%	0%
Zinc	1.2E-04	49%	51%	2.8E-05	0%	100%
Ammonia	3.5E-04	49%	51%	0.030	99%	1%
Hydrocarbons	0.010	100%	0%	0		
Chlorides	0.25	28%	72%	0.082	0%	100%
Cadmium	2.5E-04	28%	72%	8.1E-05	0%	100%
Organic Carbon	0.0044	100%	0%	0		
Sulfates	0.22	24%	76%	0.088	0%	100%
Sodium	9.6E-05	0%	100%	7.9E-05	0%	100%
Calcium	5.2E-05	0%	100%	4.3E-05	0%	100%
Manganese	0.0055	0%	100%	0.0097	0%	100%
Nitrates	2.3E-05	0%	100%	1.9E-05	0%	100%
Boron	0.0066	0%	100%	0.013	0%	100%
Other Organics	0.012	0%	100%	0.0076	0%	100%
Chromates	2.9E-06	0%	100%	1.3E-05	0%	100%
Sodium Dichromate	0			2.0E-06	100%	0%

Source: Franklin Associates

Results shown in this table represent average weight product based on the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. The purpose of this table is to illustrate the relative shares of total emissions that are released from processes and from the production and combustion of fuels, respectively. Conclusions regarding the relative performance of competing products cannot be drawn from this table because the full range of product weights for each material are not shown.

gas compared to a pound of carbon dioxide. The weights of each of these substances in the top section of Tables 2-14 through 2-17 are multiplied by their global warming potential and totaled in the GHG (greenhouse gas) section at the bottom of the table. Greenhouse gas emissions for each foodservice product are shown graphically in Figures 2-17 through 2-20. These figures show that the majority of global warming potential for each system is from carbon dioxide, while the contribution from nitrous oxide is very small.

Greenhouse gas totals for different foodservice products vary widely, based largely on their material compositions. Materials produced using fossil fuels as process fuels (e.g., plastics) have higher GHG profiles **per pound** than materials that use some non-fossil resources for process energy (e.g., paperboard). Carbon dioxide emissions associated with the combustion of wood are considered to be part of the natural carbon cycle. Because the carbon dioxide released when wood decomposes or is burned was originally taken up from the atmosphere during the growth of the tree, the carbon dioxide is considered "carbon neutral" and not a net contribution to atmospheric carbon dioxide. Carbon dioxide emissions for paper-based systems include both "carbon neutral" emissions associated with the use of wood-derived energy for the pulp content and fossil carbon dioxide emissions from the use of fossil fuels for process and transportation energy.

Greenhouse gas emissions are largely a result of fossil fuel combustion. Thus, it may be expected that greenhouse gas comparisons would track closely with the fossil energy requirements presented in the Energy Results; however, this is not the case. As discussed in the Energy Profiles section, fossil fuels account for at least 90 percent of total energy for polystyrene foodservice products, but almost half of this is energy of material resource. This accounts for the energy content of the fossil fuel resources used to produce the resin but does not result in greenhouse gas emissions. Therefore, the energy total that most closely matches the greenhouse gas total is the total fossil process and transportation energy.

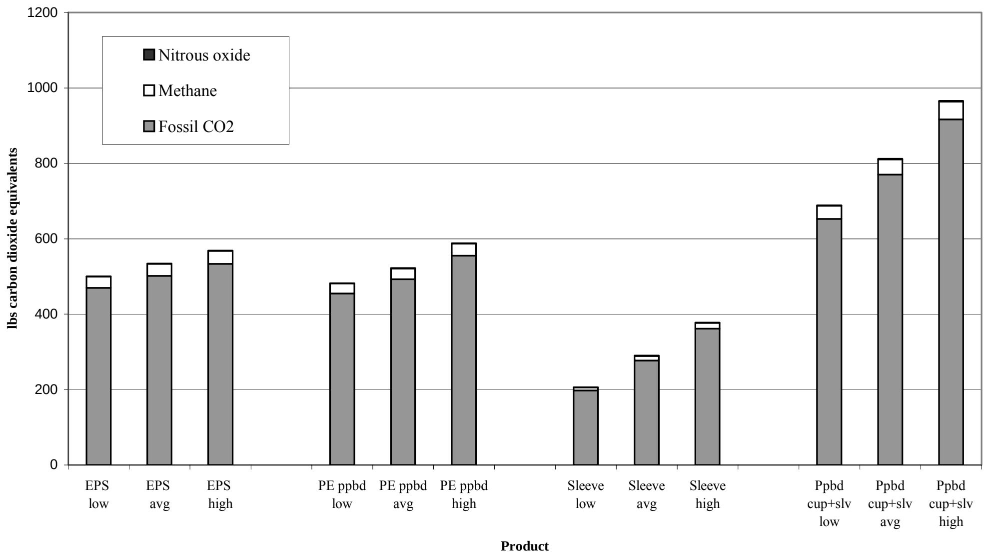
16-ounce Hot Cups. For all hot cup systems analyzed, the percent difference between GHG totals for any two systems is less than 25 percent; therefore, all comparisons are considered inconclusive.

32- ounce Cold Cups. Comparisons of GHG emissions for EPS cups and the other cold cups are inconclusive. However, the percent difference between GHG emissions for PE-coated paperboard cups and wax-coated cups is meaningful, in favor of PE-coated cups.

9-inch High-grade Plates. The difference in GHG emissions for GPPS plates compared to PE-coated paperboard is meaningful, with GPPS higher, but the comparison of GHG for GPPS and molded pulp plates is inconclusive.

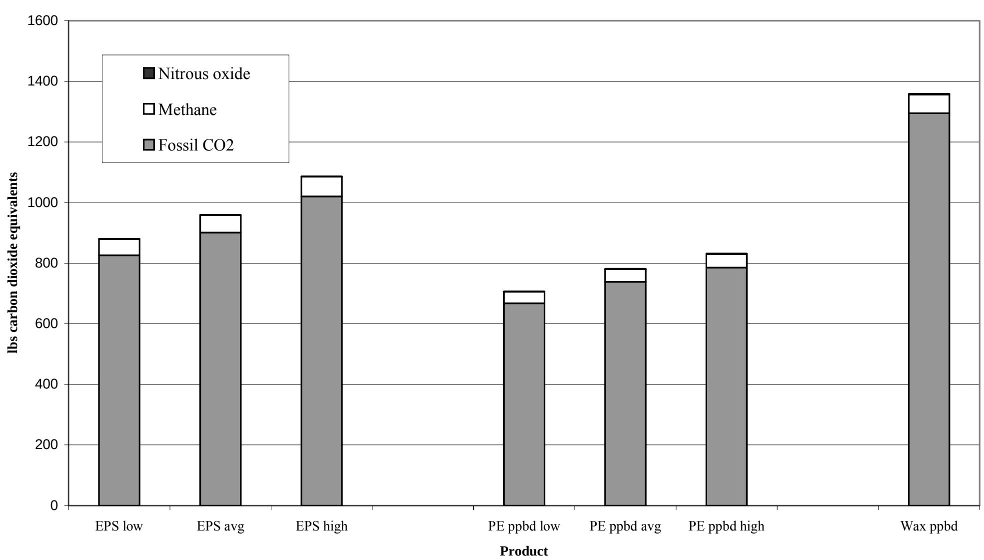
5-inch Sandwich-size Clamshells. The comparison of GHG totals for GPPS and fluted paperboard clamshells is inconclusive.

Figure 2-17. Atmospheric Emissions for 10,000 16-oz Hot Cups (lbs carbon dioxide equivalents)



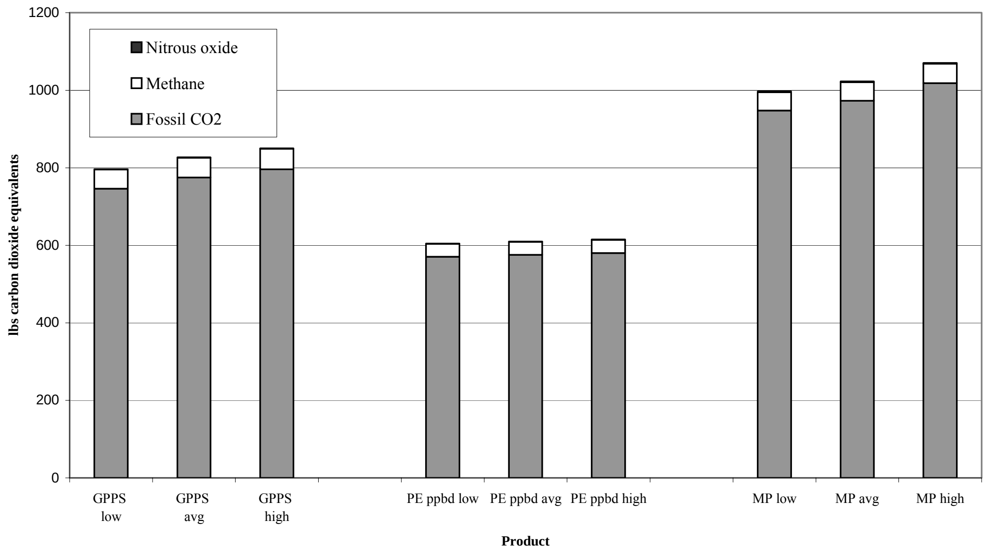
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in GHG results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-35 for a summary of meaningful differences between products.

Figure 2-18. Atmospheric Emissions for 10,000 32-oz Cold Cups (lbs carbon dioxide equivalents)



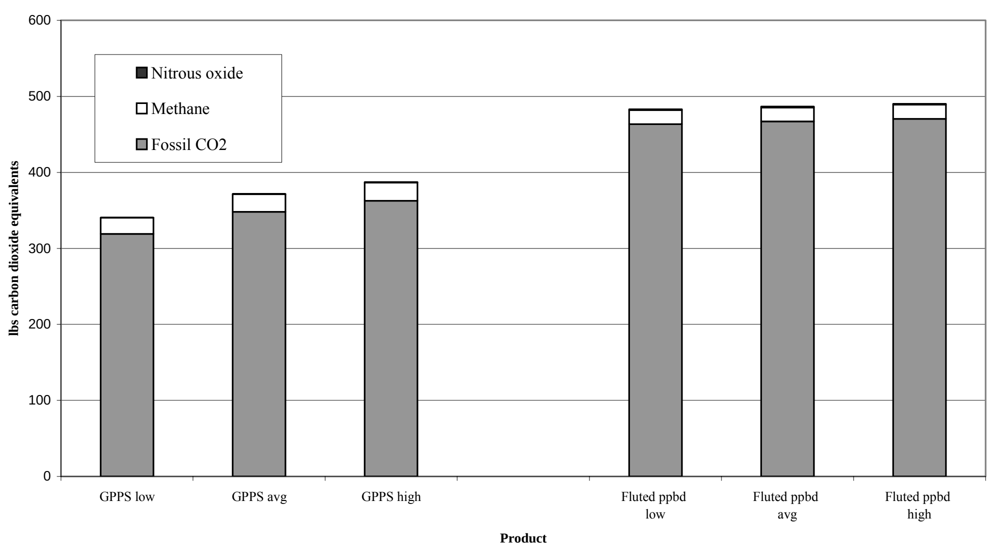
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in GHG results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-36 for a summary of meaningful differences between products.

Figure 2-19. Atmospheric Emissions for 10,000 9-inch High-Grade Plates (lbs carbon dioxide equivalents)



Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in GHG results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-37 for a summary of meaningful differences between products.

Figure 2-20. Atmospheric Emissions for 10,000 5-inch Sandwich-Size Clamshells (lbs carbon dioxide equivalents)



Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in GHG results for products in different material categories or for different weight products in the same material category are not considered meaningful unless the percent difference in the results (defined as the difference of two results divided by their average) is greater than 25%. Products in different material categories cannot be considered different if there is any smaller percent difference or overlap in results when the full ranges of product weights available in each material category are compared. See Table 2-38 for a summary of meaningful differences between products.

It may seem surprising that global warming gas emissions for products such as molded pulp plates and fluted paperboard clamshells are comparable to polystyrene-based equivalent products, since almost half of the process energy for the paperboard products is wood-based, and the wood-based energy is not assigned any global warming gas emission burden. However, although the GPPS clamshell produces 65 percent more fossil CO_2 emissions per 1,000 pounds of product than paperboard clamshells, the average weight paperboard clamshell is more than twice as heavy as the average weight GPPS clamshell. Thus, when the emissions per pound of product are multiplied by the pounds per 10,000 units of product, the total GHG is lower for 10,000 units of polystyrene product. The same situation applies to the comparison of molded pulp and GPPS plates.

Emissions Summaries. Using the 25 percent difference guideline for meaningful differences, the complete lists of atmospheric and waterborne emissions were compared for each possible pair of alternative products in each product category. The comparative results are reported in five categories: no meaningful difference in emissions between the two systems, higher emissions for system A, higher emissions for system B, emissions reported only for system B, and emissions reported only for system A. The results are shown in Tables 2-26 through 2-34. The comparisons are based on the emissions results for the average product weight in each category.

The summary tables show only the number of emissions in each comparative category; no attempt is made to determine the potential relative impacts of these emissions on human health or on the environment. The purpose of these summary tables is simply to condense the extensive list of individual emissions for each product into a manageable comparative format. Because the summary tables provide no information about the relative environmental impacts of the individual substances that are higher or lower for the systems being compared, the reader is cautioned not to use these summary tables as a basis for drawing comparative conclusions about the systems' overall environmental performance.

The emission summary tables show that there is no case in which any system produces more or less emissions in every category compared to the alternative system. In the following discussion, "higher" or "lower" refers only to meaningful differences.

16-ounce Hot Cups. In the comparison of EPS hot cups to PE-coated paperboard hot cups, only three out of 41 atmospheric emissions are higher for EPS; however, 13 out of 35 waterborne emissions are either higher for EPS or reported only for the EPS system. When the EPS hot cup is compared to the PE-coated paperboard cup with sleeve, only one atmospheric emission is higher for the EPS cup. Two waterborne emissions are higher for the EPS cup, and one waterborne emission is reported only for the EPS system.

Table 2-26
Emissions Summary for Average Weight 16-ounce Hot Cups:
EPS and PE-coated Paperboard

	Atmospheric	Waterborne
Inconclusive difference	17	7
PE ppbd higher	19	12
EPS higher	3	11
Reported only for EPS	0	2
Reported only for PE ppbd	2	3
Total emissions	**41**	**35**

Table 2-27
Emissions Summary for Average Weight 16-ounce Hot Cups:
EPS and PE-coated Paperboard with Sleeve

	Atmospheric	Waterborne
Inconclusive difference	3	9
Ppbd+sleeve higher	35	20
EPS higher	1	2
Reported only for EPS	0	1
Reported only for Ppbd+sleeve	3	4
Total emissions	**42**	**36**

Table 2-28
Emissions Summary for Average Weight 32-ounce Cold Cups:
EPS and PE-coated Paperboard

	Atmospheric	Waterborne
Inconclusive difference	15	11
PE ppbd higher	19	7
EPS higher	5	12
Reported only for EPS	0	2
Reported only for PE ppbd	2	3
Total emissions	**41**	**35**

Table 2-29
Emissions Summary for Average Weight 32-ounce Cold Cups:
EPS and Wax-coated Paperboard

	Atmospheric	Waterborne
Inconclusive difference	3	2
Wax ppbd higher	35	17
EPS higher	1	10
Reported only for EPS	0	3
Reported only for Wax ppbd	3	3
Total emissions	**42**	**35**

Table 2-30
Emissions Summary for Average Weight 32-ounce Cold Cups:
PE-coated Paperboard and Wax-coated Paperboard

	Atmospheric	Waterborne
Inconclusive difference	0	5
Wax ppbd higher	41	25
PE ppbd higher	0	2
Reported only for PE ppbd	0	1
Reported only for Wax ppbd	1	0
Total emissions	**42**	**33**

Table 2-31
Emissions Summary for Average Weight 9-inch High-grade Plates:
GPPS Foam and PE-coated Paperboard

	Atmospheric	Waterborne
Inconclusive difference	3	5
PE ppbd higher	18	7
GPPS higher	18	18
Reported only for GPPS	0	1
Reported only for PE ppbd	2	3
Total emissions	**41**	**34**

Table 2-32
Emissions Summary for Average Weight 9-inch High-grade Plates:
GPPS Foam and Molded Pulp

	Atmospheric	Waterborne
Inconclusive difference	17	7
Molded Pulp higher	20	11
GPPS higher	2	11
Reported only for GPPS	0	2
Reported only for Molded Pulp	2	3
Total emissions	**41**	**34**

Table 2-33
Emissions Summary for Average Weight 9-inch High-grade Plates:
PE-coated Paperboard and Molded Pulp

	Atmospheric	Waterborne
Inconclusive difference	17	19
Molded Pulp higher	24	11
PE ppbd higher	0	2
Reported only for PE ppbd	0	1
Reported only for Molded Pulp	0	0
Total emissions	**41**	**33**

Table 2-34
Emissions Summary for Average Weight 5-inch Sandwich-size Clamshells:
GPPS Foam and Fluted Paperboard

	Atmospheric	Waterborne
Inconclusive difference	14	5
Ppbd higher	24	10
GPPS higher	1	14
Reported only for GPPS	0	2
Reported only for Ppbd	2	5
Total emissions	**41**	**36**

32-ounce Cold Cups. When emissions for EPS cold cups are compared to emissions for PE-coated paperboard cups, five out of 41 atmospheric emissions are higher for EPS. For waterborne emissions, 12 out of 35 waterborne emissions are higher for EPS and two are reported only for the EPS system. Results are similar for the comparison of EPS and wax-coated cups – one out of 42 atmospheric emissions is higher for the EPS cup, with ten waterborne emissions higher for the EPS cup, and three waterborne emissions reported only for the EPS system. In the comparison of PE-coated cups and wax-coated cups, all atmospheric emissions are lower for the PE-coated cup, with one emission reported only for the wax-coated system. The comparison of waterborne emissions shows 25 emissions higher for wax-coated paperboard, two higher for PE-coated paperboard, and one reported only for PE-coated paperboard.

9-inch High-grade Plates. For plates, the results for GPPS foam and PE-coated paperboard plates are about even; 18 out of 41 atmospheric emissions and 18 out of 34 waterborne emissions are higher for GPPS. One waterborne emission is reported only for GPPS. In the comparison of GPPS and molded pulp plates, two out of 41 atmospheric emissions are higher for GPPS. For waterborne emissions, 11 out of 34 emissions are higher for GPPS and two are reported only for GPPS.

In the comparisons of non-PS plates, all atmospheric emission comparisons for PE-coated paperboard plates and molded pulp plates are inconclusive or lower for PE-coated plates. Waterborne results are mixed, with 11 higher for molded pulp, two higher for PE-coated paperboard, and one reported only for PE-coated paperboard.

5-inch Sandwich-size Clamshells. In the comparison of GPPS foam and fluted paperboard clamshells, the polystyrene clamshell is higher for only one out of 41 atmospheric emissions but 14 out of 36 waterborne emissions. In addition, there are two waterborne emissions that are reported only for the GPPS clamshell.

Even in those cases where most comparisons of individual emissions are meaningful in favor of one system compared to an alternative system, no overall conclusions can be made because the potential impacts of these emissions on human health and the environment are not considered in a life cycle inventory.

ESTIMATING RESULTS FOR OTHER PRODUCT WEIGHTS

The plates analyzed in this study are high-grade plates, which are the heaviest and strongest grade of disposable plates in each material category. Lighter-weight GPPS foam and paper plates are available in the marketplace but are not included in this analysis. It is possible, however, to use the results of this LCI to estimate environmental burdens for product weights other than those included in this analysis, as long as the products are of the same material composition and fabrication type as the products in the LCI.

The majority of environmental burdens for a product are for the "cradle-to-material" sequence of process steps required to produce the basic material, plus some additional burdens for the fabrication process. Thus, for products of a given material, the environmental burdens for a lighter product can be estimated by multiplying the heavier product results by the ratio of the lighter product weight to the heavier product weight.

For example, high-grade polystyrene foam plates analyzed in this study have an average weight of 10.8 grams (range from 10.4 to 11.1 grams). Low-grade polystyrene foam plate samples obtained for this study have an average weight of 5.6 grams (range from 5.0 to 6.4 grams), while mid-grade polystyrene foam plate samples have an average weight of 8.7 grams (range from 7.6 to 9.6 grams). Total energy for 10,000 average weight low-grade PS foam plates would be estimated using the total energy for average weight high-grade PS foam plates (from Table 2-4) as follows: 11.7 million Btu per 10,000 average weight high-grade PS foam plates x (5.6 grams per average weight low-grade PS foam plate)/(10.8 grams per average weight PS foam high-grade plate) = 6.1 million Btu per 10,000 average weight low-grade PS foam plates. The same calculation process would be used to estimate solid waste and greenhouse gases results.

SUMMARY OF SYSTEM COMPARISONS

Within each product category, results and comparisons of individual product systems for individual environmental burdens (i.e., energy, solid waste, greenhouse gas) have been presented and discussed in separate sections of this chapter. In this section, comparative results for energy, solid waste by weight, solid waste by volume, and greenhouse gases are summarized in one table for each product category. The differences between systems are defined as meaningful or inconclusive based on the percent difference guidelines laid out in the Energy, Solid Waste, and Environmental Emissions results sections of this chapter. These guidelines are also shown at the bottom of each table.

The comparisons in Tables 2-35 through 2-38 cover the entire range of product weights in each product category. In each two-product comparison, the lowest results for the first system are compared to the highest results for the other system, and the highest results for the first system are compared to the lowest results for the other system. If there is any overlap in results, or if both percent differences are not large enough to be considered meaningful, the difference between the two products is considered inconclusive.

16-ounce Hot Cups (Table 2-35)

When EPS cups are compared with PE-coated paperboard cups, the EPS cup produces less solid waste by weight; however, comparisons of the EPS cup and PE-coated paperboard cup are inconclusive for energy, solid waste volume, and GHG. When the sleeve is added to the paperboard cup, the EPS cup is lower in energy and solid waste by weight and by volume, but the GHG comparison is still inconclusive.

Table 2-35

Meaningful Differences* in 16-ounce Hot Cup Comparisons
(See table footnotes for guidelines)

16-OUNCE HOT CUPS	**ENERGY** Range of Total Results (MM Btu/10,000 units)		**SOLID WASTE - WEIGHT** Range of Total Results (lb/10,000 units)		**SOLID WASTE - VOLUME** Range of Total Results (cu ft/10,000 units)		**GHG** Range of Total Results (lb CO2 equiv/10,000 units)	
EPS	6.13 -	6.97	129 -	146	9.75 -	11.08	500 -	569
PE-coated Paperboard	7.29 -	8.89	358 -	437	10.74 -	13.10	482 -	588
PE-coated Paperboard with Sleeve	8.54 -	11.17	553 -	793	16.95 -	24.47	689 -	966

Product Comparison	% Difference low(1) to high(2)	% Difference high(1) to low(2)	% Difference low(1) to high(2)	% Difference high(1) to low(2)	% Difference low(1) to high(2)	% Difference high(1) to low(2)	% Difference low(1) to high(2)	% Difference high(1) to low(2)
EPS (1) and PE-coated Paperboard (2)	-37%	-5%	-109%	-84%	-29%	3%	-16%	16%
EPS (1) and PE-coated Paperboard with Sleeve (2)	-58%	-20%	-144%	-116%	-86%	-42%	-64%	-19%
PE-coated Paperboard (1) and PE-coated Paperboard with Sleeve (2)	-42%	4%	-76%	-23%	-78%	-26%	-67%	-16%

ANALYSIS	**ENERGY**	**SOLID WASTE - WEIGHT**	**SOLID WASTE - VOLUME**	**GHG**
EPS and PE-coated Paperboard	Inconclusive (a)	EPS lower	Inconclusive (a), (b)	Inconclusive (a), (b)
EPS and PE-coated Paperboard with Sleeve	EPS lower	EPS lower	EPS lower	Inconclusive (a)
PE-coated Paperboard and PE-coated Paperboard with Sleeve	Inconclusive (a), (b)	Inconclusive (a)	PE-coated ppbd lower	Inconclusive (a)

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003.

*** Meaningful Differences Explanatory Notes:**

Meaningful Difference between different material product systems (e.g., EPS, PE-coated Paperboard with and without Sleeve) as defined and used in this report occurs when the comparison of low (1) to high (2) AND the comparison of high (1) to low (2) BOTH meet the % difference criteria:

For **energy**, BOTH comparisons must be either <-10% OR >10%; that is, both % difference values must have the same sign (+ or -) and absolute value >10%.

For **solid waste by weight**, **solid waste by volume**, and **GHG**, BOTH comparisons must be either <-25% OR >25%; that is, both % difference values must have the same sign (+ or -) and absolute value >25%.

The difference between systems is considered inconclusive if:

(a) At least one of the % differences is less than the meaningful difference criteria, and/or

(b) One % difference is positive and the other is negative, indicating an overlap in results for the two systems.

Percent difference is defined as the difference between the system totals divided by the average of the two system totals.
In the % difference comparisons, low (1) is the low value reported for the system designated (1) in the comparison; high (2) is the high value for the system designated (2) in the comparison.
In the % difference comparisons, high (1) is the high value reported for the system designated (1) in the comparison; low (2) is the low value for the system designated (2) in the comparison.
A negative % difference indicates that system(1) is lower; a positive % difference indicates that system(2) is lower.

Table 2-36

Meaningful Differences* in 32-ounce Cold Cup System Comparisons
(See table footnotes for guidelines)

	ENERGY		SOLID WASTE - WEIGHT		SOLID WASTE - VOLUME		GHG	
	Range of Total Results (MM Btu/10,000 units)		Range of Total Results (lb/10,000 units)		Range of Total Results (cu ft/10,000 units)		Range of Total Results (lb CO2 equiv/10,000 units)	
32-OUNCE HOT CUPS								
EPS	10.9 -	13.5	232 -	286	17.84 -	22.02	880 -	1,087
PE-coated Paperboard	11.2 -	13.1	568 -	668	17.11 -	20.14	707 -	832
Wax-coated Paperboard (1 sample)	22.2		1,200		36.6		1,359	
	% Difference		% Difference		% Difference		% Difference	
Product Comparison	low(1) to high(2)	high(1) to low(2)	low(1) to high(2)	high(1) to low(2)	low(1) to high(2)	high(1) to low(2)	low(1) to high(2)	high(1) to low(2)
EPS (1) and PE-coated Paperboard (2)	-18%	19%	-97%	-66%	-12%	25%	6%	42%
EPS (1) and Wax-coated Paperboard (2)	-68%	-49%	-135%	-123%	-69%	-50%	-43%	-22%
PE-coated Paperboard (1) and Wax-coated Paperboard (2)	-66%	-51%	-71%	-57%	-73%	-58%	-63%	-48%

ANALYSIS	ENERGY	SOLID WASTE - WEIGHT	SOLID WASTE - VOLUME	GHG
EPS and PE-coated Paperboard	Inconclusive (b)	EPS lower	Inconclusive (a), (b)	Inconclusive (a)
EPS and Wax-coated Paperboard	EPS lower	EPS lower	EPS lower	Inconclusive (a)
PE-coated Paperboard and Wax-coated Paperboard	PE-coated paperboard lower	PE-coated paperboard lower	PE-coated paperboard lower	PE-coated paperboard lower

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003.

*** Meaningful Differences Explanatory Notes:**

Meaningful Difference between different material product systems (e.g., EPS, PE-coated Paperboard, Wax-coated Paperboard) as defined and used in this report occurs when the comparison of low (1) to high (2) AND the comparison of high (1) to low (2) BOTH meet the % difference criteria:

For **energy**, BOTH comparisons must be either <-10% OR >10%; that is, both % difference values must have the same sign (+ or -) and absolute value >10%.

For **solid waste by weight**, **solid waste by volume**, and **GHG**, BOTH comparisons must be either <-25% OR >25%; that is, both % difference values must have the same sign (+ or -) and absolute value >25%.

The difference between systems is considered inconclusive if:

(a) At least one of the % differences is less than the meaningful difference criteria, and/or

(b) One % difference is positive and the other is negative, indicating an overlap in results for the two systems.

Percent difference is defined as the difference between the system totals divided by the average of the two system totals.

In the % difference comparisons, low (1) is the low value reported for the system designated (1) in the comparison; high (2) is the high value for the system designated (2) in the comparison.

In the % difference comparisons, high (1) is the high value reported for the system designated (1) in the comparison; low (2) is the low value for the system designated (2) in the comparison.

A negative % difference indicates that system(1) is lower; a positive % difference indicates that system(2) is lower.

Table 2-37

Meaningful Differences* in 9-inch High-grade Plate System Comparisons
(See table footnotes for guidelines)

9-INCH HIGH-GRADE PLATES	ENERGY Range of Total Results (MM Btu/10,000 units)			SOLID WASTE - WEIGHT Range of Total Results (lb/10,000 units)			SOLID WASTE - VOLUME Range of Total Results (cu ft/10,000 units)			GHG Range of Total Results (lb CO2 equiv/10,000 units)		
GPPS	11.26	-	12.01	272	-	291	22.40	-	23.91	797	-	850
PE-coated Paperboard	9.98	-	10.15	514	-	522	15.56	-	15.81	605	-	615
Molded Pulp	11.57	-	12.42	552	-	593	14.74	-	15.84	997	-	1,071

Product Comparison	Energy % Difference low(1) to high(2)	Energy % Difference high(1) to low(2)	Solid Waste - Weight % Difference low(1) to high(2)	Solid Waste - Weight % Difference high(1) to low(2)	Solid Waste - Volume % Difference low(1) to high(2)	Solid Waste - Volume % Difference high(1) to low(2)	GHG % Difference low(1) to high(2)	GHG % Difference high(1) to low(2)
GPPS (1) and PE-coated Paperboard (2)	10%	18%	-63%	-55%	34%	42%	26%	34%
GPPS (1) and Molded Pulp (2)	-10%	4%	-74%	-62%	34%	47%	-29%	-16%
PE-coated Paperboard (1) and Molded Pulp (2)	-22%	-13%	-14%	-6%	-2%	7%	-56%	-47%

ANALYSIS	ENERGY	SOLID WASTE - WEIGHT	SOLID WASTE - VOLUME	GHG
GPPS and PE-coated Paperboard	PE-coated paperboard lower	GPPS lower	PE-coated paperboard lower	PE-coated paperboard lower
GPPS and Molded Pulp	Inconclusive (a), (b)	GPPS lower	Molded pulp lower	Inconclusive (a)
PE-coated Paperboard and Molded Pulp	PE-coated paperboard lower	Inconclusive (a)	Inconclusive (a)	PE-coated paperboard lower

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Results in this table apply only to high-grade plates, which are the strongest and heaviest plates available in each material category. Lighter weight polystyrene and paper plates are available but are not included in these results.

*** Meaningful Differences Explanatory Notes:**

Meaningful Difference between different material product systems (e.g., GPPS, PE-coated Paperboard, Molded Pulp) as defined and used in this report occurs when the comparison of low (1) to high (2) AND the comparison of high (1) to low (2) BOTH meet the % difference criteria:

For **energy**, BOTH comparisons must be either <-10% OR >10%; that is, both % difference values must have the same sign (+ or -) and absolute value >10%.

For **solid waste by weight**, **solid waste by volume**, and **GHG**, BOTH comparisons must be either <-25% OR >25%; that is, both % difference values must have the same sign (+ or -) and absolute value >25%.

The difference between systems is considered inconclusive if:

(a) At least one of the % differences is less than the meaningful difference criteria, and/or

(b) One % difference is positive and the other is negative, indicating an overlap in results for the two systems.

Percent difference is defined as the difference between the system totals divided by the average of the two system totals.
In the % difference comparisons, low (1) is the low value reported for the system designated (1) in the comparison; high (2) is the high value for the system designated (2) in the comparison.
In the % difference comparisons, high (1) is the high value reported for the system designated (1) in the comparison; low (2) is the low value for the system designated (2) in the comparison.
A negative % difference indicates that system(1) is lower; a positive % difference indicates that system(2) is lower.

Table 2-38

Meaningful Differences* in Sandwich-size Clamshell System Comparisons
(See table footnotes for guidelines)

	ENERGY			SOLID WASTE - WEIGHT			SOLID WASTE - VOLUME			GHG		
5-INCH CLAMSHELLS	Range of Total Results (MM Btu/10,000 units)			Range of Total Results (lb/10,000 units)			Range of Total Results (cu ft/10,000 units)			Range of Total Results (lb CO2 equiv/10,000 units)		
GPPS	4.79	-	5.44	116	-	131	9.48	-	10.78	341	-	387
Fluted Paperboard	5.31	-	5.38	285	-	289	8.59	-	8.72	483	-	490

	% Difference		% Difference		% Difference		% Difference	
Product Comparison	low(1) to high(2)	high(1) to low(2)	low(1) to high(2)	high(1) to low(2)	low(1) to high(2)	high(1) to low(2)	low(1) to high(2)	high(1) to low(2)
GPPS (1) and Fluted Paperboard (2)	-12%	3%	-86%	-74%	8%	23%	-36%	-22%

ANALYSIS	ENERGY	SOLID WASTE - WEIGHT	SOLID WASTE - VOLUME	GHG
GPPS and Fluted Paperboard	Inconclusive (a), (b)	GPPS lower	Inconclusive (a), (b)	Inconclusive (a)

Results shown in this table represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003.

*** Meaningful Differences Explanatory Notes:**

Meaningful Difference between different material product systems (e.g., GPPS, Fluted Paperboard) as defined and used in this report occurs when the comparison of low (1) to high (2) AND the comparison of high (1) to low (2) BOTH meet the % difference criteria:

For **energy**, BOTH comparisons must be either <-10% OR >10%; that is, both % difference values must have the same sign (+ or -) and absolute value >10%.

For **solid waste by weight**, **solid waste by volume**, and **GHG**, BOTH comparisons must be either <-25% OR >25%; that is, both % difference values must have the same sign (+ or -) and absolute value >25%.

The difference between systems is considered inconclusive if:

(a) At least one of the % differences is less than the meaningful difference criteria, and/or

(b) One % difference is positive and the other is negative, indicating an overlap in results for the two systems.

Percent difference is defined as the difference between the system totals divided by the average of the two system totals.
In the % difference comparisons, low (1) is the low value reported for the system designated (1) in the comparison; high (2) is the high value for the system designated (2) in the comparison.
In the % difference comparisons, high (1) is the high value reported for the system designated (1) in the comparison; low (2) is the low value for the system designated (2) in the comparison.
A negative % difference indicates that system(1) is lower; a positive % difference indicates that system(2) is lower.

The comparison of PE-coated paperboard cups with and without sleeves is inconclusive in all categories except solid waste by volume. One would expect that a cup with sleeve would always compare unfavorably with a cup without sleeve; however, the results of this comparison illustrate that the variation in product weights is important when attempting to draw general conclusions about competing products. In this case there is actually some overlap in energy results for the lightest cup + sleeve and the results for the heaviest cup without sleeve, and the differences in solid waste by weight and GHG are below the percent difference guideline.

32-ounce Cold Cups (Table 2-36)

In the product category of 32-ounce cold cups, EPS cups produce less solid waste by weight compared to PE-coated paperboard cups, but comparisons of EPS cups and PE-coated cups in other results categories are inconclusive. Compared to wax-coated paperboard cups, EPS cups are lower in energy and in weight and volume of solid waste, but the comparison of GHG is inconclusive. PE-coated cups compare favorably with wax-coated cups in all categories.

9-inch High-grade Plates (Table 2-37)

In the comparisons of GPPS high-grade plates with other plates, GPPS plates are lower in solid waste by weight compared to both PE-coated paperboard and molded pulp plates. PE-coated paperboard plates are lower than GPPS in energy, solid waste by volume, and GHG. Molded pulp plates are lower than GPPS in solid waste by volume, but comparisons of energy and GHG are inconclusive.

In the comparison of PE-coated paperboard and molded pulp plates, PE-coated plates are lower in energy and GHG than molded pulp, but solid waste comparisons are inconclusive.

5-inch Sandwich-size Clamshells (Table 2-38)

Compared to fluted paperboard, GPPS clamshells are lower in solid waste by weight, but all other comparisons of GPPS and fluted paperboard are inconclusive.

It is interesting to note that in all the comparisons in Tables 2-35 through 2-38, there is only one instance in which one system compared favorably to the other in all categories (the comparison of 32-ounce PE-coated cups and wax-coated cups). In all other comparisons, the results for different environmental results were mixed or at least one comparison was inconclusive.

OBSERVATIONS AND CONCLUSIONS

Energy

- Energy of material resource, the energy content of fuel resources used as a material input for production of materials such as plastic resins, accounts for 40 to 50 percent of total energy or polystyrene foodservice products. Coated paperboard foodservice products have lower energy of material resource, associated with product coatings produced from fuel resources.
- Process energy dominates total energy for paper-based systems.
- Over 90 percent of the total energy for polystyrene foodservice products is from fossil fuels. This includes not only the use of fossil fuels for process and transportation energy, but also the energy content of the crude oil and natural gas used as material feedstocks for production of polystyrene resin.
- Wood is a significant source of process energy for paperboard foodservice products, providing nearly half of the total energy requirements.

Solid Wastes

- Postconsumer wastes, from the disposal of foodservice products after use, dominate solid waste results both by weight and by volume.
- Because of the low density of polystyrene foam products, the total weights of solid waste for polystyrene foodservice products are significantly lower than for competing products. However, the solid waste volumes for polystyrene foam products are comparable to alternative products, or in the case of plates, higher than alternative products.

Environmental Emissions

- Greenhouse gas profiles closely track the total fossil process and transportation energy for foodservice products.
- No overall conclusions can be made about the air and waterborne emissions released from these systems because (1) no one foodservice product produces lower emissions in every category when compared to alternative products and (2) no attempt is made in an LCI such as this study to determine the potential impacts of individual emissions on human health and the environment.

CHAPTER 3

AVERAGE WEIGHT FOODSERVICE PRODUCT PLUS SECONDARY PACKAGING

INTRODUCTION

The results presented in this chapter comprise a partial LCI of the foodservice products, using their average weight, and their secondary packaging. The results comprise all processes beginning with extraction of raw materials from the earth and continuing through the production of average weight foodservice products and their secondary packaging. Transportation of packaged product from foodservice product manufacturers to retail locations and customer use locations and use by consumers are not included. Disposal of foodservice products and secondary packaging are included in the results in this chapter. Energy requirements, solid waste by weight and volume, and the major greenhouse gases are discussed at length for the cups, plates, and clamshells and their secondary packaging.

The purpose of this chapter is to evaluate the maximum potential contribution of secondary packaging to the environmental burdens for the production and disposal for each average weight product system. The results in this chapter cannot be used to draw conclusions about the relative environmental performance of product + secondary packaging systems since the full range of product weights are not represented in this chapter.

Systems Studied

Four types of foodservice products are analyzed in this study: 16-ounce hot cups, 32-ounce cold cups, 9-inch high-grade plates, and 5-inch sandwich-size clamshells. Weights for these foodservice products can be found in Table 2-1 in Chapter 2. These foodservice products are typically packaged and sent to customers in a corrugated box containing several stacks of product unitized in polyethylene film sleeves.

Development of Secondary Packaging Data. For all foodservice products, secondary packaging information was requested from manufacturers along with product samples, but response was generally poor. Additional shipping data for specific products were also obtained online where available, through manufacturers' or distributors' websites. Shipping weights for cases of product were used to estimate the weights of secondary packaging. The number of product units per case was multiplied by the weight per product unit and subtracted from the reported shipping weight of the packed case. The difference was assumed to be the weight of the secondary packaging. Although this calculation method was expected to be accurate, this proved to be an unreliable method for developing weight data for secondary packaging. In some cases the calculated weight of secondary packaging was unreasonably high, while in other cases a negative value was calculated.

It was thus necessary for Franklin Associates to pursue alternative methods to determine secondary packaging weights. Three methods were used:

- Secondary packaging weight data were requested from foodservice producers. Secondary packaging weights were provided for EPS cups by PSPC member companies. The producer of corrugated paperboard clamshells also provided packaging weight data.
- Some cases of product were purchased so that the weight of secondary packaging could be determined from direct measurements. Cases of 32-ounce paper cups with wax and polyethylene coatings were purchased and weighed.
- The weight of secondary packaging for all other foodservice products was calculated based on the square feet of corrugated box and plastic film sleeves required and the weight per square foot of these materials. The square feet of corrugated and film were calculated based on product dimensions (diameter of plates and cups or length times width of clamshells, height of one product, incremental stacking height of product, number of items per case, and number of sleeves of product per case). The weight of corrugated per square foot was based on the measured weight and surface area of the coated paper cup boxes, while the weight of plastic film was based on the average of the measured paper cup packaging and film use reported by producers.

Using the three methods described, weights of secondary packaging were determined for each type of product in each product category. In those cases where producers reported secondary packaging weights, packaging weights were also calculated based on product dimensions. In some cases calculated secondary packaging weights agreed quite closely with reported weights, while in other cases they were considerably different.

Another complicating issue was the fact that different producers shipped product in cases containing different numbers of product units. This is important, because the first layer of product has the greatest impact on the case height, while the incremental stacking height of additional product units is much smaller. Thus, the height (and secondary packaging weight) of a case of 1,000 product units is less than twice the height and weight of a case of a case of 500 product units (given the same array of sleeves of product). As a result, the secondary packaging for 10,000 products can vary significantly depending on the case size evaluated. For cups and plates, cases of product were generally available for comparable numbers of units. For clamshells, however, there was considerable variation in the number of units per case; therefore, the weight of packaging per theoretical equivalent case of 600 clamshells was calculated, based on product dimensions and the reported weight of secondary packaging for actual cases.

Table 3-1

SECONDARY PACKAGING
(pounds per 10,000 product units)

		Corrugated					Film Sleeves
	Units per Case	**Meas (1)**	**Rept (2)**	**Calc (3)**	**Min**	**Max**	**LLDPE**
16 oz Hot Cups							
EPS Foam							
Mfr 1	500		37.7	70.3	37.7	**70.3**	2.5
Mfr 2	500		40.8	63.9			2.1
PE-coated Paperboard							
Mfr 1	500			44.6	44.6	**50.4**	1.1
Mfr 2	500			50.4			1.4
Unbleached Corrugated Cup Sleeves	1200			35.2	35.2	**35.2**	no data available
32 oz Cold Cups							
EPS Foam							
Mfr 1	500		70.6	108.5	70.6	**108.5**	2.8
Mfr 2	500			95.4			3.9
PE-coated Paperboard	480	62.5			62.5	**62.5**	2.7
Wax-coated Paperboard	480	62.5			62.5	**62.5**	2.9
9 inch High-Grade Plates							
GPPS Foam - Laminated	500		43.8	74.0	43.8	**74.0**	2.0
Coated Paperboard							
Mfr 1	500			41.4	41.4	**41.4**	0.7
Mfr 2	500			41.4			0.7
Uncoated Molded Pulp							
Mfr 1	500			42.3	37.8	**42.3**	0.8
Mfr 2	500			37.8			0.6
Sandwich-size Clamshells							
	actual case						
5 inch GPPS Foam	500		35.8	71.9			3.4
5 inch Corrugated Paperboard	702		25.6	29.9			1.6
	normalized						
5 inch GPPS Foam	600			66.0	35.8	**71.9**	6.2
5 inch Corrugated Paperboard	600			33.4	25.6	**33.4**	1.6

(1) Measured.
(2) Weight reported by manufacturer.
(3) Weight calculated based on product dimensions, units/case, etc.

Source: Franklin Associates

Table 3-1 shows the various weights of secondary packaging obtained by each method for each foodservice product, scaled up for 10,000 product units. In order to determine the maximum potential contribution of secondary packaging to the overall environmental profile of average product plus packaging, the maximum weight of secondary packaging was selected for each foodservice product where more than one weight is listed, as shown in Table 3-1.

For the 16-ounce hot cups, the PE-coated paperboard cup plus sleeve requires the heaviest amount of secondary packaging. This is because the corrugated sleeves and cups are shipped in separate corrugated boxes. No weight data was available for film sleeves used to ship the corrugated cup sleeves. The weight of film sleeves used to ship the EPS foam cups is almost twice as heavy as those used for the PE-coated paperboard cups.

For the 32-ounce cold cups, the corrugated box used for the EPS foam cups is almost 1.5 times as heavy as the corrugated box used for each of the coated paperboard cups. The corrugated boxes used to ship PE-coated and wax-coated paperboard cups weigh the same.

For the 9-inch high-grade plates, the corrugated box weights for the GPPS foam plates are calculated based on product dimensions, units per case, etc. The corrugated box and film sleeve weights for the coated paperboard and uncoated molded pulp plates are similar. The weight of the film sleeves used for the GPPS foam plates is almost 3 times greater than the film sleeves used for the paperboard and molded pulp plates.

For the 5-inch sandwich-size clamshells, using the normalized case weights, the corrugated case weight for the corrugated paperboard clamshell is less than half the weight of the case used for the GPPS foam clamshell. Using the normalized film sleeves weights, the total weight of film sleeves used for packaging the corrugated paperboard clamshell is almost 4 times less than the total weights of film sleeves used for the GPPS clamshells.

Packaging weights tend to be higher for foamed products such as the polystyrene products analyzed. Because the foamed products are generally thicker than corresponding paperboard products, their incremental stacking height is greater, requiring a larger dimension box or a greater area of film sleeve compared to paperboard products for the same number of product units. This is particularly true for polystyrene foam cups, which are not only thicker than paperboard alternatives but also have a molded rim that increases the incremental stacking height.

LCI RESULTS

Total energy, solid waste by weight and volume, and greenhouse gas emissions results are presented in this chapter for the foodservice product systems and their secondary packaging. These results focus on the environmental burden contributions of secondary packaging used for each primary product, while the primary foodservice products are the focus of Chapter 2. This chapter focuses on:

- the burdens associated with the packaging versus the product and
- the increased burden of the secondary packaging for 10,000 average weight product units of the primary product

Total energy results are shown in Tables 3-2 through 3-5 and Figures 3-1 through 3-4. Solid waste results by weight and volume are shown in Tables 3-6 through 3-9 and Figures 3-5 through 3-12. Greenhouse gas emissions are shown in Tables 3-10 through 3-13 and Figures 3-13 through 3-16. Throughout these results categories, the first table and figure presents results for the 16-ounce hot cup systems, followed in order by the 32-ounce cold cup systems, the 9-inch high-grade plate systems, and the 5-inch sandwich-size clamshell systems.

Data development and assumptions for the production of individual products and secondary packaging components are described in Chapters 1 and 2 and the report appendices.

Energy Results

In the results tables, each primary foodservice product material is shown across the top of the columns. Under each primary product material, three columns are shown--the total energy for the primary product, the total energy for the secondary packaging, and the sum of the two previous columns.

16-ounce Hot Cups. Table 3-2 and Figure 3-1 show the total energy for 10,000 16-ounce hot cups and their secondary packaging. The total energy for the primary foodservice product ranges from 87 to 92 percent of the primary product plus secondary packaging total energy. The secondary packaging for the polystyrene cup system increases the total energy by the greatest percentage (15 percent). The total energy for the poly-coated paperboard cups and the poly-coated paperboard cup plus sleeve increase by 9 percent and 12 percent respectively when the secondary packaging is added.

32-ounce Cold Cups. Table 3-3 and Figure 3-2 show the total energy for 10,000 32-ounce cold cups and their secondary packaging. The total energy for the primary foodservice product ranges from 89 to 96 percent of the primary product plus secondary packaging total energy. The secondary packaging for the polystyrene cup system increases the total energy by the greatest percentage (12 percent). The total energy for the poly-coated paperboard cup and the wax-coated paperboard cup increase by 7 percent and 4 percent, respectively, when the secondary packaging is added.

9-inch High-grade Plates. Table 3-4 and Figure 3-3 show the total energy for 10,000 9-inch high-grade plates and their secondary packaging. The total energy for the primary foodservice product ranges from 92 to 96 percent of the primary product plus secondary packaging total energy. The addition of secondary packaging increases the total energy for the polystyrene plate by 9 percent. The total energy for both the poly-coated paperboard plate and the molded pulp plate increase by 5 percent when the secondary packaging is added.

Table 3-2

Total Energy for 10,000 16-ounce Hot Cups and Secondary Packaging

	Polystyrene			Poly-Coated Paperboard			Corrugated Cup Sleeves			PE Ppbd Cup + Sleeve		
	Product	Sec Pkg	Total	Product	Sec Pkg	Total	Product	Sec Pkg	Total	Product	Sec Pkg	Total
Total Energy (Million Btu)	6.55	0.96	7.51	7.89	0.67	8.57	1.75	0.44	2.19	9.64	1.11	10.75
Total Energy (%)	87%	13%	100%	92%	8%	100%	80%	20%	100%	90%	10%	100%

Source: Franklin Associates

Results in this table represent average weight product plus secondary packaging. The purpose of this table is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-2.

Table 3-3

Total Energy for 10,000 32-ounce Cold Cups and Secondary Packaging

	Polystyrene			Poly-Coated Paperboard			Wax-Coated Paperboard		
	Product	Sec Pkg	Total	Product	Sec Pkg	Total	Product	Sec Pkg	Total
Total Energy (Million Btu)	11.9	1.48	13.4	12.3	0.88	13.2	22.2	0.89	23.1
Total Energy (%)	89%	11%	100%	93%	7%	100%	96%	4%	100%

Source: Franklin Associates

Results in this table represent average weight product plus secondary packaging. The purpose of this table is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-3.

Table 3-4

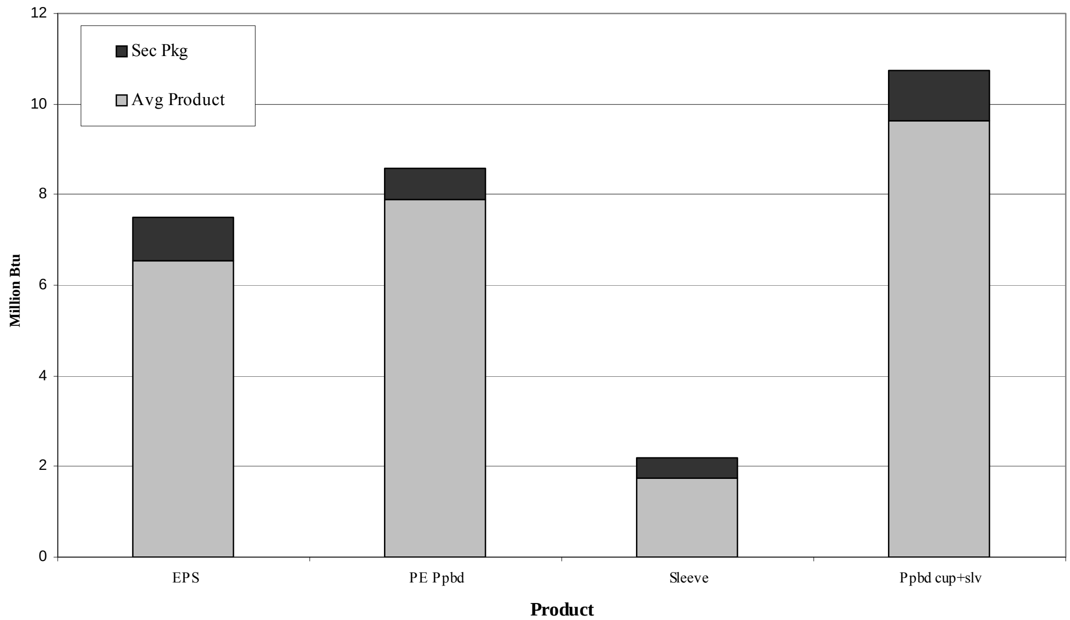
Total Energy for 10,000 9-inch High-grade Plates and Secondary Packaging

	Polystyrene			Poly-Coated Paperboard			Molded Pulp		
	Product	Sec Pkg	Total	Product	Sec Pkg	Total	Product	Sec Pkg	Total
Total Energy (Million Btu)	11.7	1.00	12.7	10.1	0.54	10.6	11.9	0.55	12.4
Total Energy (%)	92%	8%	100%	95%	5%	100%	96%	4%	100%

Source: Franklin Associates

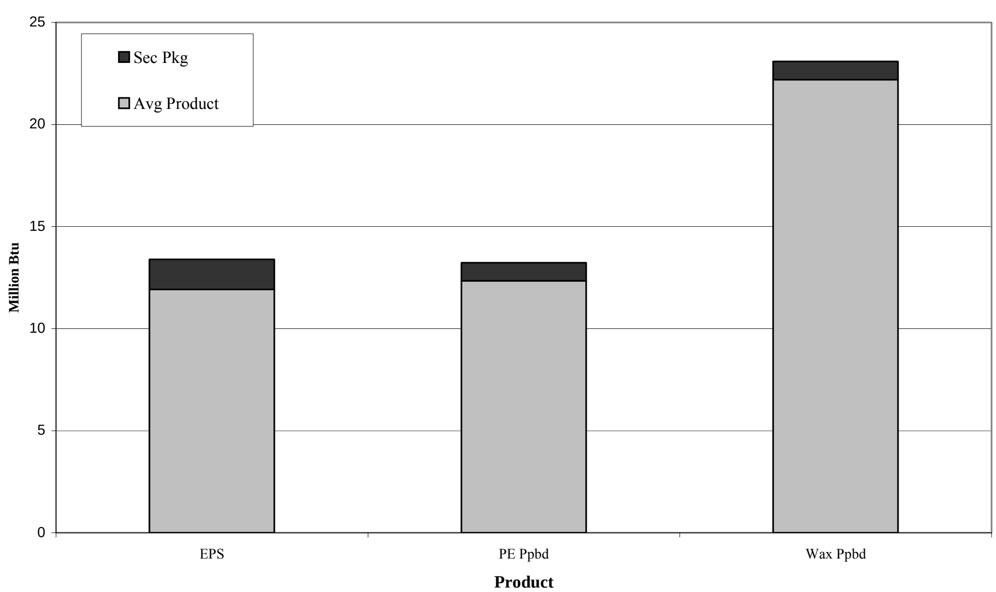
Results in this table represent average weight product plus secondary packaging. The purpose of this table is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Results in this table apply only to average weight high-grade plates, which are the strongest and heaviest plates available in each material category. Lighter weight polystyrene and paper plates are available but are not included in these results.
Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-4.

Figure 3-1. Total Energy for 10,000 16-oz Hot Cups and Secondary Packaging (Million Btu)



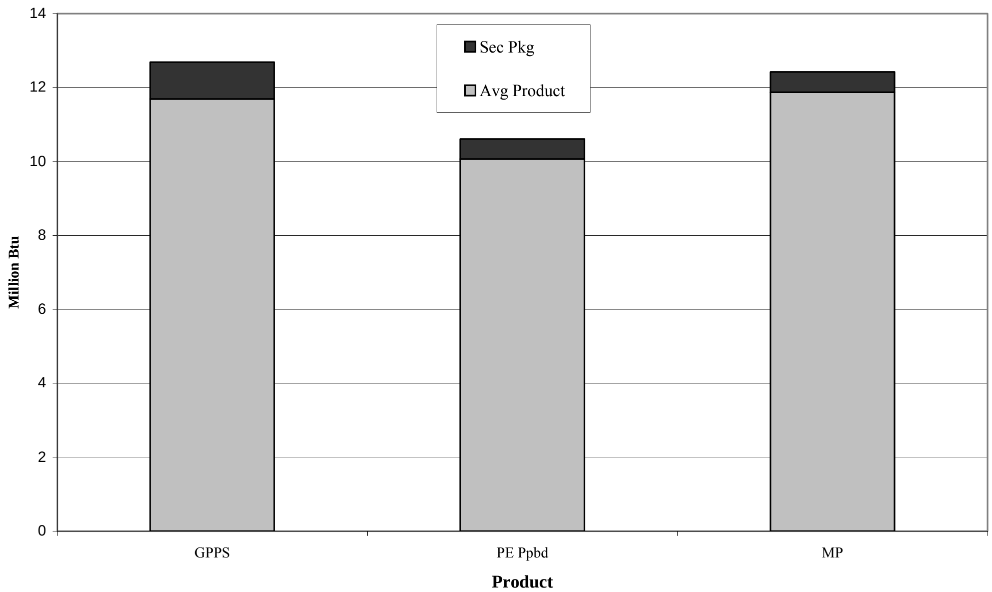
Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure 3-2. Total Energy for 10,000 32-oz Cold Cups and Secondary Packaging (Million Btu)



Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure 3-3. Total Energy for 10,000 9-inch High-Grade Plates and Secondary Packaging (Million Btu)



Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

5-inch Sandwich-size Clamshells. Table 3-5 and Figure 3-4 show the total energy for 10,000 5-inch clamshells and their secondary packaging. The total energy for the primary foodservice product ranges from 82 to 92 percent of the primary product plus secondary packaging total energy. Secondary packaging increases the total energy for the polystyrene clamshell by 22 percent. The total energy for the fluted paperboard clamshell increases by 9 percent when the secondary packaging is added.

Solid Waste

Solid waste is broadly categorized into process wastes, fuel-related wastes, and postconsumer wastes. These categories are discussed in Chapter 2. As with energy results tables, each primary product material is shown across the top of the columns. Under each primary product material, three columns are shown--the total solid waste for the primary product, the total solid waste for the secondary packaging, and the sum of the two previous columns. The results tables show the solid waste by weight and volume. Tables and figures are shown at the end of this section.

It is helpful to understand how the results for solid waste by category relate to the results for energy in the previous section and tables. Solid wastes for a process include not only waste materials generated from the process itself, but also solid wastes from the production and combustion of fuels used for process energy. Thus, fuel-related solid waste includes the solid waste associated with process energy as well as transportation energy.

Table 3-5

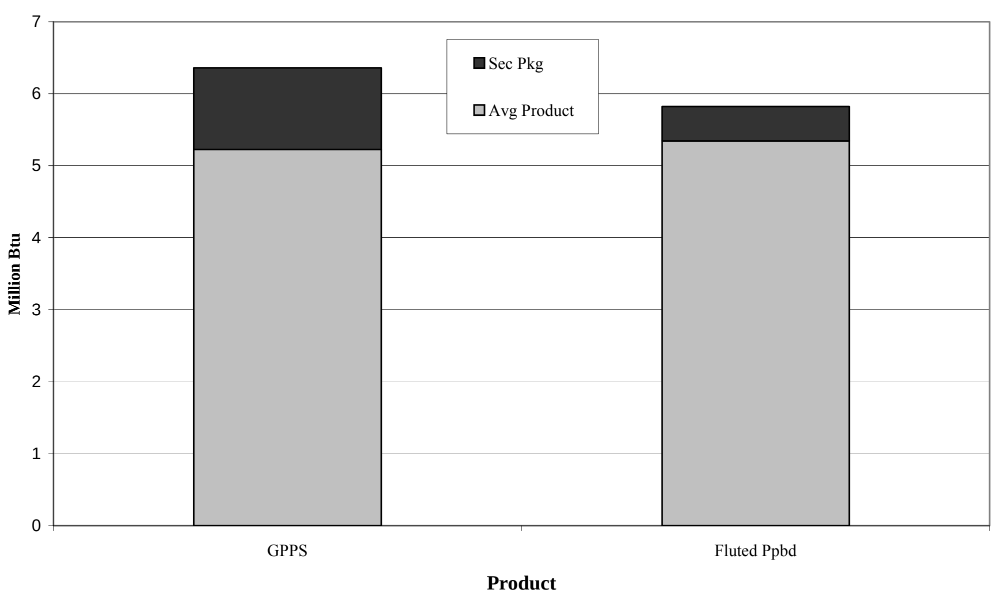
Total Energy for 10,000 5-inch Sandwich-size Clamshells and Secondary Packaging

	Polystyrene			Fluted Paperboard		
	Product	Sec Pkg	Total	Product	Sec Pkg	Total
Total Energy (Million Btu)	5.22	1.14	6.36	5.35	0.48	5.82
Total Energy (%)	82%	18%	100%	92%	8%	100%

Source: Franklin Associates

Results in this table represent average weight product plus secondary packaging. The purpose of this table is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-5.

Figure 3-4. Total Energy for 10,000 5-inch Sandwich-Size Clamshells and Secondary Packaging (Million Btu)



Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Landfills fill up because of volume, not weight. While weight is the conventional measure of waste, landfill volume is more relevant to the environmental concerns of land use. The problem is the difficulty in deriving accurate landfill volume factors. However, Franklin Associates has developed a set of landfill density factors for different materials based upon an extensive sampling by the University of Arizona. While these factors are considered to be only estimates, their use helps add valuable perspective. Volume factors are estimated to be accurate to +/- 25%.

Weights of solid waste are converted into volumes using landfill density factors. Process and fuel-related solid waste are generally reported as totals without detail on the composition and densities of individual substances within these categories; thus, the weights of process and fuel-related waste are converted to volume using an average conversion factor for industrial solid waste. The weight to volume conversions for postconsumer solid waste, however, are based on the landfill densities for materials from the University of Arizona studies and reflect the volumes that specific materials are likely to take up in a landfill. As would be expected, the lower density materials such as loose fill occupy more landfill space relative to equivalent quantities of higher density materials.

16-ounce Hot Cups. Table 3-6 shows the total solid waste by weight and volume for 10,000 16-ounce hot cups and the secondary packaging. Figure 3-5 shows the total solid waste by weight for 10,000 16-ounce hot cups and secondary packaging. The total solid waste by weight for the primary foodservice product ranges from 67 to 89 percent of the primary product plus secondary packaging total solid waste by weight. The secondary packaging for the polystyrene system is 33 percent of the total solid waste, while secondary packaging makes up only 11 percent for both paperboard systems. The secondary packaging for the polystyrene cup system increases the total solid waste by weight by the greatest percentage (50 percent). The total solid waste by weight for the poly-coated paperboard cups and the poly-coated paperboard cup plus sleeve increase by 13 percent and 12 percent respectively when the secondary packaging is added. Even with the addition of secondary packaging, the polystyrene hot cup system still produces the smallest amount of solid waste by weight.

Figure 3-6 shows the total solid waste by volume for 10,000 16-ounce hot cups and secondary packaging. The total solid waste by volume for the primary foodservice product ranges from 83 to 89 percent of the primary product plus secondary packaging total solid waste by volume. The difference between the weight and volume percent for the polystyrene product is best explained by examining the landfill density of the polystyrene product versus the paperboard products (see Chapter 2 discussion). The secondary packaging for the polystyrene cup system increases the total solid waste volume by the greatest percentage (21 percent).

Table 3-6

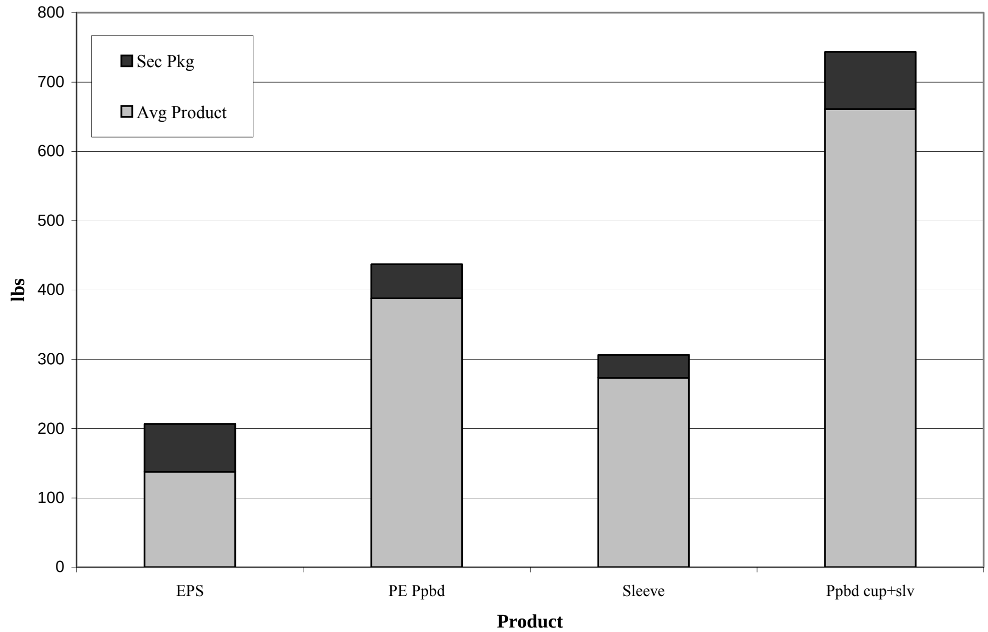
Solid Wastes by Weight and Volume for 10,000 16-ounce Hot Cups and Secondary Packaging

	Polystyrene			Poly-Coated Paperboard			Corrugated Cup Sleeves			PE Ppbd Cup + Sleeve		
	Product	Sec Pkg	Total	Product	Sec Pkg	Total	Product	Sec Pkg	Total	Product	Sec Pkg	Total
Solid Wastes By Weight (lb)												
Process	5.31	5.13	10.4	55.4	3.63	59.1	15.3	2.45	17.8	70.8	6.08	76.8
Fuel	49.5	16.0	65.5	97.3	11.4	109	52.8	7.79	60.6	150	19.2	169
Postconsumer	82.8	48.0	131	235	34.0	269	205	22.8	228	440	56.9	497
Total lb	**138**	**69.1**	**207**	**388**	**49.0**	**437**	**273**	**33.1**	**306**	**661**	**82.1**	**743**
Total Weight Percent	**67%**	**33%**	**100%**	**89%**	**11%**	**100%**	**89%**	**11%**	**100%**	**89%**	**11%**	**100%**
Solid Wastes By Volume (cu ft)												
Process	0.106	0.10	0.21	1.11	0.073	1.18	0.31	0.049	0.36	1.42	0.12	1.54
Fuel	0.99	0.32	1.31	1.95	0.23	2.17	1.06	0.16	1.21	3.00	0.38	3.38
Postconsumer	9.32	1.74	11.1	8.57	1.23	9.80	7.36	0.82	8.19	15.9	2.05	18.0
Total cu ft	**10.4**	**2.16**	**12.6**	**11.6**	**1.53**	**13.2**	**8.73**	**1.03**	**9.75**	**20.4**	**2.56**	**22.9**
Total Volume Percent	**83%**	**17%**	**100%**	**88%**	**12%**	**100%**	**89%**	**11%**	**100%**	**89%**	**11%**	**100%**

Source: Franklin Associates

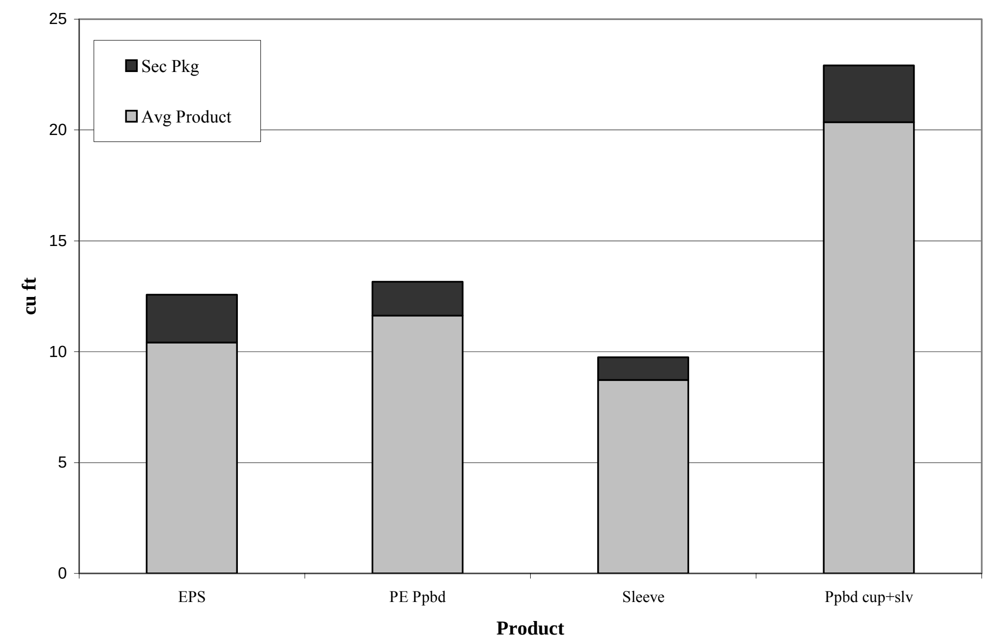
Results in this table represent average weight product plus secondary packaging. The purpose of this table is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-10.

Figure 3-5. Solid Waste by Weight for 10,000 16-oz Hot Cups and Secondary Packaging (lbs)



Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure 3-6. Solid Waste by Volume for 10,000 16-oz Hot Cups and Secondary Packaging (cu ft)



Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

32-ounce Cold Cups. Table 3-7 shows the total solid waste by weight and volume for 10,000 32-ounce cold cups and the secondary packaging. Figure 3-7 shows the total solid waste by weight for 10,000 32-ounce cold cups and secondary packaging. The total solid waste by weight for the primary foodservice product ranges from 70 to 95 percent of the primary product plus secondary packaging total solid waste by weight. The secondary packaging for the polystyrene system is 30 percent of the total solid waste, while secondary packaging makes up only 5 to 9 percent for both paperboard systems. The secondary packaging for the polystyrene cup system increases the total solid waste by weight by the greatest percentage (42 percent). The total solid waste by weight for the poly-coated paperboard cups and the wax-coated paperboard cup increase by 10 percent and 5 percent respectively when the secondary packaging is added. Even with the addition of secondary packaging, the polystyrene cold cup system still produces the smallest amount of solid waste by weight.

Figure 3-8 shows the total solid waste by volume for 10,000 32-ounce cold cups and secondary packaging. The total solid waste by volume for the primary foodservice product ranges from 85 to 95 percent of the primary product plus secondary packaging total solid waste by volume. The difference between the weight and volume percent for the polystyrene product is best explained by examining the landfill density of the polystyrene product versus the paperboard products (see Chapter 2 discussion). The secondary packaging for the polystyrene cup system increases the total solid waste volume by the greatest percentage (17 percent).

9-inch High-grade Plates. Table 3-8 shows the total solid waste by weight and volume for 10,000 9-inch high-grade plates and the secondary packaging. Figure 3-9 shows the total solid waste by weight for 10,000 9-inch high-grade plates and secondary packaging. The total solid waste by weight for the primary foodservice product ranges from 80 to 93 percent of the primary product plus secondary packaging total solid waste by weight. The secondary packaging for the polystyrene plate system increases the total solid waste by weight by the greatest percentage (26 percent). The total solid waste by weight for the poly-coated paperboard plates and the molded pulp plates increase by 8 percent and 7 percent respectively when the secondary packaging is added.

Figure 3-10 shows the total solid waste by volume for 10,000 9-inch high-grade plates and secondary packaging. The total solid waste by volume for the primary foodservice product ranges from 91 to 93 percent of the primary product plus secondary packaging total solid waste by volume. The difference between the weight and volume percent for the polystyrene product is best explained by examining the landfill density of the polystyrene product versus the paperboard products (see Chapter 2 discussion).

Table 3-7

Solid Wastes by Weight and Volume for 10,000 32-ounce Cold Cups and Secondary Packaging

	Polystyrene			Poly-Coated Paperboard			Wax-Coated Paperboard		
	Product	Sec Pkg	Total	Product	Sec Pkg	Total	Product	Sec Pkg	Total
Solid Wastes By Weight (lb)									
Process	9.76	7.89	17.7	92.1	4.62	96.7	377	4.65	381
Fuel	87.3	24.6	112	149	14.3	164	270	14.4	285
Postconsumer	156	73.9	230	387	43.3	430	553	43.5	596
Total lb	**253**	**106**	**359**	**628**	**62.3**	**691**	**1,200**	**62.5**	**1,262**
Total Weight Percent	**70%**	**30%**	**100%**	**91%**	**9%**	**100%**	**95%**	**5%**	**100%**
Solid Wastes By Volume (cu ft)									
Process	0.20	0.16	0.35	1.84	0.092	1.93	11.0	0.093	11.1
Fuel	1.75	0.49	2.24	2.99	0.29	3.27	5.41	0.29	5.70
Postconsumer	17.5	2.67	20.2	14.1	1.57	15.7	20.1	1.58	21.7
Total cu ft	**19.5**	**3.33**	**22.8**	**18.9**	**1.95**	**20.9**	**36.6**	**1.96**	**38.6**
Total Volume Percent	**85%**	**15%**	**100%**	**91%**	**9%**	**100%**	**95%**	**5%**	**100%**

Source: Franklin Associates

Results in this table represent average weight product plus secondary packaging. The purpose of this table is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-11.

Table 3-8

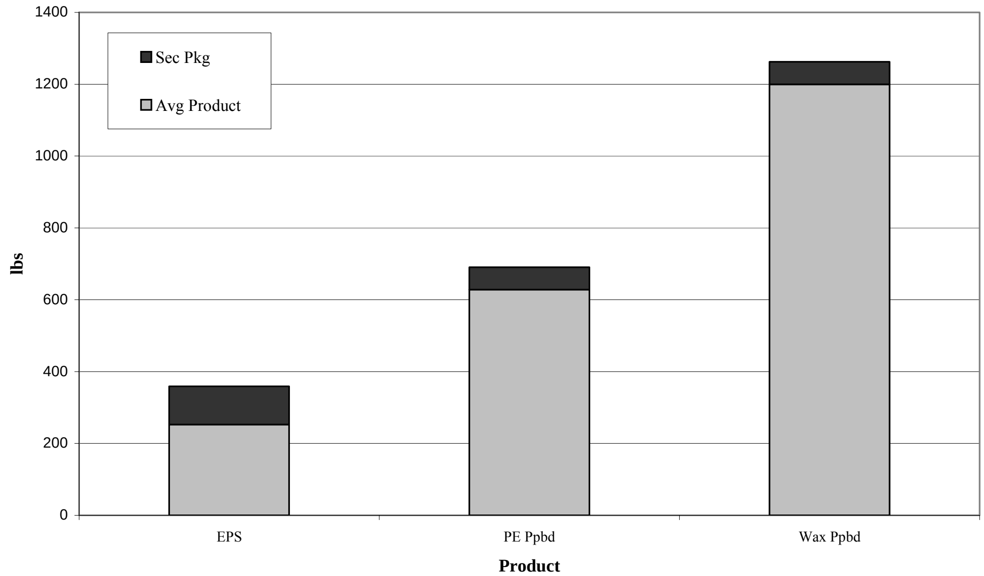
Solid Wastes by Weight and Volume for 10,000 9-inch High-grade Plates and Secondary Packaging

	Polystyrene			Poly-Coated Paperboard			Molded Pulp		
	Product	Sec Pkg	Total	Product	Sec Pkg	Total	Product	Sec Pkg	Total
Solid Wastes By Weight (lb)									
Process	8.17	5.35	13.5	76.8	2.95	79.8	91.7	3.01	94.7
Fuel	84.3	16.7	101	117	9.29	126	181	9.48	191
Postconsumer	190	50.1	240	324	27.6	352	294	28.1	322
Total lb	**283**	**72.2**	**355**	**518**	**39.9**	**558**	**567**	**40.6**	**607**
Total Weight Percent	**80%**	**20%**	**100%**	**93%**	**7%**	**100%**	**93%**	**7%**	**100%**
Solid Wastes By Volume (cu ft)									
Process	0.16	0.11	0.27	1.54	0.059	1.60	1.83	0.060	1.89
Fuel	1.69	0.33	2.02	2.34	0.19	2.52	3.62	0.19	3.81
Postconsumer	21.4	1.81	23.2	11.8	1.00	12.8	9.67	1.02	10.7
Total cu ft	**23.3**	**2.25**	**25.5**	**15.7**	**1.24**	**16.9**	**15.1**	**1.27**	**16.4**
Total Volume Percent	**91%**	**9%**	**100%**	**93%**	**7%**	**100%**	**92%**	**8%**	**100%**

Source: Franklin Associates

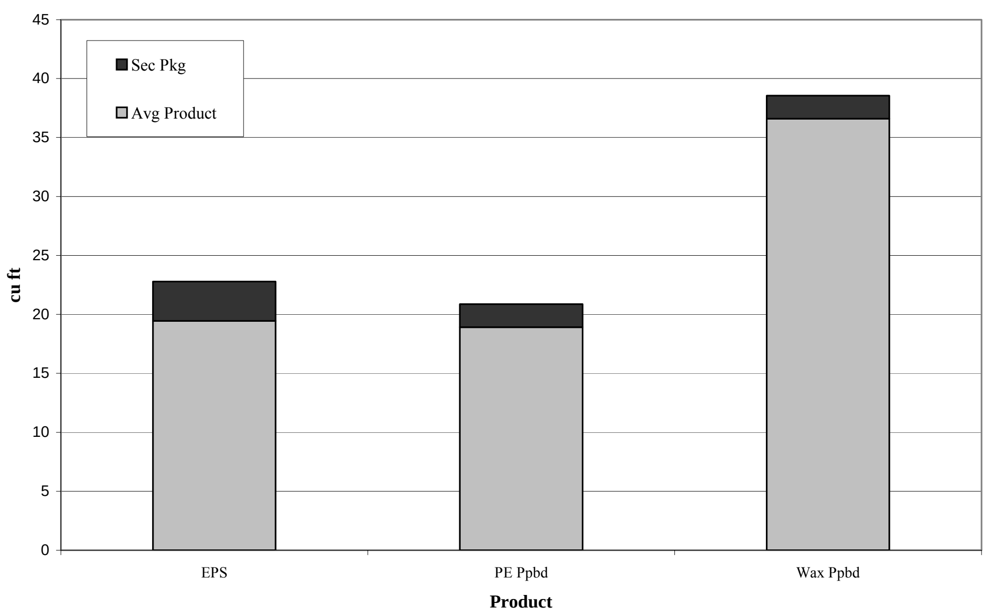
Results in this table represent average weight product plus secondary packaging. The purpose of this table is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Results in this table apply only to average weight high-grade plates, which are the strongest and heaviest plates available in each material category. Lighter weight polystyrene and paper plates are available but are not included in these results.
Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-12.

Figure 3-7. Solid Waste by Weight for 10,000 32-oz Cold Cups and Secondary Packaging (lbs)



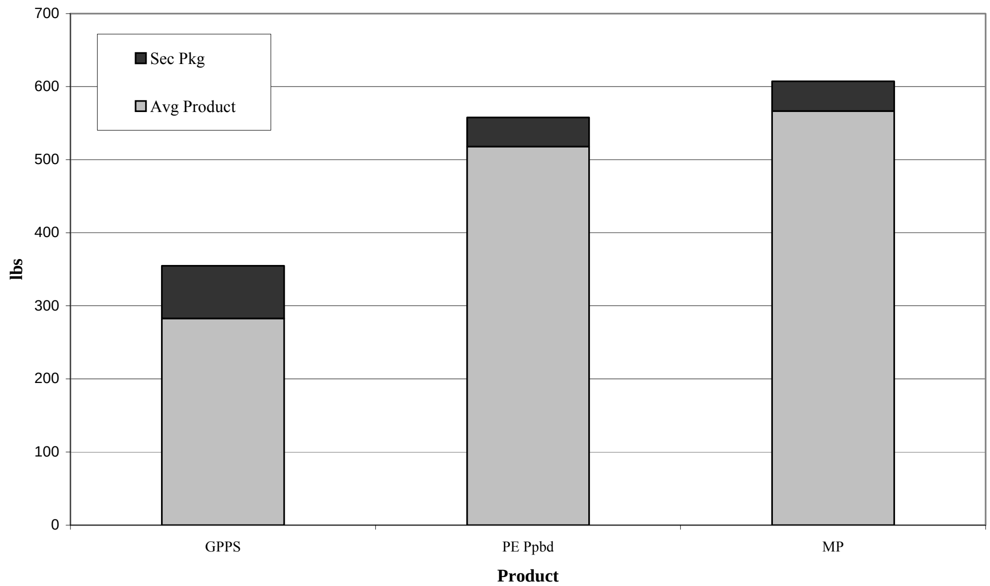
Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure 3-8. Solid Waste by Volume for 10,000 32-oz Cold Cups and Secondary Packaging (cu ft)



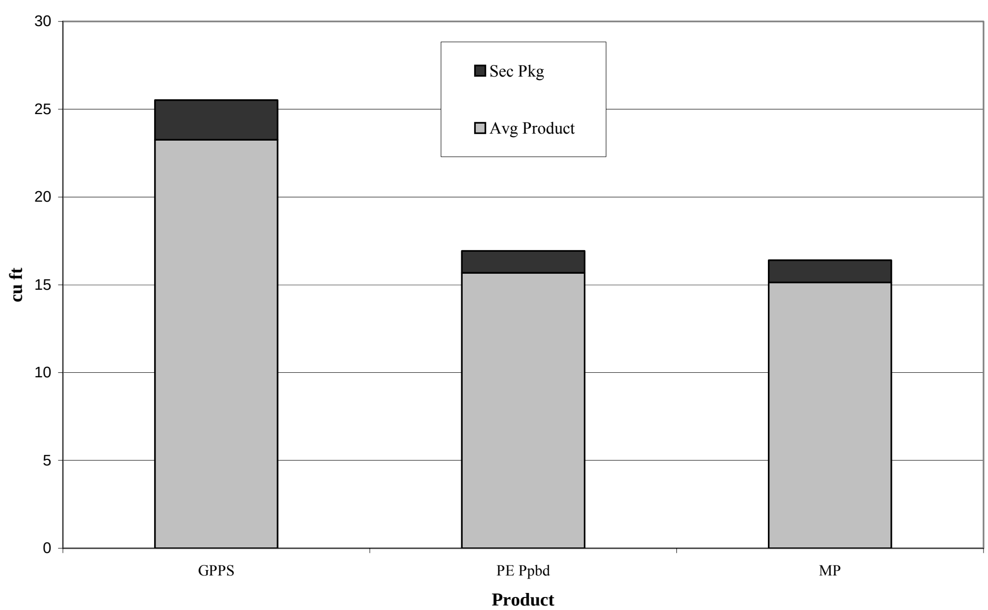
Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure 3-9. Solid Waste by Weight for 10,000 9-inch High-Grade Plates and Secondary Packaging (lbs)



Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure 3-10. Solid Waste by Volume for 10,000 9-inch High-Grade Plates and Secondary Packaging (cu ft)



Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

5-inch Sandwich-size Clamshells. Table 3-9 shows the total solid waste by weight and volume for 10,000 5-inch sandwich-size clamshells and the secondary packaging. Figure 3-11 shows the total solid waste by weight for 10,000 5-inch sandwich-size clamshells and secondary packaging. The total solid waste by weight for the primary foodservice product ranges from 63 to 90 percent of the primary product plus secondary packaging total solid waste by weight. The secondary packaging for the polystyrene clamshell system increases the total solid waste by weight by the greatest percentage (60 percent), due to the small amount of solid waste produced by the polystyrene clamshell compared to the other clamshells. The total solid waste by weight for the fluted paperboard clamshells increases by 12 percent when the secondary packaging is added.

Figure 3-12 shows the total solid waste by volume for 10,000 5-inch sandwich-size clamshells and secondary packaging. The total solid waste by volume for the primary foodservice product ranges from 81 to 89 percent of the primary product plus secondary packaging total solid waste by volume. The difference between the weight and volume percent for the polystyrene product is best explained by examining the landfill density of the polystyrene product versus the paperboard products (see Chapter 2 discussion).

Greenhouse Gas Emissions

Atmospheric and waterborne emissions for each system, including emissions from processes and those associated with the combustion of fuels, can be found in Chapter 2.

It is not practical to attempt to discuss all the atmospheric emission categories listed in Chapter 2 (over 40 different substances listed for each system); therefore, the following discussion focuses on the high priority atmospheric issue of greenhouse gas (GHG) emissions. The primary three atmospheric emissions reported in this analysis that contribute to global warming are fossil fuel-derived carbon dioxide, methane, and nitrous oxide. (Non-fossil carbon dioxide emissions, such as those from the burning of wood, are considered part of the natural carbon cycle and are not considered a net contributor to global warming.) The 100-year global warming potential for each of these substances as reported in the Intergovernmental Panel on Climate Change (IPCC) 2001 report are: carbon dioxide 1, methane 23, and nitrous oxide 296. The global warming potential represents the relative global warming contribution of a pound of a particular greenhouse gas compared to a pound of carbon dioxide. The weights of each of these substances are multiplied by their global warming potential and totaled in Tables 3-10 through 3-13.

Table 3-9

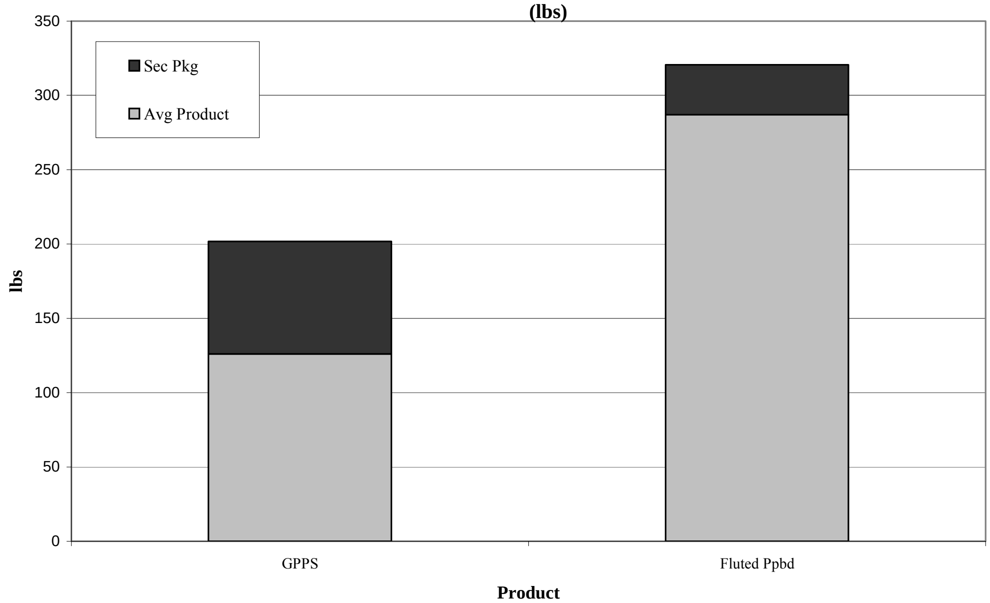
Solid Wastes by Weight and Volume for 10,000 5-inch Sandwich-size Clamshells and Secondary Packaging

	Polystyrene			Fluted Paperboard		
	Product	Sec Pkg	Total	Product	Sec Pkg	Total
Solid Wastes By Weight (lb)						
Process	3.57	5.63	9.21	22.6	2.49	25.1
Fuel	37.9	17.0	54.9	82.6	7.70	90.3
Postconsumer	84.6	52.9	137	182	23.4	205
Total lb	**126**	**75.6**	**202**	**287**	**33.6**	**321**
Total Weight Percent	**63%**	**37%**	**100%**	**90%**	**10%**	**100%**
Solid Wastes By Volume (cu ft)						
Process	0.071	0.11	0.18	0.45	0.050	0.50
Fuel	0.76	0.34	1.10	1.65	0.15	1.81
Postconsumer	9.52	1.93	11.4	6.55	0.85	7.40
Total cu ft	**10.3**	**2.39**	**12.7**	**8.65**	**1.05**	**9.71**
Total Volume Percent	**81%**	**19%**	**100%**	**89%**	**11%**	**100%**

Source: Franklin Associates

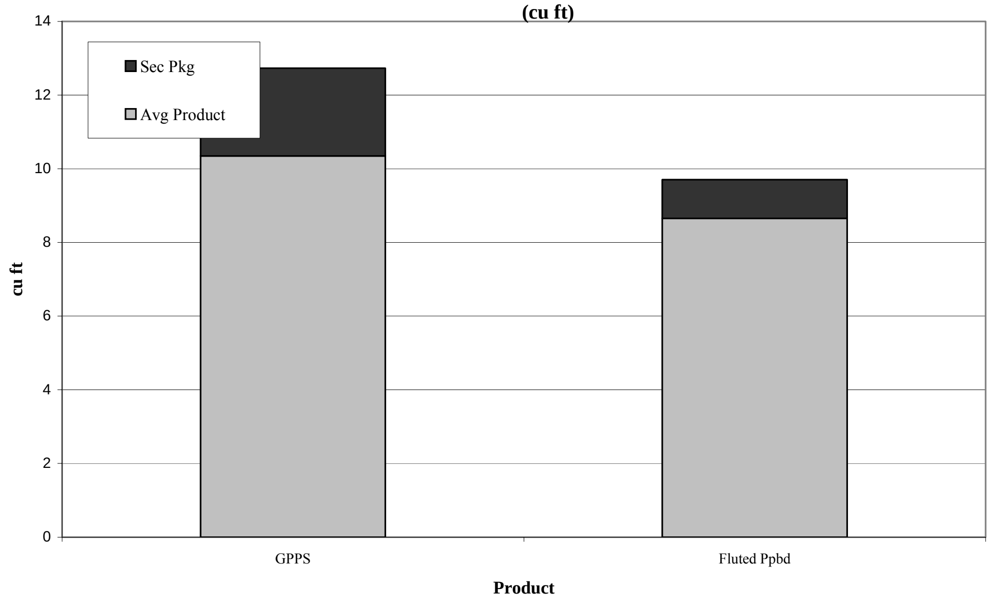
Results in this table represent average weight product plus secondary packaging. The purpose of this table is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-13.

Figure 3-11. Solid Waste by Weight for 10,000 5-inch Sandwich-Size Clamshells and Secondary Packaging (lbs)



Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure 3-12. Solid Waste by Volume for 10,000 5-inch Sandwich-Size Clamshells and Secondary Packaging (cu ft)



Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Materials produced using fossil fuels as process and transportation fuels have higher GHG profiles than materials that use non-fossil resources for process energy. The use of fossil fuel resources as material inputs for material production, as in the case of plastic resins produced from crude oil and natural gas, increases the reported energy of material resource of the product; however, this energy content does not result in GHG emissions unless the material is burned. As stated in the methodology chapter, emissions from the landfilling and combustion of foodservice products at end of life are not included in this analysis for any foodservice product or packaging.

Table 3-10 and Figure 3-13 show greenhouse gas emissions in pounds of carbon dioxide equivalents for 10,000 16-ounce hot cups and the secondary packaging. The addition of secondary packaging to the primary hot cup systems increases the release of GHG emissions by 14 percent for the PE-coated paperboard cup system, 15 percent for paperboard cups with sleeves, and 19 percent for EPS hot cup systems.

Table 3-11 and Figure 3-14 show the greenhouse gas emissions in pounds of carbon dioxide equivalents for 10,000 32-ounce cold cups and the secondary packaging. The addition of secondary packaging to the primary cold cup systems increases the release of GHG emissions by 7 percent for wax-coated cold cup systems, 12 percent for PE-coated paperboard cup systems, and 16 percent for EPS cup systems.

Table 3-12 and Figure 3-15 show the greenhouse gas emissions in pounds of carbon dioxide equivalents for 10,000 9-inch high-grade plates and the secondary packaging. The addition of secondary packaging to the primary plate systems increases the release of GHG emissions by 6 percent for molded pulp plates, 9 percent for PE-coated paperboard plates, and 13 percent for GPPS foam plates.

Table 3-13 and Figure 3-16 show the greenhouse gas emissions in pounds of carbon dioxide equivalents for 10,000 5-inch sandwich-size clamshells and the secondary packaging. The addition of secondary packaging to the primary clamshell systems increases the release of GHG emissions by 10 percent for fluted paperboard clamshells and 30 percent for GPPS foam clamshells.

CONCLUSIONS

The percent increases in environmental burdens for each average weight product system for the addition of secondary packaging are summarized in Table 3-14. Because foamed products (EPS, GPPS) are generally thicker than corresponding paperboard products, their incremental stacking height is greater, requiring a larger dimension box or a greater area of film sleeve compared to paperboard products for the same number of product units. As a result, the weight of secondary packaging and the corresponding environmental burdens tend to be higher for foamed products. On average, secondary packaging increases the environmental burdens for average weight paperboard products by 4 to 12 percent, while packaging adds 14 to 46 percent to the environmental burdens for average weight foam products (EPS, GPPS).

Table 3-10

Greenhouse Gas Emissions for 10,000 16-ounce Hot Cups and Secondary Packaging

	Polystyrene			Poly-Coated Paperboard			Corrugated Cup Sleeves			PE Ppbd Cup + Sleeve		
	Product	Sec Pkg	Total	Product	Sec Pkg	Total	Product	Sec Pkg	Total	Product	Sec Pkg	Total
Greenhouse Gas Summary (lb of Carbon Dioxide Equivalents)												
Fossil CO2	502	96	598	493	68	561	278	45	323	770	113	884
Methane	32.1	04.5	36.6	28.6	03.1	31.7	11.7	02.0	13.6	40.3	05.1	45.4
Nitrous oxide	0.55	0.25	0.80	0.88	0.18	1.07	0.76	0.12	0.89	1.65	0.31	1.95
Total	**534**	**101**	**635**	**522**	**71**	**593**	**290**	**48**	**338**	**812**	**119**	**931**
Total (%)	**84%**	**16%**	**100%**	**88%**	**12%**	**100%**	**86%**	**14%**	**100%**	**87%**	**13%**	**100%**

Source: Franklin Associates

Results in this table represent average weight product plus secondary packaging. The purpose of this table is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-14.

Table 3-11

Greenhouse Gas Emissions for 10,000 32-ounce Cold Cups and Secondary Packaging

	Polystyrene			Poly-Coated Paperboard			Wax-Coated Paperboard		
	Product	Sec Pkg	Total	Product	Sec Pkg	Total	Product	Sec Pkg	Total
Greenhouse Gas Summary (lb of Carbon Dioxide Equivalents)									
Fossil CO2	901	147	1,049	739	86.6	825	1,295	87.0	1,382
Methane	57.9	6.92	64.8	41.9	4.17	46.1	62.0	4.22	66.2
Nitrous oxide	0.95	0.39	1.35	1.30	0.23	1.52	2.35	0.23	2.58
Total	**960**	**155**	**1,115**	**782**	**91.0**	**873**	**1,359**	**91.4**	**1,451**
Total (%)	**86%**	**14%**	**100%**	**90%**	**10%**	**100%**	**94%**	**6%**	**100%**

Source: Franklin Associates

Results in this table represent average weight product plus secondary packaging. The purpose of this table is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-15.

Table 3-12

Greenhouse Gas Emissions for 10,000 9-inch High-grade Plates and Secondary Packaging

	Polystyrene			Poly-Coated Paperboard			Molded Pulp		
	Product	Sec Pkg	Total	Product	Sec Pkg	Total	Product	Sec Pkg	Total
Greenhouse Gas Summary (lb of Carbon Dioxide Equivalents)									
Fossil CO2	775	99.9	875	575	55.0	630	973	56.1	1,029
Methane	51.5	4.65	56.2	33.5	2.51	36.0	48.0	2.54	50.6
Nitrous oxide	0.98	0.27	1.25	0.98	0.15	1.13	2.28	0.15	2.43
Total	**827**	**105**	**932**	**610**	**57.7**	**668**	**1,023**	**58.8**	**1,082**
Total (%)	**89%**	**11%**	**100%**	**91%**	**9%**	**100%**	**95%**	**5%**	**100%**

Source: Franklin Associates

Results in this table represent average weight product plus secondary packaging. The purpose of this table is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Results in this table apply only to average weight high-grade plates, which are the strongest and heaviest plates available in each material category. Lighter weight polystyrene and paper plates are available but are not included in these results.
Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-16.

Table 3-13

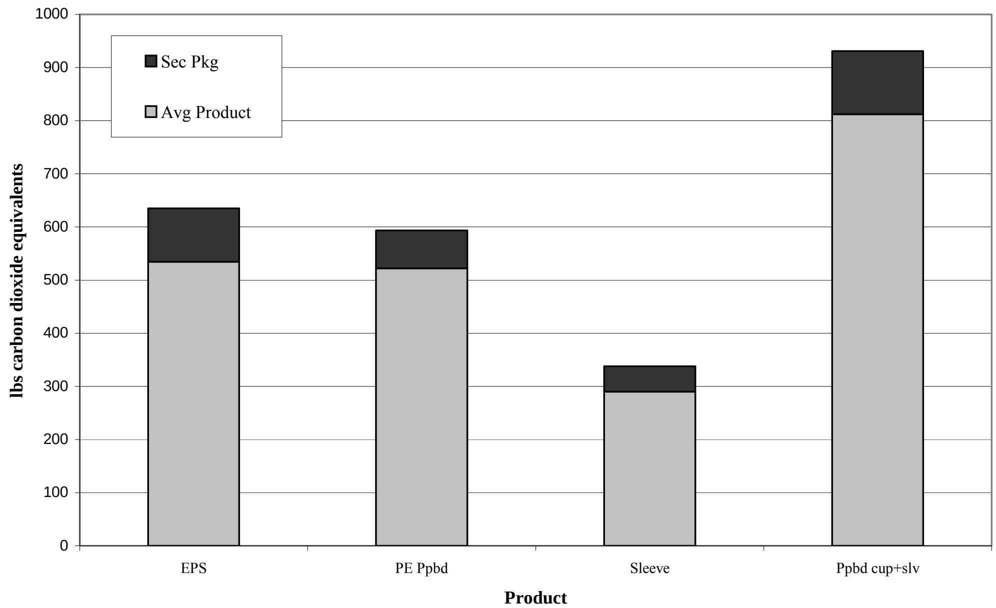
Greenhouse Gas Emissions for 10,000 5-inch Sandwich-size Clamshells and Secondary Packaging

	Polystyrene			Fluted Paperboard		
	Product	Sec Pkg	Total	Product	Sec Pkg	Total
Greenhouse Gas Summary (lb of Carbon Dioxide Equivalents)						
Fossil CO2	348	106	454	467	47	514
Methane	23.0	5.54	28.5	18.5	2.28	20.7
Nitrous oxide	0.44	0.27	0.71	1.13	0.12	1.25
Total	**372**	**112**	**483**	**487**	**49**	**536**
Total (%)	**77%**	**23%**	**100%**	**91%**	**9%**	**100%**

Source: Franklin Associates

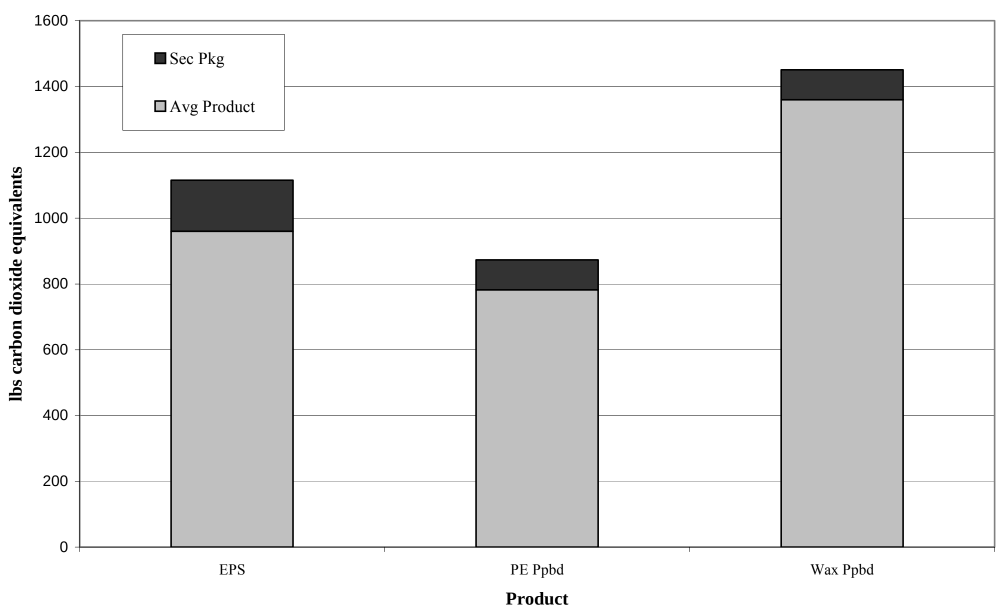
Results in this table represent average weight product plus secondary packaging. The purpose of this table is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-17.

Figure 3-13. Greenhouse Gas Emissions for 10,000 16-oz Hot Cups (lbs carbon dioxide equivalents)



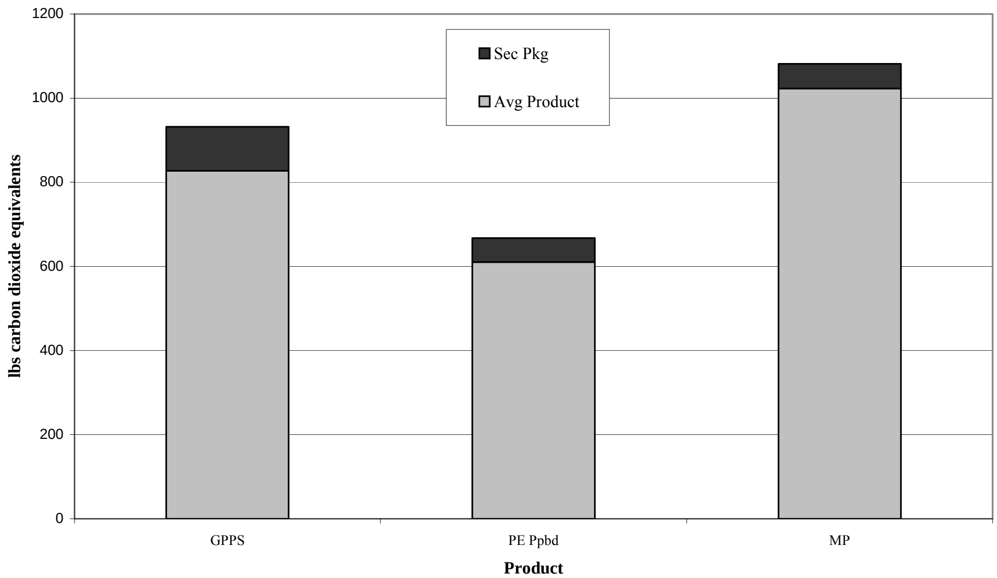
Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure 3-14. Greenhouse Gas Emissions for 10,000 32-oz Cold Cups (lbs carbon dioxide equivalents)



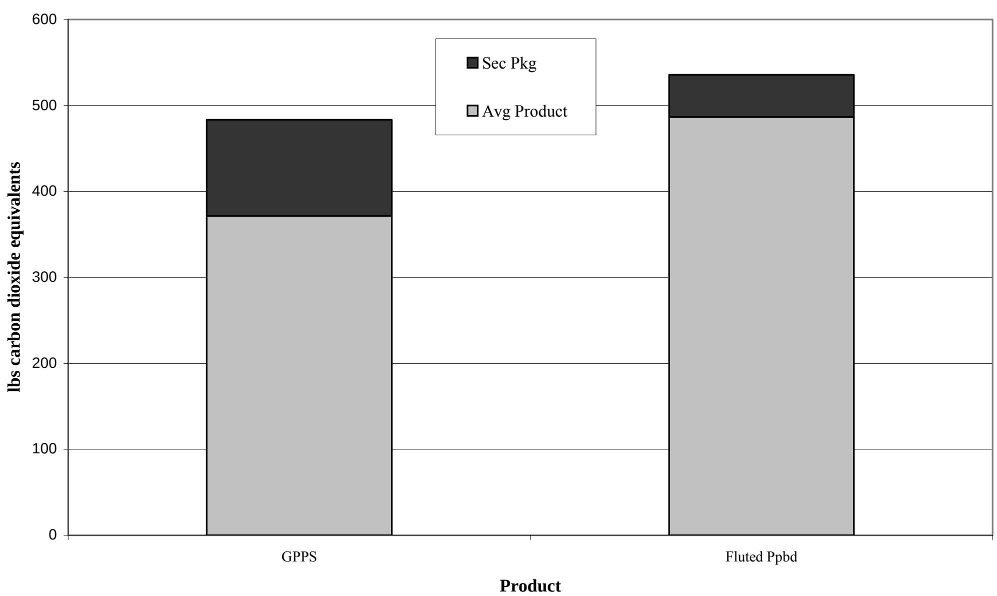
Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure 3-15. Greenhouse Gas Emissions for 10,000 9-inch High-Grade Plates (lbs carbon dioxide equivalents)



Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure 3-16. Greenhouse Gas Emissions for 10,000 5-inch Sandwich-Size Clamshells (lbs carbon dioxide equivalents)



Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Table 3-14

Summary: Percent Increase in Environmental Burdens for Addition of Secondary Packaging to Average Weight Product

		Solid Waste		
	Energy	**Weight**	**Volume**	**GHG**
16-ounce Hot Cup				
EPS	15%	50%	21%	19%
PE-coated Paperboard	9%	13%	13%	14%
Ppbd Cup + Sleeve	12%	12%	13%	15%
32-ounce Cold Cup				
EPS	12%	42%	17%	16%
PE-coated Paperboard	7%	10%	10%	12%
Wax-coated Paperboard	4%	5%	5%	7%
9-inch High-grade Plate				
GPPS	9%	26%	10%	13%
PE-coated Paperboard	5%	8%	8%	9%
Molded Pulp	5%	7%	8%	6%
5-inch Sandwich-size Clamshell				
GPPS	22%	60%	23%	30%
Fluted Paperboard	9%	12%	12%	10%

		Solid Waste		
	Energy	**Weight**	**Volume**	**GHG**
Average Percent Increase				
EPS cups	14%	46%	19%	17%
GPPS plates and clamshells	15%	43%	16%	21%
PE-coated paperboard cups and plates	7%	10%	10%	12%
Wax-coated paperboard cups	4%	5%	5%	7%
Molded pulp plates	5%	7%	8%	6%
Fluted paperboard clamshells	9%	12%	12%	10%

Source: Franklin Associates.

Results in this table represent average weight product plus secondary packaging. The purpose of this table is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Tables.

CHAPTER 4

AVERAGE WEIGHT FOODSERVICE PRODUCT WITH RECYCLING OR COMPOSTING

INTRODUCTION

Recycling and composting are means by which products are diverted from the municipal solid waste stream and the useful life of the material is extended. The results presented in this chapter evaluate the effect of low levels of recycling and composting on the life cycle environmental burdens of foodservice products, relative to the burdens for the same systems with no end-of-life recycling or composting. Recycling is evaluated for polystyrene foodservice products, and composting is evaluated for paperboard and molded pulp products.

The purpose of this chapter is to evaluate the effect of low levels of recycling and composting in reducing environmental burdens for average weight foodservice products in each category. The results in this chapter cannot be used to draw conclusions about the relative environmental performance of alternative foodservice products in each category since the full range of product weights are not represented in this chapter.

Individual programs with measurable levels of foodservice product recycling and/or composting may exist in some specific locations around the country. For example, there is a well-publicized program in place to recover food and packaging waste at the U.S. EPA facility in Research Triangle Park, North Carolina. Food wastes and degradable packaging, including foodservice products, are collected and composted in windrows by Brooks Contractor, Inc. in Goldston, NC. Only biodegradable foodservice packaging is used in the EPA facility. Although an average of 2,200 to 2,500 pounds (1.1 to 1.25 tons) of dining facility organics are collected each month, this represents only a small fraction of the total food and packaging wastes generated in the Goldston, NC metropolitan area.

National average statistics on foodservice recycling and composting were researched for this study, but no reliable quantitative data could be found. Despite small individual local programs like the one at Research Triangle Park, national average rates for recycling and composting of foodservice products are generally acknowledged to be very low. However, it was decided that it would give useful perspective in this study to model the effects of a low national average level of recycling for polystyrene foodservice products and composting of paperboard foodservice products. Two percent was selected as the level to be evaluated.

METHODOLOGY

Recycling

Plastic products are typically recycled in an open-loop system, where a product made from virgin material is manufactured, recovered for recycling, and manufactured into a new but different product which is generally not recycled. This extends the life of the initial material, but only for a limited time.

Material in an open-loop system is typically used to make two products. Initially, virgin material is used to make a product which is recycled into a second product that is not recycled. Thus, for open-loop recycling, the energy and emissions of virgin material manufacture, recycling, and eventual disposal of the recycled material are divided evenly between the first and second product. This analysis inherently assumes that the recycled material replaces virgin material when producing the second product.

Composting

In this study, composting is evaluated for paper-based foodservice items. The burdens for the production of the material that is composted are divided between the original use as a foodservice product and the second use as compost. Unlike recycling, where material must be reprocessed into resin and then refabricated into a second product, the composting step is the fabrication step for the second product, i.e., compost; thus, the burdens for composting are allocated entirely to the compost product. Because compost remains in place where it is applied and is not collected and disposed after use, the amount of material diverted from the solid waste stream for composting is assumed to be permanently diverted from landfill.

Systems Studied

Four types of foodservice products are analyzed in this study: 16-ounce hot cups, 32-ounce cold cups, 9-inch high-grade plates, and 5-inch sandwich-size clamshells. The average weight of each type of product in each product category is evaluated at zero percent recycling or composting and at two percent recycling or composting.

LCI RESULTS

Total energy, solid waste by weight and volume, and greenhouse gas emissions results are presented in this chapter for average weight foodservice products at zero percent and two percent recycling or composting.

Total energy results are shown in Tables 4-1 through 4-4 and Figures 4-1 through 4-4. Solid waste results by weight and volume are shown in Tables 4-5 through 4-8 and Figures 4-5 through 4-12. Greenhouse gas emissions are shown in Tables 4-9 through 4-12 and Figures 4-13 through 4-16. Throughout this chapter, results tables and figures are shown in the following order: 16-ounce hot cup systems, 32-ounce cold cup systems, 9-inch high-grade plate systems, and 5-inch sandwich-size clamshell systems.

For simplicity, in the discussion of results that follows, the general term **"unrecovered"** is used to refer to a system at zero percent recycling or composting, and the term **"recovered"** is used to refer to a system in which two percent of product at end of life is recovered and recycled or composted.

Energy Results

Tables 4-1 through 4-4 and Figures 4-1 through 4-4 show that there is very little energy difference between the unrecovered and recovered systems. For all foodservice products and materials, the percent reduction in total energy for two percent recycling or composting is one percent or less.

For recycling of polystyrene products, the energy required to produce the virgin recovered material is divided between its use as a foodservice product and its second use in a recycled plastic product; however, energy requirements for collection and reprocessing of postconsumer material offset this reduction in virgin material production energy. As a result, two percent recycling reduces total energy by only about one-half percent for the polystyrene systems. For paperboard products, all energy for composting is assigned to the compost product, so there is no offsetting energy increase for utilization of recovered material, and the total energy reductions are higher, around one percent.

Solid Waste

Solid waste is broadly categorized into process wastes, fuel-related wastes, and postconsumer wastes. These categories are discussed in Chapter 2. The results tables show the solid waste by weight and volume.

It is helpful to understand how the results for solid waste by category relate to the results for energy in the previous section and tables. Solid wastes for a process include not only waste materials generated from the process itself, but also solid wastes from the production and combustion of fuels used for process energy. Thus, fuel-related solid waste includes the solid waste associated with process energy as well as transportation energy.

Weight of Solid Waste. Tables 4-5 through 4-8 and Figures 4-5 through 4-8 show results for solid waste by weight for unrecovered and recovered systems. As with energy results, the differences between the total weight of solid waste for unrecovered and recovered systems is small in all cases.

Table 4-1

Total Energy for 10,000 16-ounce Hot Cups at 0% and 2% Recycling or Composting

	Polystyrene		Poly-Coated Paperboard		Corrugated Cup Sleeves		PE Ppbd Cup + Sleeve	
	0% R	2% R	0% C	2% C	0% C	2% C	0% C	2% C
Total Energy (MM Btu)	6.55	6.52	7.89	7.82	1.75	1.73	9.64	9.56
Percent Reduction		**0.5%**		**0.9%**		**0.9%**		**0.9%**

Source: Franklin Associates

Results in this table represent average weight product at 0% and 2% recycling or composting. The purpose of this table is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-2.

Table 4-2

Total Energy for 10,000 32-ounce Cold Cups at 0% and 2% Recycling and Composting

	Polystyrene		Poly-Coated Paperboard		Wax-Coated Paperboard	
	0% R	2% R	0% C	2% C	0% C	2% C
Total Energy (MM Btu)	11.92	11.86	12.3	12.2	22.2	22.0
Percent Reduction		**0.5%**		**0.9%**		**0.9%**

Source: Franklin Associates

Results in this table represent average weight product at 0% and 2% recycling or composting. The purpose of this table is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-3.

Table 4-3

Total Energy for 10,000 9-inch High-grade Plates at 0% and 2% Recycling or Composting

	Polystyrene		Poly-Coated Paperboard		Molded Pulp	
	0% R	2% R	0% C	2% C	0% C	2% C
Total Energy (MM Btu)	11.7	11.6	10.1	9.97	11.9	11.8
Percent Reduction		**0.6%**		**1.0%**		**0.7%**

Source: Franklin Associates

Results in this table represent average weight product at 0% and 2% recycling or composting. The purpose of this table is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Results in this table apply only to average weight high-grade plates, which are the strongest and heaviest plates available in each material category. Lighter weight polystyrene and paper plates are available but are not included in these results.
Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-4.

Table 4-4

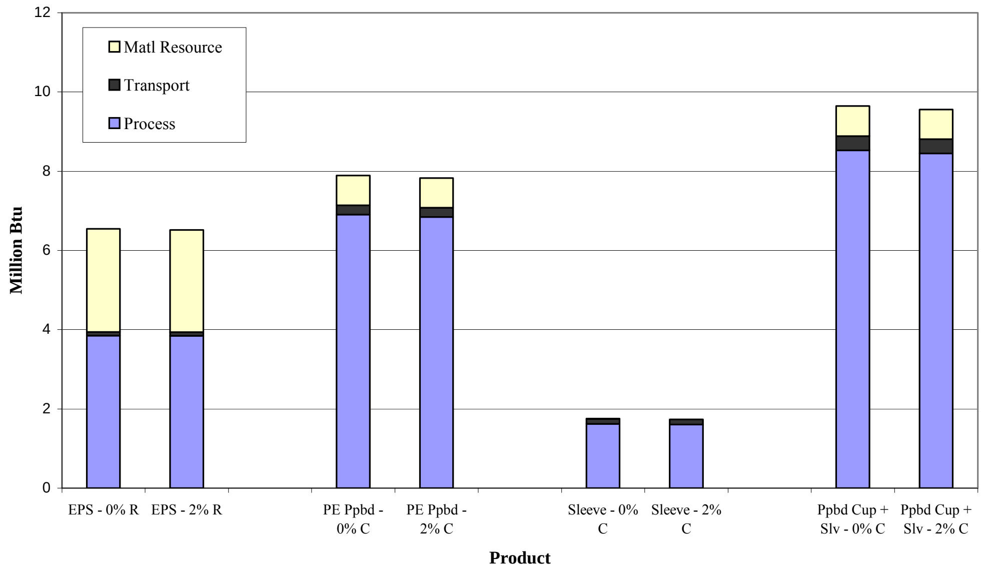
Total Energy for 10,000 5-inch Sandwich-size Clamshells at 0% and 2% Recycling or Composting

	Polystyrene		Fluted Paperboard	
	0% R	2% R	0% C	2% C
Total Energy (MM Btu)	5.22	5.19	5.35	5.30
Percent Reduction		**0.6%**		**0.9%**

Source: Franklin Associates

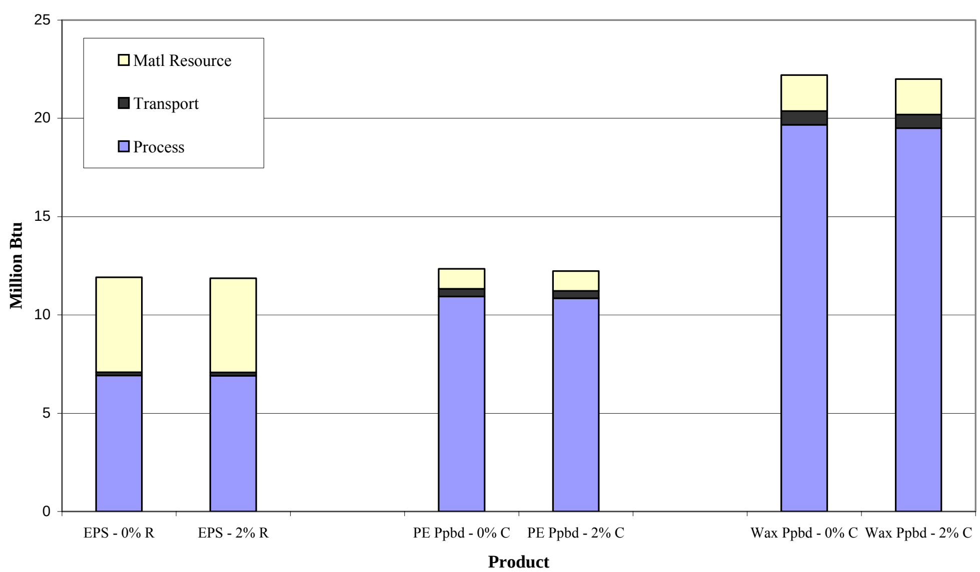
Results in this table represent average weight product at 0% and 2% recycling or composting. The purpose of this table is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-5.

Figure 4-1. Total Energy for 10,000 16-oz Hot Cups at 0% and 2% Recycling or Composting (Million Btu)



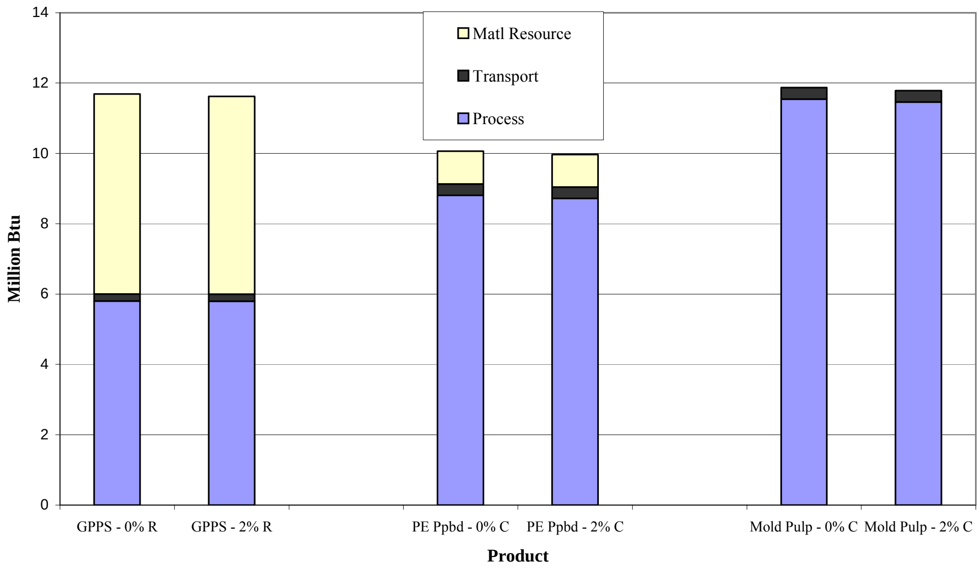
Results in this figure represent average weight product at 0% and 2% recycling or composting. The purpose of this figure is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure 4-2. Total Energy for 10,000 32-oz Cold Cups at 0% and 2% Recycling or Composting (Million Btu)



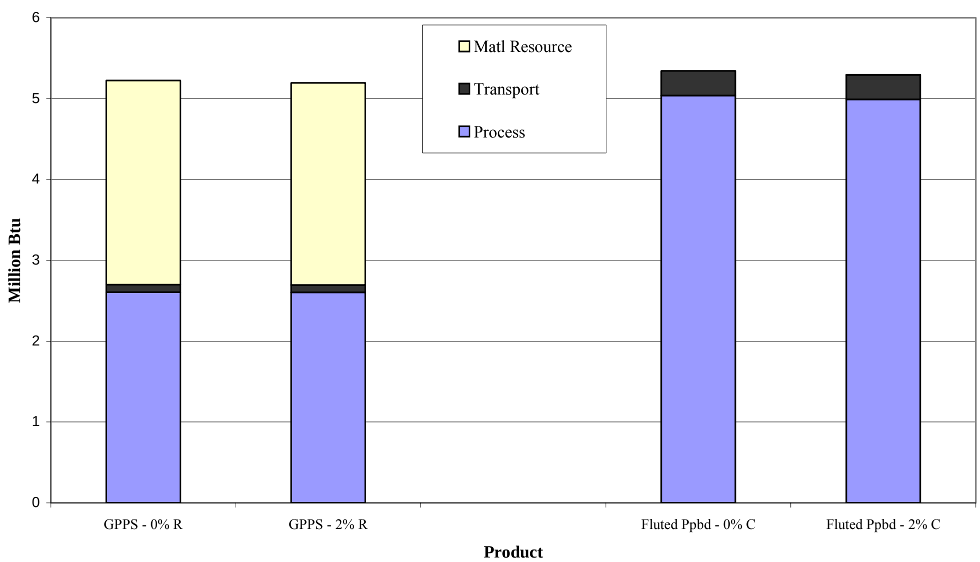
Results in this figure represent average weight product at 0% and 2% recycling or composting. The purpose of this figure is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure 4-3. Total Energy for 10,000 9-inch High-Grade Plates at 0% and 2% Recycling or Composting (Million Btu)



Results in this figure represent average weight product at 0% and 2% recycling or composting. The purpose of this figure is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure 4-4. Total Energy for 10,000 5-inch Sandwich-Size Clamshells at 0% and 2% Recycling or Composting (Million Btu)



Results in this figure represent average weight product at 0% and 2% recycling or composting. The purpose of this figure is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Table 4-5

Solid Wastes by Weight and Volume for 10,000 16-ounce Hot Cups at 0% and 2% Recycling or Composting

	Polystyrene		Poly-Coated Paperboard		Corrugated Cup Sleeves		PE Ppbd Cup + Sleeve	
	0% R	2% R	0% C	2% C	0% C	2% C	0% C	2% C
Solid Wastes By Weight (lb)								
Process	5.31	5.28	55.4	54.9	15.3	15.0	70.8	69.9
Fuel	49.5	49.6	97.3	96.5	52.8	51.8	150	148
Postconsumer	82.8	82.0	235	230	205	201	440	431
Total lb	**138**	**137**	**388**	**382**	**273**	**268**	**661**	**650**
Percent Reduction		**0.6%**		**1.5%**		**2.0%**		**1.7%**
Solid Wastes By Volume (cu ft)								
Process	0.106	0.106	1.11	1.10	0.31	0.30	1.42	1.40
Fuel	0.99	0.99	1.95	1.93	1.06	1.04	3.00	2.97
Postconsumer	9.32	9.22	8.57	8.40	7.36	7.22	15.9	15.6
Total cu ft	**10.4**	**10.32**	**11.6**	**11.4**	**8.73**	**8.55**	**20.4**	**20.0**
Percent Reduction		**0.9%**		**1.7%**		**2.0%**		**1.8%**

Source: Franklin Associates

Results in this table represent average weight product at 0% and 2% recycling or composting. The purpose of this table is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-10.

Table 4-6

Solid Wastes by Weight and Volume for 10,000 32-ounce Cold Cups at 0% and 2% Recycling or Composting

	Polystyrene		Poly-Coated Paperboard		Wax-Coated Paperboard	
	0% R	2% R	0% C	2% C	0% C	2% C
Solid Wastes By Weight (lb)						
Process	9.76	9.72	92.1	91.2	377	375
Fuel	87.3	87.5	149	148	270	268
Postconsumer	156	154	387	379	553	542
Total lb	**253**	**251**	**628**	**618**	**1,200**	**1,185**
Percent Reduction		**0.6%**		**1.6%**		**1.2%**
Solid Wastes By Volume (cu ft)						
Process	0.20	0.19	1.84	1.82	11.0	11.0
Fuel	1.75	1.75	2.99	2.96	5.41	5.36
Postconsumer	17.5	17.3	14.1	13.8	20.1	19.7
Total cu ft	**19.5**	**19.3**	**18.9**	**18.6**	**36.6**	**36.1**
Percent Reduction		**0.9%**		**1.7%**		**1.3%**

Source: Franklin Associates

Results in this table represent average weight product at 0% and 2% recycling or composting. The purpose of this table is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-11.

Table 4-7

Solid Wastes by Weight for 10,000 9-inch High-grade Plates at 0% and 2% Recycling or Composting

	Polystyrene		Poly-Coated Paperboard		Molded Pulp	
	0% R	2% R	0% C	2% C	0% C	2% C
Solid Wastes By Weight (lb)						
Process	8.17	8.14	76.8	76.1	91.7	90.9
Fuel	84.3	84.6	117	116	181	180
Postconsumer	190	188	324	318	294	288
Total lb	**283**	**281**	**518**	**510**	**567**	**559**
Percent Reduction		**0.6%**		**1.6%**		**1.4%**
Solid Wastes By Volume (cu ft)						
Process	0.16	0.16	1.54	1.52	1.83	1.82
Fuel	1.69	1.69	2.34	2.32	3.62	3.60
Postconsumer	21.4	21.2	11.8	11.6	9.67	9.48
Total cu ft	**23.3**	**23.1**	**15.7**	**15.4**	**15.1**	**14.9**
Percent Reduction		**0.9%**		**1.7%**		**1.5%**

Source: Franklin Associates

Results in this table represent average weight product at 0% and 2% recycling or composting. The purpose of this table is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Results in this table apply only to average weight high-grade plates, which are the strongest and heaviest plates available in each material category. Lighter weight polystyrene and paper plates are available but are not included in these results.

Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-12.

Table 4-8

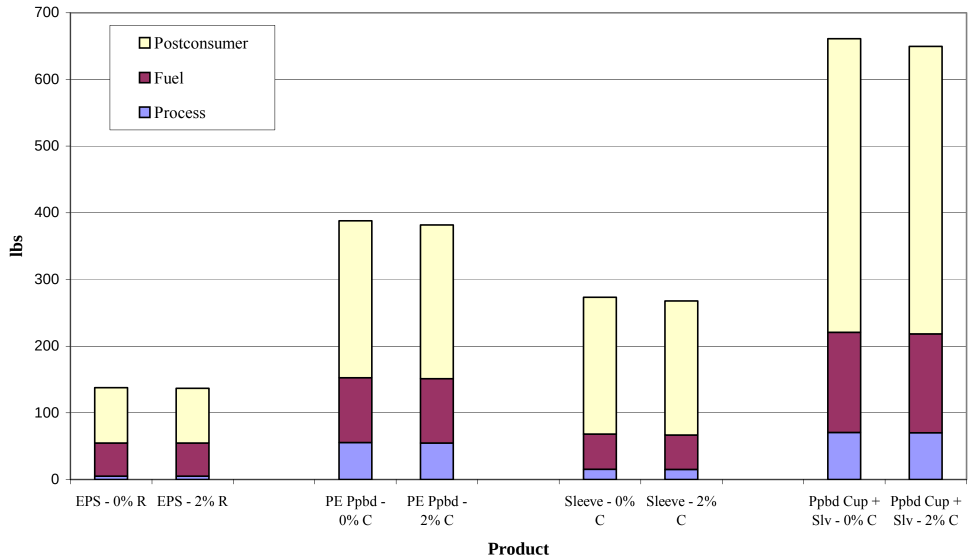
Solid Wastes by Weight for 10,000 5-inch Sandwich-size Clamshells at 0% and 2% Recycling or Composting

	Polystyrene		Fluted Paperboard	
	0% R	2% R	0% C	2% C
Solid Wastes By Weight (lb)				
Process	3.57	3.56	22.6	22.2
Fuel	37.9	38.0	82.6	81.0
Postconsumer	84.6	83.7	182	178
Total lb	**126**	**125**	**287**	**281**
Percent Reduction		**0.6%**		**2.0%**
Solid Wastes By Volume (cu ft)				
Process	0.071	0.071	0.45	0.44
Fuel	0.76	0.76	1.65	1.62
Postconsumer	9.52	9.42	6.55	6.42
Total cu ft	**10.3**	**10.3**	**8.65**	**8.48**
Percent Reduction		**0.9%**		**2.0%**

Source: Franklin Associates

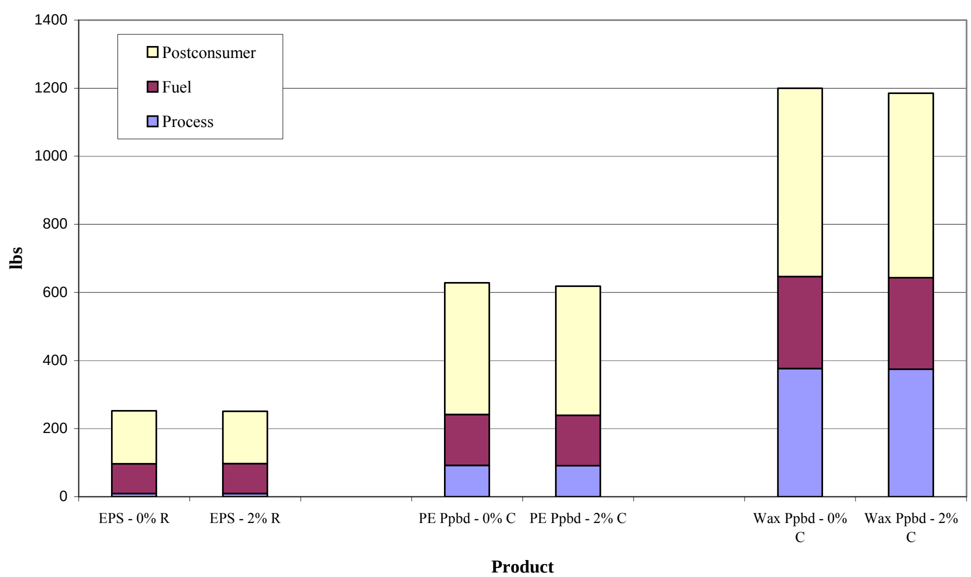
Results in this table represent average weight product at 0% and 2% recycling or composting. The purpose of this table is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-13.

Figure 4-5. Solid Waste by Weight for 10,000 16-oz Hot Cups at 0% and 2% Recycling or Composting (lbs)



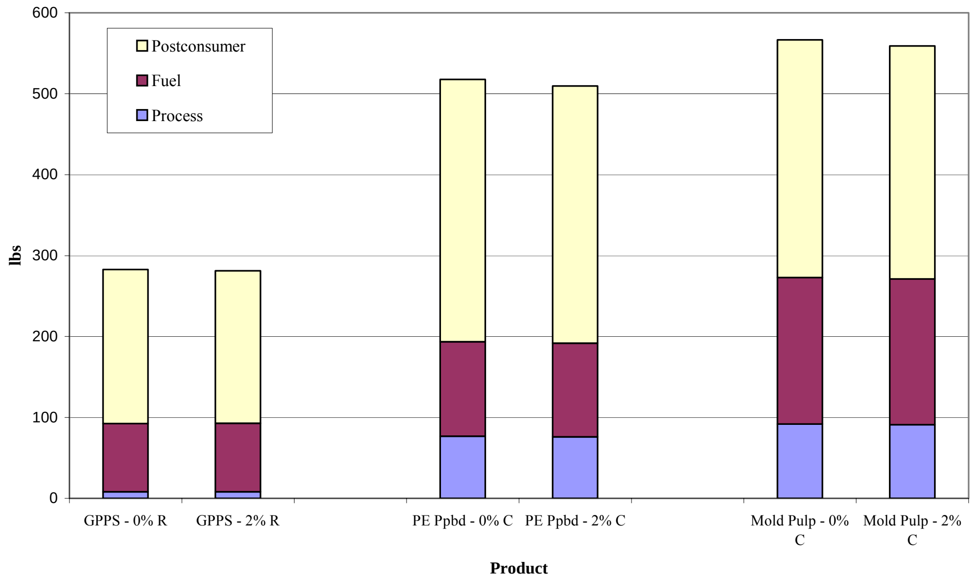
Results in this figure represent average weight product at 0% and 2% recycling or composting. The purpose of this figure is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure 4-6. Solid Waste by Weight for 10,000 32-oz Cold Cups at 0% and 2% Recycling or Composting (lbs)



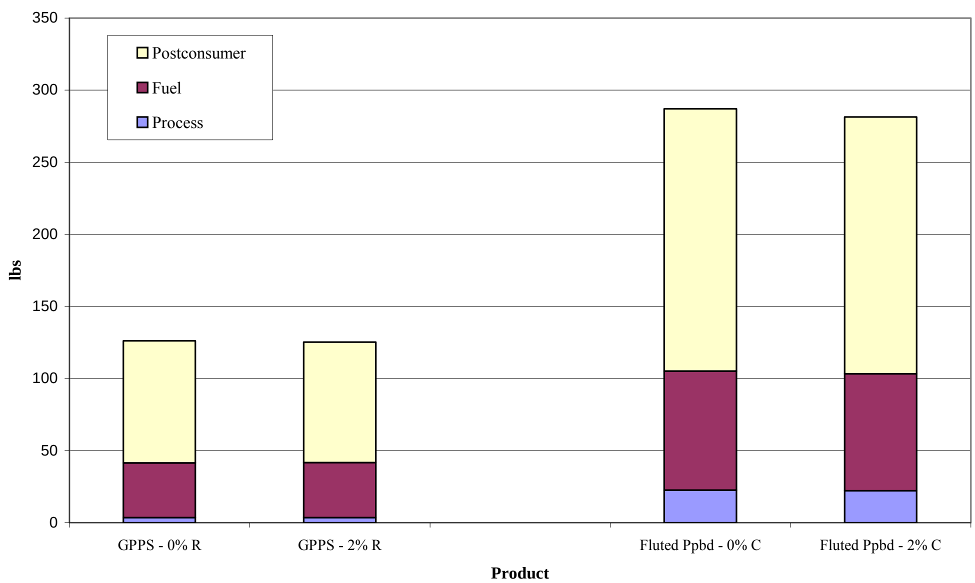
Results in this figure represent average weight product at 0% and 2% recycling or composting. The purpose of this figure is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure 4-7. Solid Waste by Weight for 10,000 9-inch High-Grade Plates at 0% and 2% Recycling or Composting (lbs)



Results in this figure represent average weight product at 0% and 2% recycling or composting. The purpose of this figure is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure 4-8. Solid Waste by Weight for 10,000 5-inch Sandwich-Size Clamshells at 0% and 2% Recycling or Composting (lbs)



Results in this figure represent average weight product at 0% and 2% recycling or composting. The purpose of this figure is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

For all systems, recycling or composting reduces the weight of postconsumer waste. For polystyrene systems this is largely offset by increases in process and fuel-related wastes for recycling. For paperboard systems that are composted, all the burdens for the composting process are assigned to the compost product; thus, all three categories of solid waste decrease (postconsumer, process, and fuel-related), although by very small amounts. As a result, two percent recycling reduces total weight of solid waste for polystyrene systems by only about one-half percent, while two percent composting reduces the total solid waste weight for paperboard systems by about two percent.

Volume of Solid Waste. Landfills fill up because of volume, not weight. While weight is the conventional measure of waste, landfill volume is more relevant to the environmental concerns of land use. Chapters 2 and 3 describe how weights of solid waste are converted into volumes using landfill density factors.

The general observations regarding the effect of recycling and composting on solid waste are also true for solid waste by volume, as shown in Tables 4-5 through 4-8 and Figures 4-9 through 4-12. However, while two percent recycling reduces total weight of solid waste for polystyrene systems by only about one-half percent, the percent reduction in solid waste volume is higher, at almost one percent. Because of the low density of polystyrene foam products, a small reduction in solid waste weight has a larger effect on solid waste volume.

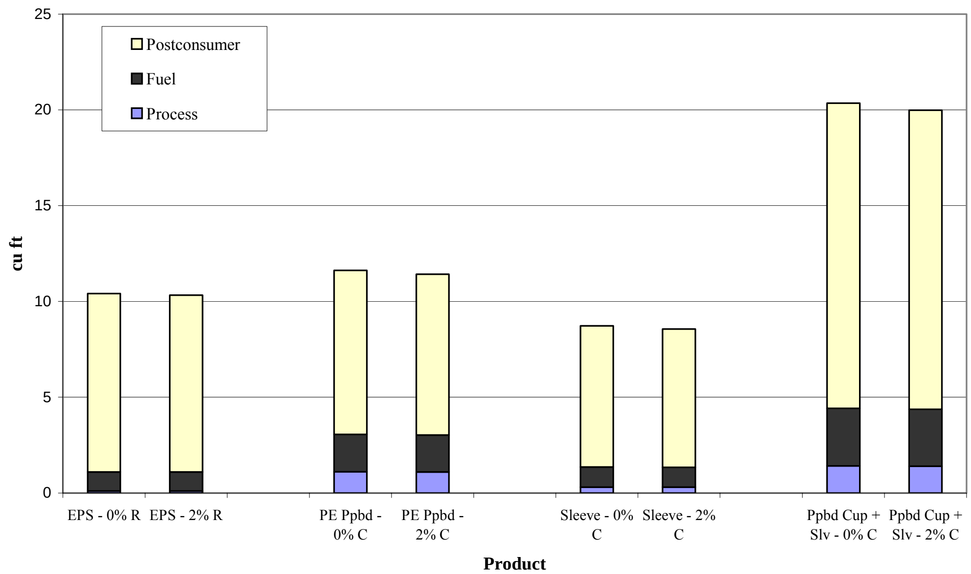
GREENHOUSE GAS EMISSIONS

Atmospheric and waterborne emissions for each system, including emissions from processes and those associated with the combustion of fuels, can be found in Chapter 2.

It is not practical to attempt to discuss all the atmospheric emission categories listed in the Chapter 2 tables (over 40 different substances listed for each system); therefore, the following discussion focuses on the effect of recycling and composting on the high priority atmospheric issue of greenhouse gas (GHG) emissions. Chapters 2 and 3 describe how the global warming potentials shown in Tables 4-9 through 4-13 are calculated from emissions of fossil fuel-derived carbon dioxide, methane, and nitrous oxide.

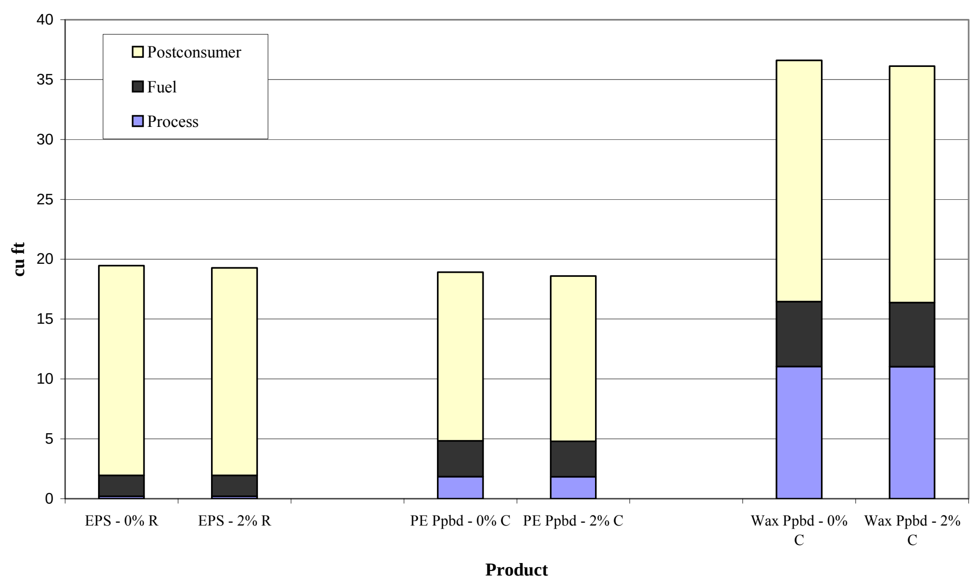
Tables 4-9 through 4-12 and Figures 4-13 through 4-16 show greenhouse gas emissions in pounds of carbon dioxide equivalents for 10,000 units of each foodservice product at zero percent and two percent recycling or composting. Because the added burdens for postconsumer material collection and reprocessing largely offset the savings in virgin material production burdens, two percent recycling of polystyrene products results in a very small reduction in total GHG (one-tenth of one percent). On average, two percent composting reduces GHG burdens for the paperboard systems by about one percent.

Figure 4-9. Solid Waste by Volume for 10,000 16-oz Hot Cups at 0% and 2% Recycling or Composting (cu ft)



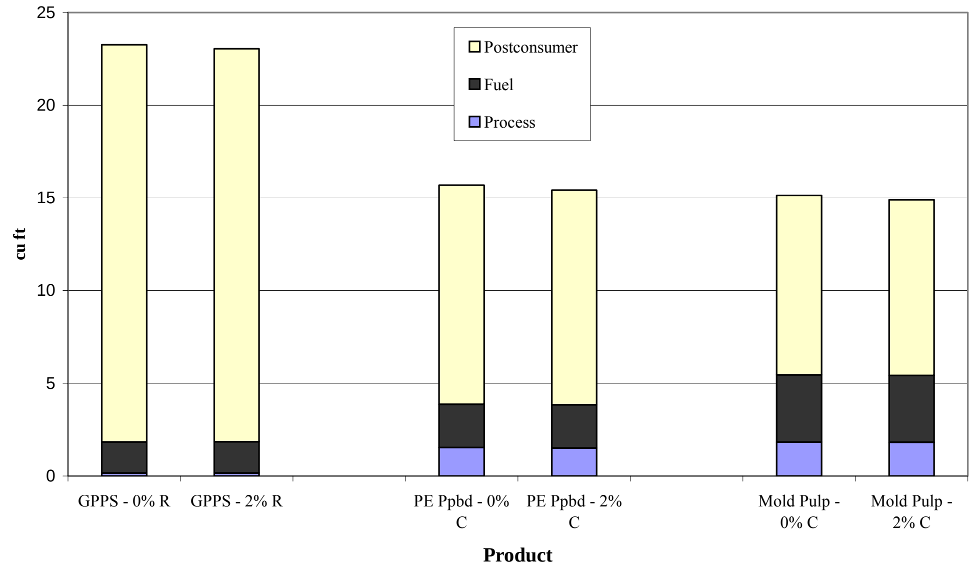
Results in this figure represent average weight product at 0% and 2% recycling or composting. The purpose of this figure is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure 4-10. Solid Waste by Volume for 10,000 32-oz Cold Cups at 0% and 2% Recycling or Composting (cu ft)



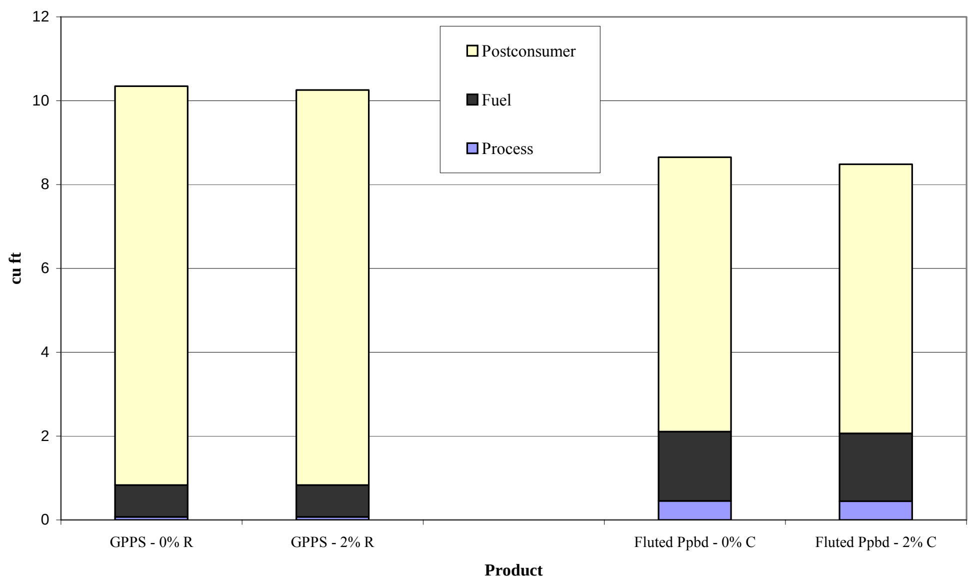
Results in this figure represent average weight product at 0% and 2% recycling or composting. The purpose of this figure is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure 4-11. Solid Waste by Volume for 10,000 9-inch High-Grade Plates at 0% and 2% Recycling or Composting (cu ft)



Results in this figure represent average weight product at 0% and 2% recycling or composting. The purpose of this figure is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range

Figure 4-12. Solid Waste by Volume for 10,000 5-inch Sandwich-Size Clamshells at 0% and 2% Recycling or Composting (cu ft)



Results in this figure represent average weight product at 0% and 2% recycling or composting. The purpose of this figure is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full

Table 4-9

Greenhouse Gas Emissions for 10,000 16-ounce Hot Cups at 0% and 2% Recycling or Composting

	Polystyrene		Poly-Coated Paperboard		Corrugated Cup Sleeves		PE Ppbd Cup + Sleeve	
	0% R	2% R	0% C	2% C	0% C	2% C	0% C	2% C
Greenhouse Gas Summary (lb of Carbon Dioxide Equivalents)								
Fossil CO2	502	501	493	489	278	273	770	762
Methane	32.1	32.0	28.6	28.4	11.7	11.5	40.3	39.8
Nitrous oxide	0.55	0.55	0.88	0.88	0.76	0.75	1.65	1.63
Total lb	**534**	**534**	**522**	**518**	**290**	**285**	**812**	**803**
Percent Reduction		**0.1%**		**0.8%**		**1.7%**		**1.1%**

Source: Franklin Associates

Results in this table represent average weight product at 0% and 2% recycling or composting. The purpose of this table is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-14.

Table 4-10

Greenhouse Gas Emissions for 10,000 32-ounce Cold Cups at 0% and 2% Recycling or Composting

	Polystyrene		Poly-Coated Paperboard		Wax-Coated Paperboard	
	0% R	2% R	0% C	2% C	0% C	2% C
Greenhouse Gas Summary (lb of Carbon Dioxide Equivalents)						
Fossil CO2	901	900	739	732	1295	1284
Methane	57.9	57.8	41.9	41.6	62.0	61.5
Nitrous oxide	0.95	0.96	1.30	1.29	2.35	2.33
Total	**960**	**959**	**782**	**775**	**1359**	**1348**
Percent Reduction		**0.1%**		**0.8%**		**0.8%**

Source: Franklin Associates

Results in this table represent average weight product at 0% and 2% recycling or composting. The purpose of this table is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-15.

Table 4-11

Greenhouse Gas Emissions for 10,000 9-inch High-grade Plates at 0% and 2% Recycling or Composting

	Polystyrene		Poly-Coated Paperboard		Molded Pulp	
	0% R	2% R	0% C	2% C	0% C	2% C
Greenhouse Gas Summary (lb of Carbon Dioxide Equivalents)						
Fossil CO2	775	774	575	570	973	968
Methane	51.5	51.4	33.5	33.2	48.0	47.8
Nitrous oxide	0.98	0.99	0.98	0.97	2.28	2.27
Total	**827**	**826**	**610**	**604**	**1,023**	**1,018**
Percent Reduction		**0.1%**		**0.9%**		**0.5%**

Source: Franklin Associates

Results in this table represent average weight product at 0% and 2% recycling or composting. The purpose of this table is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Results in this table apply only to average weight high-grade plates, which are the strongest and heaviest plates available in each material category. Lighter weight polystyrene and paper plates are available but are not included in these results.
Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-16.

Table 4-12

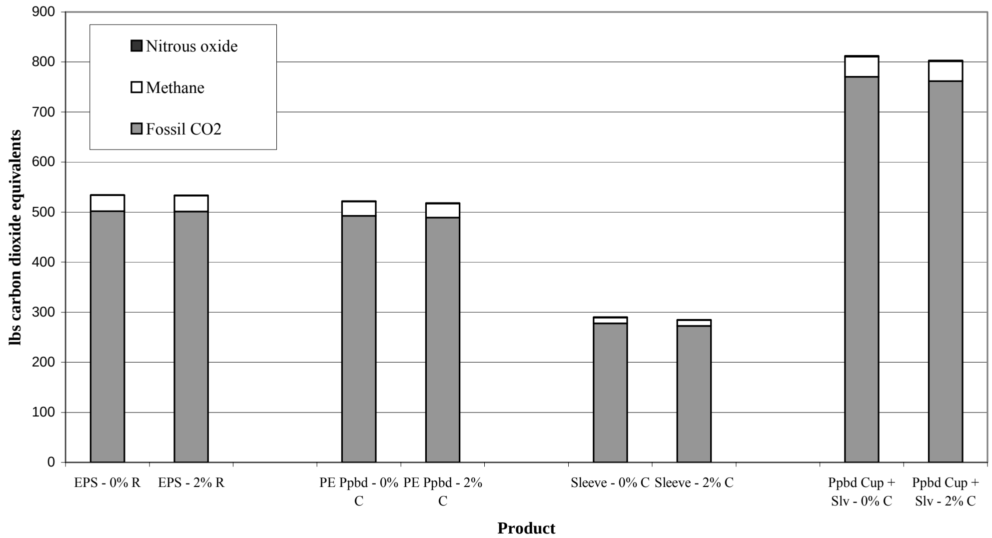
Greenhouse Gas Emissions for 10,000 5-inch Sandwich-size Clamshells at 0% and 2% Recycling or Composting

	Polystyrene		Fluted Paperboard	
	0% R	2% R	0% C	2% C
Greenhouse Gas Summary (lb of Carbon Dioxide Equivalents)				
Fossil CO2	348	348	467	459
Methane	23.0	22.9	18.5	18.1
Nitrous oxide	0.44	0.44	1.13	1.11
Total	**372**	**371**	**487**	**478**
Percent Reduction		**0.1%**		**1.7%**

Source: Franklin Associates

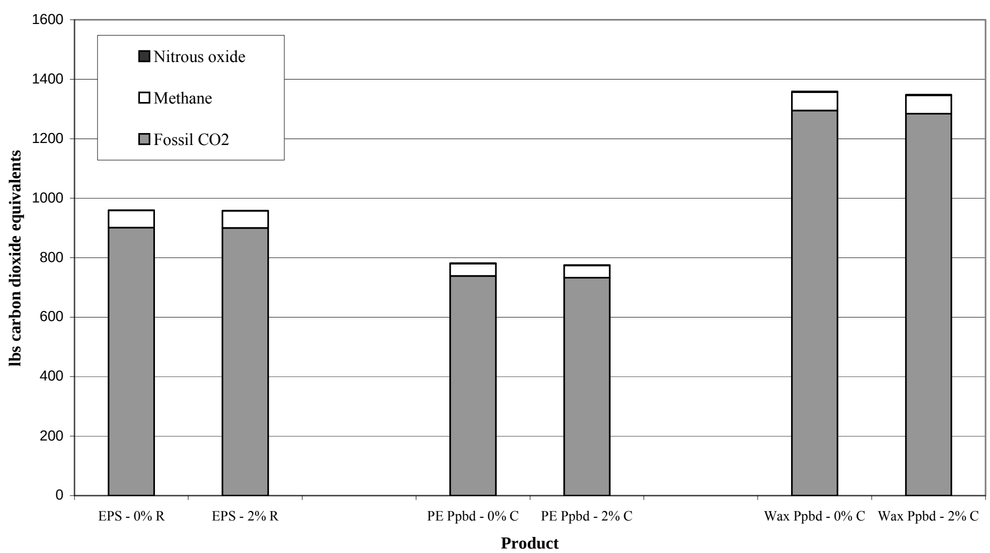
Results in this table represent average weight product at 0% and 2% recycling or composting. The purpose of this table is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 Table 2-17.

Figure 4-13: Greenhouse Gas Emissions for 10,000 16-oz Hot Cups at 0% and 2% Recycling or Composting
(lbs carbon dioxide equivalents)



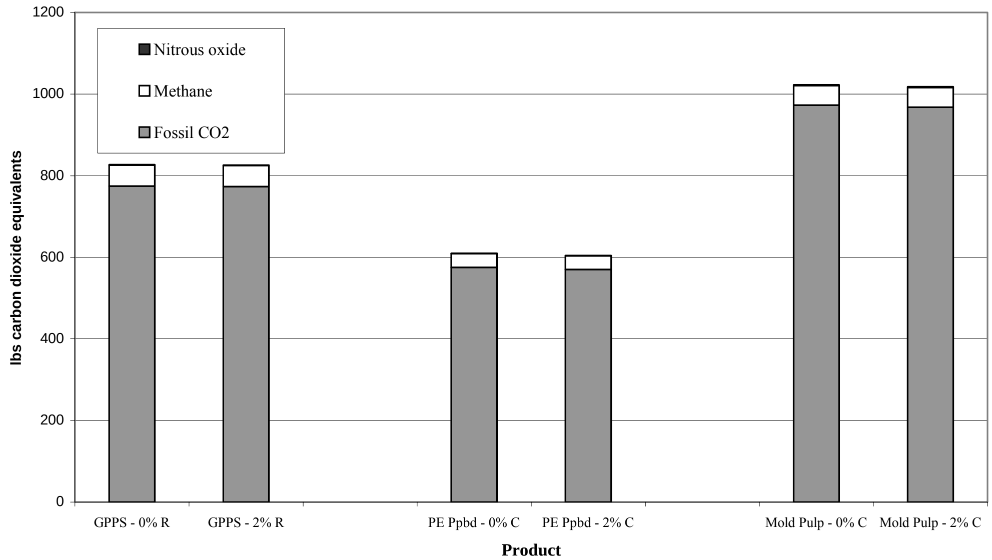
Results in this figure represent average weight product at 0% and 2% recycling or composting. The purpose of this figure is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure 4-14: Greenhouse Gas Emissions for 10,000 32-oz Cold Cups at 0% and 2% Recycling or Composting
(lbs carbon dioxide equivalents)



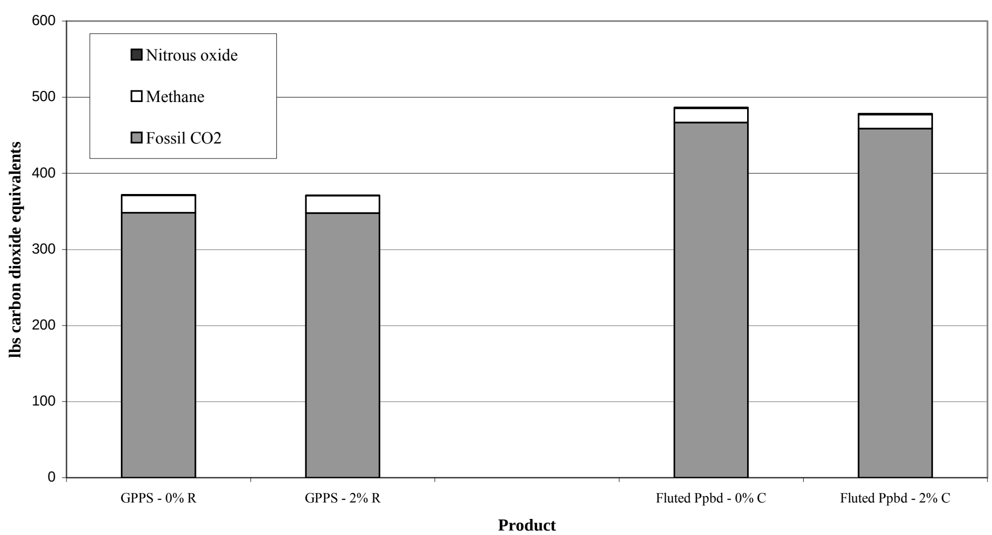
Results in this figure represent average weight product at 0% and 2% recycling or composting. The purpose of this figure is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure 4-15: Greenhouse Gas Emissions for 10,000 9-inch High Grade Plates at 0% and 2% Recycling or Composting (lbs carbon dioxide equivalents)



Results in this figure represent average weight product at 0% and 2% recycling or composting. The purpose of this figure is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

Figure 4-16: Greenhouse Gas Emissions for 10,000 5-inch Sandwich-size Clamshells at 0% and 2% Recycling or Composting (lbs carbon dioxide equivalents)



Results in this figure represent average weight product at 0% and 2% recycling or composting. The purpose of this figure is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this figure because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2.

GHG reductions often correspond closely with energy reductions, i.e., when combustion of fossil fuels is the main source of energy. However, for polystyrene recycling, the reductions in energy burdens for virgin material production do not correlate with the GHG reductions. For polystyrene, there are no GHG emissions associated with the energy of material resource component of the savings in virgin material production burdens.

CONCLUSIONS

The percent reductions in total burdens due to recycling and composting are summarized in Table 4-13. Across all foodservice materials in all categories, two percent recycling or composting reduces total environmental burdens by two percent or less. The percent reduction for recycling is less than one percent, since some of the savings in virgin material production burdens are offset by the burdens for collection and reprocessing of postconsumer material.

Table 4-13

Summary: Percent Reduction in Environmental Burdens for 2% Recycling or Composting of Average Weight Product

		Solid Waste		
	Energy	**Weight**	**Volume**	**GHG**
16-ounce Hot Cup				
EPS	0.5%	0.6%	0.9%	0.1%
PE-coated Paperboard	0.9%	1.5%	1.7%	0.8%
Ppbd Cup + Sleeve	0.9%	1.7%	1.8%	1.1%
32-ounce Cold Cup				
EPS	0.5%	0.6%	0.9%	0.1%
PE-coated Paperboard	0.9%	1.6%	1.7%	0.8%
Wax-coated Paperboard	0.9%	1.2%	1.3%	0.8%
9-inch High-grade Plate				
GPPS	0.6%	0.6%	0.9%	0.1%
PE-coated Paperboard	1.0%	1.6%	1.7%	0.9%
Molded Pulp	0.7%	1.4%	1.5%	0.5%
5-inch Sandwich-size Clamshell				
GPPS	0.6%	0.6%	0.9%	0.1%
Fluted Paperboard	0.9%	2.0%	2.0%	1.7%

		Solid Waste		
	Energy	**Weight**	**Volume**	**GHG**
Average Percent Reduction				
Recycling of EPS products	0.5%	0.6%	0.9%	0.1%
Recycling of GPPS products	0.6%	0.6%	0.9%	0.1%
Composting of paperboard products	0.9%	1.6%	1.7%	0.9%

Source: Franklin Associates

Results in this table represent average weight product at 0% and 2% recycling or composting. The purpose of this table is to illustrate the effect of recycling or composting in reducing the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of competing products cannot be drawn from this table because results for the full range of product weights for each material are not shown. For results for the full range of product samples for each material, see Chapter 2 tables.

CHAPTER 5

CONSIDERATIONS FOR INTERPRETATION OF DATA AND RESULTS

INTRODUCTION

An important issue with LCI results is whether two numbers are really different from one another. For example, if one product has a total system requirement of 100 energy units, is it really different from another product system that requires 110 energy units? If the error or variability in the data is sufficiently large, it cannot be concluded that the two numbers are actually different.

STATISTICAL CONSIDERATIONS

A statistical analysis that yields clear numerical answers would be ideal, but unfortunately LCI data are not amenable to this. The data are not (1) random samples from (2) large populations that result in (3) "normal curve" distributions. LCI data meet none of these requirements for statistical analysis. LCI data for a given sub-process (such as potato production, roundwood harvesting, or caustic soda manufacture, for example) are generally selected to be representative of a process or industry, and are typically calculated as an average of two to five data points. In statistical terminology, these are not random samples, but "judgment samples," selected so as to reduce the possible errors incurred by limited sampling or limited population sizes. Formal statistics cannot be applied to judgment samples; however, a hypothetical data framework can be constructed to help assess in a general sense the reliability of LCI results.

The first step in this assessment is reporting standard deviation values from LCI data, calculated by:

$$s = \sqrt{\frac{\sum (x_1 - x_{mean})^2}{n-1}},$$

where x_i is a measured value in the data set and x_{mean} is the average of n values. An analysis of sub-process data from Franklin Associates, Ltd. files shows that, for a typical sub-process with two to five different companies supplying information, the standard deviation of the sample is about 30 percent of the sample average.

In a typical LCI study, the total energy of a product system consists of the sum of many sub-processes. For the moment, consider an example of adding only two numbers. If both numbers are independent of each other and are an average of measurements which have a sample standard deviation, s, of 30, the standard deviation of the sum is obtained by adding the variances of each term to form the sum of the variances, then taking the square root. Variances are calculated by squaring the standard deviation, s^2, so the sum of the variances is $30^2 + 30^2 = 900 + 900 = 1800$. The new standard deviation of the sum is the square root of the sum of the variances, or $\sqrt{1800}$ = 42.4. In this example, suppose both average values are 100, with a sum of 200. If reported as a percent of the sum, the new standard deviation is 42.4/200 = 21.3% of the sum. Another way of obtaining this value is to use the formula $s_{\%} = \frac{s/x_{mean}}{\sqrt{n}}$, where the term $s_{\%}$ is defined as the standard deviation of n data points, expressed as a % of the average, where each entry has approximately the same standard deviation, s. For the example, then, $s_{\%} = \frac{30\%}{\sqrt{2}}$ = 21.3%.

Going back to a hypothetical LCI example, consider a common product system consisting of a sum of approximately 40 subsystems. First, a special hypothetical case is examined where *all of the values are approximately the same size, and all have a standard deviation of 30%*. The standard deviation in the result is $s_{\%} = \frac{30\%}{\sqrt{40}}$ = 4.7%. The act of summing reduces the standard deviation of the result with respect to the standard deviation of each entry because of the assumption that errors are randomly distributed, and by combining values there is some cancellation of total error because some data values in each component system are higher than the true values and some are lower.

The point of this analysis, however, is to compare two results, e.g., the energy totals for two different product systems, and decide if the difference between them is significant or not. To test a hypothetical data set it will be assumed that two product systems consist of a sum of 40 values, and that the standard deviation, $s_{\%}$, is 4.7% for each product system.

If there is statistical knowledge of the sample only, and not of the populations from which they were drawn, “t” statistics can be used to find if the two product totals are different or not. The expression selected is:

$\mu 1 - \mu 2 = x1 - x2 +/- t_{.025} s' \sqrt{\frac{1}{n1} + \frac{1}{n2}}$, where $\mu 1 - \mu 2$. is the difference in population means, x_1-x_2 is the difference in sample means, and s' is a pooled standard deviation of the two samples. For the hypothetical case, where it is assumed that the standard deviation of the two samples is the same, the pooled value is simply replaced with the standard deviation of the samples.

The goal is to find an expression that compares our sample means to “true,” or population, means. A new quantity is defined:

$\Delta = (\mu 1 - \mu 2) - (x1 - x2)$, and the sample sizes are assumed to be the same (i.e., n_1=n_2). The result is $\Delta = t_{.025} s' \sqrt{\frac{2}{n}}$, where Δ is the minimum difference corresponding to a 95%

confidence level, s' is the standard deviation of the sum of n values, and $t_{.025}$ is a t statistic for 95% confidence levels. The values for t are a function of n and are found in tables. This expression can be converted to percent notation by dividing both sides by the average of the sample means, which results in $\Delta\% = t_{.025} s'\% \sqrt{\frac{2}{n}}$, where $\Delta\%$ is now the percent difference corresponding to a 95% confidence level, and s'% is the standard deviation expressed as a percent of the average of the sample means. This formula can be simplified for the example calculation by remembering that $s'\% = \frac{s\%}{\sqrt{n}}$, where s% is the standard deviation of each energy entry for a product system. Now the equation becomes $\Delta\% = t_{.025} s\% \frac{\sqrt{2}}{n}$. For the example, t = 2.0, s = 30%, and n = 40, so that $\Delta\%$ = 2.1%. This means that if the two product system energy totals differ by more than 2.1%, there is a 95% confidence level that the difference is significant. That is, if 100 independent studies were conducted (in which new data samples were drawn from the same population and the study was conducted in the identical manner), then 95 of these studies would find the energy values for the two product systems to differ by more than 2.1%.

The previous discussion applies only to a hypothetical and highly idealized framework to which statistical mathematics apply. LCI data differ from this in some important ways. One is that the 40 or so numbers that are added together for a final energy value of a product system are of widely varying size and have different variances. The importance of this is that large numbers contribute more to the total variance of the result. For example, if 20 energy units and 2,000 energy units are added, the sum is 2,020 energy units. If the standard deviation of the smaller value is 30% (or 6 units), the variance is 6^2 = 36. If the standard deviation of the larger number is 10% (or 200), the variance is 200^2 = 40,000. The total variance of the sum is 36 + 40,000 = 40,036, leading to a standard deviation in the sum of $\frac{\sqrt{(40036)}}{2020}$ = 9.9%. Clearly, the variance in the result is much more greatly influenced by larger numbers. In a set of LCI energy data, standard deviations may range from 10% to 60%. If a large number has a large percentage standard deviation, then the sum will also be more uncertain. If the variance of the large number is small, the answer will be more certain. To offset the potential problem of a large variance, Franklin Associates goes to great lengths to increase the reliability of the larger numbers, but there may simply be inherent variability in some numbers which is beyond the researchers' control.

If only a few numbers contribute most of the total energy in a system, the value of $\Delta\%$ goes up. This can be illustrated by going back to the formula for $\Delta\%$ and calculating examples for n = 5 and 10. From statistical tables, the values for $t_{.025}$ are 2.78 for n = 5, and 2.26 for n = 10. Referring back to the hypothetical two-product data set with s% = 30% *for each entry*, the corresponding values for $\Delta\%$ are 24% for n = 5 and 9.6% for n = 10. Thus, if only 5 numbers out of 40 contribute most of the energy, the percent *difference* in the two product system energy values must increase to 24% to achieve the 95% confidence level that the two values are different. The minimum difference decreases to 9.6% if there are 10 major contributors out of the 40 energy numbers in a product system.

CONCLUSIONS

The discussion above highlights the importance of sample size, and of the variability of the sample. However, once again it must be emphasized that the statistical analysis does not apply to LCI data. It only serves to illustrate the important issues. Valid standard deviations cannot be calculated because of the failure of the data to meet the required statistical formula assumptions. Nevertheless, it is important to achieve a maximum sample size with minimum variability in the data. Franklin Associates examines the data, identifies the large values contributing to a sum, then conducts more intensive analysis of those values. This has the effect of increasing the number of data points, and therefore decreasing the "standard deviation." Even though a calculated standard deviation of 30% may be typical for Franklin Associates' LCI data, the actual confidence level is much higher for the large values that control the variability of the data than for the small values. However, none of this can be quantified to the satisfaction of a statistician who draws conclusions based upon random sampling. In the case of LCI data, it comes down to a matter of professional judgment and experience. The increase in confidence level resulting from judgment and experience is not measurable.

It is the professional judgment of Franklin Associates, based upon over 25 years of experience in analyzing LCI data, that a 10% rule is a reasonable value for $\Delta\%$ for stating results of product system energy totals. That is, if the energy of one system is 10% different from another, it can be concluded that the difference is significant. It is clear that this convention is a matter of judgment. This is not claimed to be a highly accurate statement; however, the statistical arguments with hypothetical, but similar, data lend plausibility to this convention.

We also conclude that the weight of postconsumer solid waste data can be analyzed in a similar way. These data are at least as accurate as the energy data, perhaps with even less uncertainty in the results. Therefore, the 10% rule applies to postconsumer solid waste weight. However, we apply a 25% rule to the solid waste volume data because of greater potential variability in the volume conversion factors.

Air and water pollution and industrial solid waste data are not included in the 10% rule. Their variability is much higher. Data reported by similar plants may differ by a factor of two, or even a factor of ten or higher in some cases. Standard deviations may be as high as 150%, although 75% is typical. This translates to a hypothetical standard deviation in a final result of 12%, or a difference of at least 25% being required for a 95% confidence of two totals being different if 10 subsystems are major contributors to the final results. However, this rule applies only to single emission categories, and cannot be extended to general statements about environmental emissions resulting from a single product system. The interpretation of environmental emission data is further complicated by the fact that not all plants report the same emission categories, and that there is not an accepted method of evaluating the relative importance of various emissions.

It is the intent of this appendix to convey an explanation of Franklin Associates' 10% and 25% rules and establish their plausibility. **Franklin Associates' policy is to consider product system totals for energy and weight of postconsumer solid waste weight to be different if there is at least a 10% difference in the totals. Otherwise, the difference is considered to be insignificant. In the detailed tables of this report there are many specific pollutant categories that are variable between systems. For the air and waterborne emissions, industrial solid waste, and postconsumer solid waste volume, the 25% rule should be applied.** The formula used to calculate the difference between two systems is:

$$\% \text{ Diff} = \left(\frac{x-y}{\frac{x+y}{2}} \right) \text{ X } 100,$$

where x and y are the summed totals of energy or waste for two product systems. The denominator of this expression is the average of the two values.

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GLOSSARY OF TERMS USED IN THE LCI REPORT AND APPENDICES

Biochemical Oxygen Demand (BOD). An indication of the amount of organic material present in water or wastewater.

Biomass. The total dry organic matter or stored energy content of living organisms that is present at a specific time in a defined unit of the Earth's surface. As an energy source, the Energy Information Administration defines biomass as organic non-fossil material of biological origin constituting a renewable energy source.

Btu (British thermal unit). A standard unit for measuring the quantity of heat energy equal to the quantity of heat required to raise the temperature of 1 pound of water by 1 degree Fahrenheit.

Carbon Cycle, Natural. The process by which carbon dioxide is taken up by trees and released at a later time when these trees, or products made from them, decompose or are burned. The U.S. EPA uses the convention that carbon dioxide releases from wood-derived materials do not constitute a net contribution to global carbon dioxide, because the carbon dioxide removed from the atmosphere during the trees' growth cycle is simply being returned to the atmosphere.

Carbon Dioxide Equivalents. A greenhouse gas's potential to contribute to global warming, relative to carbon dioxide, which is assigned a global warming potential of 1.

Carbon Dioxide. A naturally occurring gas and also a by-product of burning fossil fuels and biomass, as well as land-use changes and other industrial processes. It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured and therefore has a Global Warming Potential of 1[11].

Carbon Dioxide, Fossil. Carbon dioxide associated with the combustion of fossil fuels.

Carbon Dioxide, Non-fossil. Carbon dioxide associated with natural sources or combustion of biomass.

Chemical Oxygen Demand (COD). The amount of oxygen required for the oxidation of compounds in water, as determined by a strong oxidant such as dichromate.

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[11] Definition from the glossary of the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report **- Climate Change 2001.**

Coal. A black or brownish-black solid, combustible substance formed by the partial decomposition of vegetable matter without access to air. The rank of coal, which includes anthracite, bituminous coal, subbituminous coal, and lignite, is based on fixed carbon, volatile matter, and heating value. Coal rank indicates the progressive alteration, or coalification, from lignite to anthracite.

Combustion Energy. The high heat value directly released when coal, fuel oil, natural gas, or wood are burned for energy consumption.

Combustion Emissions. The environmental emissions directly emitted when coal, fuel oil, natural gas, or wood are burned for energy consumption.

Composting. Controlled biological decomposition of organic material, occurring under aerobic conditions; a managed process through which microorganisms break down plant and animal materials into more available forms suitable for application to the soil.

Crude Oil. A mixture of hydrocarbons that exists in liquid phase in underground reservoirs and remains liquid at atmospheric pressure after passing through surface separating facilities.

Curie (Ci). The metric unit of radioactive decay. The quantity of any radioactive nuclide that undergoes 3.7×10^{10} disintegrations/sec.

Distillate Fuel Oil. A general classification for one of the petroleum fractions produced in conventional distillation operations. It is used primarily for space heating, on-and off-highway diesel engine fuel (including railroad engine fuel and fuel for agricultural machinery), and electric power generation. Included are products known as No. 1, No. 2, and No. 4 diesel fuels.

Energy of Material Resource. The energy value of fuel resources withdrawn from the planet's finite fossil reserves and used as material inputs for materials such as plastic resins. Alternative terms used by other LCI practitioners include "Feedstock Energy" and "Inherent Energy."

Fossil Fuel. Carbon-based fuel from fossil carbon deposits such as oil, natural gas, and coal.

Fuel-related Emissions. Emissions (atmospheric, waterborne, and solid waste) associated with the combustion of fuel, including carbon dioxide emissions, products of incomplete combustion, residual ash, etc.

Fugitive Emissions. Unintended leaks of substances that escape to the environment without treatment. These are typically from the processing, transmission, and/or transportation of fossil fuels, but may also include leaks and spills from reaction vessels, other chemical processes, etc.

Geothermal Energy. Energy from the internal heat of the earth, which may be residual heat, friction heat, or a result of radioactive decay. The heat is found in rocks and fluids at various depths and can be extracted by drilling and/or pumping.

Global Warming Potential (GWP). An index, describing the radiative characteristics of well-mixed greenhouse gases, that represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in absorbing outgoing infrared radiation. This index approximates the time-integrated warming effect of a unit mass of a given greenhouse gas in today's atmosphere, relative to that of carbon dioxide[12].

Greenhouse Effect. The entrapment of heat within the Earth's surface-troposphere system due to the absorption of infrared radiation by greenhouse gases[13].

Greenhouse Gas. Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds. This property causes the greenhouse effect. Water vapor, carbon dioxide, nitrous oxide, methane, and ozone are the primary greenhouse gases in the Earth's atmosphere[14].

Heat Content of a Quantity of Fuel, Gross. The total amount of heat released when a fuel is burned. Coal, crude oil, and natural gas all include chemical compounds of carbon and hydrogen. When those fuels are burned, the carbon and hydrogen combine with oxygen in the air to produce carbon dioxide and water. Some of the energy released in burning goes into transforming the water into steam and is usually lost. The amount of heat spent in transforming the water into steam is counted as part of gross heat but is not counted as part of net content. Also referred to as the higher heating value. Btu conversion factors typically used by EIA represent gross heat content. Called combustion energy in this appendix.

Heat Content of a Quantity of Fuel, Net. The amount of usable heat energy released when a fuel is burned under conditions similar to those in which it is normally used. Also referred to as the lower heating value. Btu conversion factors typically used by EIA represent gross heat content.

Hydrocarbons. A subcategory of organic compounds that contain only hydrogen and carbon. These compounds may exist in either the gaseous, liquid, or solid phase, and have a molecular structure that varies from the simple to the very heavy and very complex. The category Non-Methane Hydrocarbons (NMHC) is sometimes used when methane is reported separately.

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[12] Definition from the glossary of the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report **- Climate Change 2001.**

[13] Adapted from the definition in the glossary of the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report **- Climate Change 2001.**

[14] Partial definition for this term from the glossary of the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report **- Climate Change 2001.**

Liquefied Petroleum Gases (LPG). Ethane, ethylene, propane, propylene, normal butane, butylene, isobutane, and isobutylene produced at refineries or natural gas processing plants, including plants that fractionate raw natural gas plant liquids.

Methane (CH_4). A hydrocarbon that is a greenhouse gas produced through anaerobic (without oxygen) decomposition of waste in landfills, animal digestion, decomposition of animal wastes, production and distribution of natural gas and oil, coal production, and incomplete fossil fuel combustion[15]. Methane is the principal constituent of natural gas.

(**Motor) Gasoline.** A complex mixture of relatively volatile hydrocarbons, with or without small quantities of additives, that has been blended to form a fuel suitable for use in spark-ignition engines. "Motor gasoline" includes reformulated gasoline, oxygenated gasoline, and other finished gasoline.

Natural Gas. A mixture of hydrocarbons (principally methane) and small quantities of various nonhydrocarbons existing in the gaseous phase or in solution with crude oil in underground reservoirs.

Nitrogen Oxides (NO_X). Compounds of nitrogen and oxygen produced by the burning of fossil fuels, or any other combustion process taking place in air. The two most important oxides in this category are nitrogen oxide (NO) and nitrogen dioxide (NO_2). Nitrous oxide (N_2O), however, is not included in this category and is considered separately.

Nitrous Oxide (N_2O). A greenhouse gas emitted through soil cultivation practices, especially the use of commercial and organic fertilizers, fossil fuel combustion, nitric acid production, and biomass burning[16].

Non-Methane Volatile Organic Compounds (NMVOC). Organic compounds, other than methane, that participate in atmospheric photochemical reactions.

Other Organics. Compounds containing carbon combined with hydrogen and other elements such as oxygen, nitrogen, sulfur or others. Compounds containing only carbon and hydrogen are classified as hydrocarbons and are not included in this category.

Particulate Matter (Particulates). Small solid particles or liquid droplets suspended in the atmosphere, ranging in size from 0.005 to 500 microns.

Particulates are usually characterized as primary or secondary. Primary particulates, usually 0.1 to 20 microns in size, are those injected directly into the atmosphere by chemical or physical processes. Secondary particulates are produced as a result of chemical reactions that take place in the atmosphere. In our reports, particulates refer only to primary particulates.

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15 Adapted from the definition in the glossary of the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report **- Climate Change 2001.**

16 Adapted from the definition in the glossary of the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report **- Climate Change 2001.**

Particulates reported by Franklin Associates are not limited by size range, and are sometimes called total suspended particulates (TSP). The category PM-10 refers to all particulates less than 10 microns in (aerodynamic) diameter. This classification is sometimes used when health effects are being considered, since the human nasal passages will filter and reject any particles larger than 10 microns. PM 2.5 (less than 2.5 microns in diameter) is now considered the size range of most concern for human health effects.

Petroleum. A generic term applied to oil and oil products in all forms, such as crude oil, lease condensate, unfinished oils, petroleum products, natural gas plant liquids, and nonhydrocarbon compounds blended into finished petroleum products.

Postconsumer Waste. Product or material that has served its intended use and is discarded by the consumer.

Precombustion Energy. The energy required for the production and processing of energy fuels, such as coal, fuel oil, natural gas, or uranium, starting with their extraction from the ground, up to the point of delivery to the customer.

Precombustion Fuel-related Emissions. The environmental emissions due to the combustion of fuels used in the production and processing of the primary fuels; coal, fuel oil, natural gas, and uranium.

Precombustion Process Emissions. The environmental emissions due to the production and processing of the primary fuels; coal, fuel oil, natural gas, and uranium, that are process rather than fuel-related emissions.

Process Emissions. Emissions (atmospheric, waterborne, and solid waste) that result from a process, such as gases given off during a chemical reaction, residual material remaining in the bottom of a reaction vessel, unrecycled trim scrap from fabrication processes, etc.

Process Energy. Energy used for any/all processes that extract, transform, fabricate or otherwise effect changes on a material or product during its life cycle.

Residual Fuel Oil. The heavier oils that remain after the distillate fuel oils and lighter hydrocarbons are distilled away in refinery operations. Included are No. 5, No. 6, and Navy Special. It is used for commercial and industrial heating, electricity generation, and to power ships.

Secondary Packaging. Packaging used to directly protect and contain a product for delivery to a consumer. Includes the primary container (such as a corrugated box) and packaging used to unitize individual products within the primary container (such as film sleeves, paperboard dividers, etc.).

Sulfur Oxides (SO_X). Compounds of sulfur and oxygen, such as sulfur dioxide (SO_2) and sulfur trioxide (SO_3).

Total Dissolved Solids (TDS). The TDS in water consists of inorganic salts, minute organic particles, and dissolved materials. In natural waters, salts are chemical compounds composed of anions such as carbonates, chlorides, sulfates, and nitrates, and cations such as potassium, magnesium, calcium, and sodium.

Total Suspended Solids (TSS). TSS gives a measure of the turbidity of the water. Suspended solids cause the water to be milky or muddy looking due to the light scattering from very small particles in the water.

Transportation Energy. The energy used to move materials or products from location to location during the journey from raw material extraction through end of life disposition.

Volatile Organic Compounds (VOCs). Organic compounds that participate in atmospheric chemical reactions.

Windrows, Windrowing. Open-air production of compost by piling organic material in long rows and allowing it to decompose. The piles are allowed to stand until the digestion process reaches the required stage, and the material is normally turned regularly.

PEER REVIEW REPORTS
AND
FRANKLIN ASSOCIATES RESPONSES

FINAL PEER REVIEW

LIFE CYCLE INVENTORY OF POLYSTYRENE FOAM, BLEACHED PAPERBOARD, AND CORRUGATED PAPERBOARD FOODSERVICE PRODUCTS

Prepared for

THE POLYSTYRENE PACKAGING COUNCIL (PSPC)
&
FRANKLIN ASSOCIATES, LTD.

by

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June 9, 2005

INTRODUCTION

At the request of the Polystyrene Packaging Council (PSPC), the consulting firm of Franklin Associates, Ltd. (FAL) has expanded and updated a life cycle inventory of foodservice products FAL conducted in 1990.

Prior to beginning the study in 2002, FAL retained an independent peer review panel to review and comment on the following areas: goal, target audience, scope, boundaries, and data collection approach. A copy of the panel's initial report, including FAL's responses to the reviewers' comments, is attached.

This report is the panel's review of FAL's final report. It has been completed in accordance with ISO 14040:1997, 7.

Before proceeding, the panel wishes to state that FAL has done its typical excellent job in preparing the life cycle inventory. There are some deficiencies, but the overall work meets the high professional standards that life cycle assessment practitioners have come to expect from FAL.

COMMENTS

Goal

FAL states that the goal is "to provide foodservice industry stakeholders with the information needed to better understand the current environmental profiles of…products (polystyrene and paperboard) studied". The study fulfills this specified goal.

However, the goal has changed since the beginning of the study. Initially, it was stated as "to include more recent data on materials originally considered, to consider newly developed materials, and to complete the study in accordance with current ISO standards." FAL does explain that since "bio-based foodservice products…were only available from one producer…such a limited sample would not be acceptable," and they were not included in the study. Since ISO 14041 recognizes that goal-setting is an iterative process, such a change is normal. However, FAL does not explain that the study goal has changed, as required by ISO 14041:1998, 5.3.1.

A statement has been added to the report to explicitly state that the study goal changed.

Further, the rationale for dropping bio-based products—"only available from one producer"—is puzzling. Data were available from only one producer for 32-oz wax-coated paperboard cold cups, 5-inch corrugated paperboard clamshells, and unbleached corrugated hot cup sleeves; yet all these products were included in the study.

Biobased products tend to have unique compositions, while other products for which only one sample was available are much more consistent in composition (e.g., 90% paperboard + 10% wax coating). Thus, a single product sample of wax-coated cup can be considered a reasonable representative of wax-coated cups in general, while a single biobased product reflects one specific formulation and product weight. Explanation has been added to the report.

FAL is careful to note that "the study results…may be used inappropriately to make general comparative assertions," but "this is not an explicit goal of the study and discouraged by the authors." It further states that the "study does not meet all the ISO 14040…requirements for…making general comparative assertions." The temptation with a study of any two or more products is to compare them; by their very nature, charts and graphs of study results encourage comparison. However, the "Conclusions and Observations" in the "Executive Summary" seem to violate the authors' warnings. The entire study distinctly identifies four unique product categories with unique functions. Especially of concern is the crossing of product categories to compare materials in this section.

*The **Conclusions and Observations** section cites specific observations supported by study results and does not make general comparative assertions regarding competing products and materials. Wording has been added in the **Conclusions and Observations** section and the **Limitations** section to clarify the distinction between general comparative assertions of environmental superiority and specific comparative statements supported by study results.*

Scope

As defined in ISO 14040:1997, 5.1.2, the scope of a life cycle assessment (LCA) shall consider and describe functional unit, product systems studied, product system boundaries, allocation procedures, assumptions, and limitations. This life cycle inventory (LCI)—a part of an LCA—clearly meets these requirements. The overall scope is inclusive and not prejudicial to any product examined. FAL clearly states that this study is an LCI and is not an impact assessment.

FAL focuses the study on four package categories (product systems): 16-oz hot cups, 32-oz cold cups, 9-inch high grade plates, and 5-inch sandwich size clamshells. This scope has been modified from the four systems originally defined for the study: hot and cold cups, plates, clamshells, and meat/poultry trays. FAL explains the reason for not including meat/poultry trays, but does not explicitly identify the scope change, as required by ISO 14041: 1998, 5.3.1.

A statement has been added to the report to explicitly state that the study scope changed.

Boundaries

The boundaries chosen seem appropriate.

- The boundaries range from field, forest, or extraction from the earth through disposal, but exclude transportation of packaged products to consumers and consumer use. The two excluded categories are apt to be highly subject to assumptions; FAL wisely and properly omitted them.

  No response required.

- The raw material boundaries include actual solid materials used, but omit water and air as raw materials or in process use. This is a conventional but regrettable omission, as water consumption can be of significant environmental concern. Not only is water used in production of all examined products, but the source and quality of the water are different.

  We agree that water use is an important environmental concern that should be addressed in life cycle inventory; however, because of the lack of availability of good data on water use for unit processes, Franklin Associates' LCI database does not include water use.

- Much of the impact of pulpwood or corn crop-growing is omitted.

  The LCI includes the production of basic fertilizer inputs used in farming, as well as farming energy use. As noted in the Chapter 1 section on ***Water Use, Land Use, and Farming****, the quantities and compositions of pesticides, herbicides, and other chemical agents used in farming vary widely, and data on the production of specialized agricultural chemicals are largely unavailable.*

  Emissions of agricultural chemicals are difficult to quantify since there are many types of pesticides, herbicides, etc. used, each varying in application rate and degradability. Emission rates also vary widely depending on the soil type and topography, application process, weather factors such as wind and rain, etc. Because manufacture of specialized agricultural chemicals is not included in this study and because of the wide variability in emissions in agricultural runoff, emissions of these substances are not included in this study.

- Air emissions focus on greenhouse gases carbon dioxide, nitrous oxide, and methane. By convention, water vapor, the most significant greenhouse gas, is not included.

  No response required.

- Lack of citation of greenhouse gas emissions from landfills is probably appropriate, as values will vary greatly and coated-paper products are not likely to readily degrade. But a philosophical issue does arise. If all the carbon present in landfilled paper products were converted to methane by anaerobic digestion—versus to CO_2 by incineration or composting—would landfilling lead to a net increase in greenhouse gas effects? The answer must be "yes" because the infrared energy-holding capacity of methane is 23 times greater than CO_2. But then "good" CO_2 versus "bad" CO_2 must be considered. Since FAL cannot resolve these issues in this study, FAL has wisely chosen to avoid them, but might point out a subject for future research.

A paragraph addressing this issue has been added to Chapter 1 in the section ***Emissions from Combustion and Landfilling of Postconsumer Waste.***

- FAL conducts a short study on the effects of minimal (2%) recycling or composting of the food service items on their life cycle inventory. Based on the lack of US Food & Drug Administration "letters of no objection" to the use of post-consumer polystyrene in food contact containers, the polystyrene used is all virgin material. The situation for paper products is less clear, as some recycled content is possible. A more specific definition of the paperboard material source is desired.

  *A section describing the recycled content modeled for each paperboard foodservice product has been added to the report (****Paperboard Product Assumptions*** *in Chapter 2). All recycling of foodservice products modeled in Chapter 4 is open-loop recycling, with no secondary product specified. Because of food contact concerns, the secondary product utilizing the recycled material is expected not to be a foodservice product.*

  It appears about 43% of the cup sleeve material is post-consumer. A statement is needed in Chapter 1 on allocation of burdens for post-consumer material used in both the packages studied and secondary packaging.

  Flow diagrams and descriptions of the recycled content in corrugated cup sleeves and corrugated boxes are provided in Appendix E and Appendix F, respectively. These corrugated products are composed of linerboard and medium. The medium is made from semichemical paperboard and recycled paperboard. The linerboard is made from unbleached paperboard and recycled paperboard. Both the semichemical and unbleached paperboard have some recycled fiber content. The complex modeling of the open-loop and closed-loop content of the box takes into account not only the virgin and recycled content of the four types of paperboard that make up the linerboard and medium, but also the rate at which postconsumer corrugated boxes (and the postconsumer and virgin fiber in them) are recovered and recycled. Allocation of burdens for open-loop and closed-loop recycling is described in the ***Recycling*** *section of Chapter 1.*

- The boundaries of water-borne emissions are after treatment, which is appropriate.

No response required.

- As generally accepted, FAL states that minor components (generally less than 1%) are not included in the study. Depending on what environmental issue this LCI may be consulted to address, the lack of minor components could be unfortunate. However, controlling study cost and unwillingness of producers to reveal minor constituents both make such omissions understandable. FAL correctly does not include such matters as Freon leaks from air conditioning for workers or emissions from automobiles used to transport workers to production areas.

  No response required.

Assumptions

Overall, the assumptions in this study are reasonable and clearly stated. However, the significant impact of one key methodological assumption needs to be considered further.

This assumption is: the "energy of material resource" is confined to products made using oil and natural gas as raw materials; wood used in manufacturing products has no "energy of material resource". The rationale for this assumption is stated at multiple points in the report. For example, on page ES-7, the report states that this methodological assumption is invoked because "the use of wood in this country is primarily as a material input and not as a fuel". While this statement is certainly true, assuming that the "energy of material resource" for wood is zero conflicts with other data presented in the report (Table 2-7), which indicate that roughly 50% of the process energy use for paper products is wood-derived.

The way wood energy is treated in this study is not inconsistent with our defined energy of material resource (EMR) accounting convention. Our choice of the EMR convention used in this study is to quantify the depletion of resources that would otherwise be extracted and used as energy resources. On this basis, it is not inconsistent to report actual energy derived from wood as process energy yet not assign EMR to the energy content of the wood that becomes part of the product. Within the geographic boundaries for this study, forest resources are harvested for use as a material. If not used to produce paperboard, lumber, etc., the trees would be left standing and would not be harvested for fuel; thus, while wood wastes or byproducts are sometimes utilized as an energy source, material use of wood in a product is not considered a diversion from its use as an energy resource.

It is a matter of professional judgment whether wood should be assigned an "energy of material resource". However, this decision could significantly affect study findings.

Consider the case of the 5-inch clamshell products. Figure ES-4 shows no significant difference in the life cycle energy use for general purpose polystyrene (GPPS) and fluted paperboard clamshells. If the "energy of material resource" of wood were included, these results would be quite different. A rough estimate of the wood use associated with the paperboard containers is given by the product weight (225 lb per 10,000 containers, Table ES-1). Assuming a heating value of paper of roughly 7,500 Btu/lb (Perry's Chemical Engineers' Handbook, Chapter 9) would lead to a material resource energy of approximately 1.7 million Btu per 10,000 containers, increasing the total energy requirement of the paper product by roughly 35%.

This is, of course, a very simplified calculation. It assumes no wood use in the manufacture of GPPS, and that the wood use for secondary packaging of these two products is similar. Nevertheless, it points out how important this methodological assumption is to the findings of the LCI. In the case of the GPPS and fluted paperboard clamshells, assuming an energy resource content for wood leads to a significant difference in life cycle energy requirements for the two products. Assuming no energy resource content for wood leads to the conclusion that there is no significant difference in energy requirements for the two products.

While the panel recognizes that FAL has given its rationale for this methodological choice at multiple points in the report (for example, pages 1-9 and 1-10), it recommends that FAL also provide a brief quantitative assessment of the importance of this assumption in its response to this review.

*Text has been added to the **Energy Results** section of Chapter 2 to address how the energy of material resource accounting convention used in this study affects the comparison of plastic and paperboard systems. Readers could also use the approach suggested by the reviewers to estimate EMR for wood products.*

Data

Data used are generally appropriate and reasonable, but some questions arose during study review.

- FAL's inclusion of data variability between product manufacturers in its analyses is truly welcomed. However, it is unfortunate that product weights were based on such small sample sizes (Tables ES-1, 2-1, and B-1). While LCI data may not follow statistical normal distributions, as described in Chapter 5, manufacturing processes frequently do. Evaluating the weights of a larger number of samples from each manufacturer could have shown even greater extremes in product data and influenced conclusions of no significant difference.

  A considerable level of effort was expended on the collection of samples for the broad range of products in this study. In response to the peer reviewers' comment, we went back to the product samples remaining from the analysis and weighed larger samples in order to evaluate the precision of manufacturing processes for disposable cups and plates. We selected six foodservice products for which we had multiple samples and weighed 20 samples from the same *manufacturer for each product. The results of this experiment show a narrow weight distribution for most products, indicating the high precision of the associated manufacturing processes.*

- The treatment of secondary packaging needs refinement. Tables ES-2, 3-1, and B-2 show only two of six "calculated" weights are similar to "reported" weights. This does not lead to credibility for those weights that are only "calculated". On page B-3 FAL explains how box and film weights were calculated. It appears FAL has "designed" the box based on product dimensions; however, FAL's design does not appear to have been validated against boxes actually used by product manufacturers. Many factors can affect box weight, including amount of end overlap, weight of linerboard, single or double-wall construction. In addition, warehouse and shipping considerations significantly impact box design. For example, the EPS cups appear to need stronger/heavier secondary packaging than the product design itself requires. The manufacturer's desire to stack product very high in the warehouse to conserve floor space drives the need for this stronger/heavier box. "Calculated" secondary packaging weights could significantly affect conclusions.

  Calculated ("designed") box weights were based on product dimensions; thus we agree that calculated weights used as maximum weights may not have adequately represented actual use of additional or sturdier box material to provide stacking strength. However, for EPS cups, Table 3-1 shows that the "designed" weight for EPS cups is actually 54 to 87% higher than the reported weight in each case where reported weights were available. Because of the lack of secondary packaging data provided by manufacturers and distributors, it would not have been possible to validate calculated box weights without purchasing cases of each product in each material category in each product category. Additionally, within a single product/material category (e.g., PE-coated paperboard cold cups), the amount of secondary packaging for the same product was observed (and can be expected) to vary from manufacturer to manufacturer. Taking into account the various combinations of variations in product weights and variations in secondary packaging weights results in an unmanageable number of permutations. In the professional judgment of the practitioners, the approach described in the report is considered adequate to fulfill the intent of Chapter 3, which was to approximate the importance of the potential contribution of secondary packaging to the overall environmental profile for products in each product category.

- A statement is needed that data have been examined and found to be complete and relevant. Crude oil production information is critical, since emissions which occur during extraction have the least economic effect and a great possibility of occurring; yet the data set cited is old. Statements in the Appendices, such as lead emissions resulting from addition of tetraethyl lead to fuel (page A-70) and 49% of US crude oil being imported (page C-3), also raise questions.

Updating the fuels and energy database is a time-consuming and expensive undertaking that is not done every year. The data used in the modeling reflect the 1998 version of the Franklin fuels and energy database, which was the most current version that was available at the time the study was conducted. Most of the public data sources for fuel use and emissions were 1995-1997 publications. Combustion energy values are 1995 values. Average fuel use for electricity generation is 1996 data. Crude oil production data are 1994 values, while refinery data are 1993 values. Specific sources of data on the production and combustion of each fuel and for electricity generation are clearly referenced in the text and tables, with full source information (including age) provided in the References section at the end of the appendix. ***Note to reviewers:*** *At the same time that this study was being conducted, Franklin Associates was updating the fuels and energy database; however, this update was not completed in time to use it for this study. A brief comparison of the 1998 and 2003 fuels and energy databases follows:*

> *The 2003 fuels and energy appendix uses similar data sources as the 1998 version. In most cases, updated data were available for AP-42 emission factors, commerce statistics, and other key sources.*
>
> *The 2003 emission factors for most processes are comparable to the 1998 factors, with exception of methane. While actual methane emissions have probably not increased in the last five years, more data on methane emissions have become available. The methane emissions from petroleum extraction, natural gas extraction, and coal mining are thus higher in the 2003 appendix than in the 1998 appendix. Another difference between the two versions is that the 2003 appendix reports more waterborne effluents for crude oil and natural gas extraction than the 1998 appendix. Again, this can be attributed to the availability of a new, more complete data source rather than an actual increase in emissions.*
>
> *The 2003 appendix also cites updated statistics for petroleum imports. However, since life cycle data are not available for foreign crude oil extraction processes, we model foreign oil production using domestic production data plus ocean transport. This probably understates actual emissions from crude oil production, which is not produced with the same environmental standards as domestic oil. However, we have no better option until data for the foreign production of crude oil becomes available.*
>
> *Finally, the statement in Appendix A about lead-based additives in gasoline has been deleted. The 1998 version of Appendix A shows lead emissions for gasoline combustion, but the 2003 version does not.*

- Data quality indices (DQI's) are presented for the fuel components. DQI's are also needed for the plastics data in Appendix C and the paper data in Appendices D, E, and F.

  Because the data sets for the energy and emissions associated with the production and combustion of fuel are derived from multiple data sources with varying age, representativeness, completeness, etc., DQIs are provided in Appendix A to provide the reader with an overall summary of the data quality for individual fuels. In the other appendices, only a few references are typically cited for the individual data tables for each material unit process. The reader can identify the source and age of the data by checking the full reference citations in the list provided at the end of the chapter. This gives the reader a better indication of the data quality than a summary DQI.

- Carbon dioxide is present when gas and oil are extracted. Comment is needed on the fate of that gas, whether it is vented, collected and processed, or reinjected.

  AP-42 does not provide factors for crude oil/natural gas extraction; its petroleum factors begin with the refining processes. The World Bank Group Pollution Prevention and Abatement Handbook lists nitrogen oxides, VOCs, and methane as process emissions from crude oil and natural gas extraction, but does not cite any carbon dioxide emissions.

  Although we recognize that natural gas flaring may occur at onshore oil extraction sites, no data were available to quantify the amount of natural gas flared, and no emission factors were available for flaring operations. Further research in this area might improve the data quality.

- Table A-2, Data for the Production and Processing of 1,000 Cubic Feet of Natural Gas, does not include any CO_2. This appears to be an oversight.

  As described in the preceding response for crude oil/natural gas extraction, the data sources for natural gas production and processing emissions do not report CO_2 emissions. Table A-2 does include atmospheric emissions of methane and non-methane hydrocarbons, e.g., from unflared venting or fugitive emissions.

- FAL would help the reader by listing those points in the various processes where coproducts are generated. In Appendix C benzene is but one product of the BTX section of a refinery; the assignment of common BTX burdens needs to be clearly stated. The citation of chlorine, sodium hydroxide, and hydrogen for a caustic electrolytic cell is made on page D-7. Other coproducts should also be explicitly cited.

  The appendices have been reviewed and a list of coproducts footnoted in the relevant tables wherever allocation was performed.

- The tables in Appendix C generally show inputs equaling outputs with less than 1% (10 pounds out of 1000 pounds of product) unaccounted for. Table C-8 for styrene production shows 1,086 pounds fed and about 1,002 pounds of product and waste. The remaining 84 pounds, 8.4%, are unaccounted for.

  Table C-8 is based on data sets provided several years ago by styrene producers. At the time the data were collected, the mass balance discrepancy was not noted and corrected, so the exact source of the imbalance is not known. Based on a stoichiometric analysis of the data, it appears that the quantities of reagents shown are in excess of the amount required to produce the specified quantity of output. This suggests that the process inputs may have been overreported (for example, failure to adjust for recycling of excess reagents) or that some low-value byproducts or waste products were produced but not reported. Research for a more recent project indicates that styrene tars are used as a fuel source that reduces purchased energy requirements; thus, it appears that the most likely explanation for the mass imbalance is that it does not report outputs of styrene tars used for fuel. This would not affect the accuracy of the LCI results, since the inputs required to produce the tars are reported and the purchased energy requirements reflect the use of the output tars.

- In Appendix D, Table D-4, production of lime, shows 1,875 pounds fed and 1,809 pounds exiting. Table D-14, bleached Kraft pulp, shows 4,932 pounds fed to create 1,298 pounds of pulp and emissions. Clarification is needed. Table D-19, coated paperboard plates, shows 1,094 pounds fed and 1,000 pounds of product and emissions. The mass balances need to be accurate even though the biomass carries only a slight burden and is used as fuel.

  Table D-4: The lime table assumes that five percent of the input mined material is non-$CaCO_3$ material, but we do not explicitly account for this loss in the outputs. Depending on the type and quality of the non-carbonate material and local markets, the five percent may be returned to the land without entering the waste management system, in which case it would not be reported as a waste, or it may become a low-value coproduct which would bear a minimal share of process burdens. Either situation is sufficient to resolve the material balance within a small percent.

  Table D-14: Combustion of wood wastes (e.g., bark, chips) for energy accounts for a portion of the mass inbalance. We can account for this by converting the Btus of wood reported as process energy to a weight of wood (1998 Appendix A uses 4,500 Btu/lb). Moisture, which accounts for approximately 50 percent of the weight of incoming roundwood, is another input that explains the mass imbalance. Also, during the pulping process, lignin is extracted from the wood and ends up in the process liquor; however, further research is required to directly estimate the amount of lignin from wood that ends up in the liquor during *the pulping process. The total weight of wood input reported in Table D-14 has been broken out into subcategories of moisture content, wood wastes burned for fuel, and lignin in process liquor (estimated by difference).*

Table D-19: The 94 pounds of material loss is calculated based on the trim scrap from cutting round plates out of sheets of paperboard. Because paperboard plate manufacturers did not participate in the study, it is not clear whether this scrap is generated before or after the coating process.

If the trim scrap is generated before coating, it is likely that the scrap will be sold as a coproduct, in which case it should carry a small share of the plate fabrication burdens. Fabrication energy accounts for about 4 percent of the total energy requirements for the paperboard plates, so allocation of process energy between 1000 lb of plates and 94 lb of saleable trim scrap would have a small effect on overall energy results for paperboard plates.

If the scrap is coated, it is more likely to be disposed of as a process waste from plate fabrication. Since the solid wastes for paperboard plates are already higher than solid wastes for GPPS plates, this potential omission does not affect the comparison between paperboard and PS plates.

- Water is a raw material for Table D-6, production of sodium hydroxide or chlorine. The coproducts should be listed on Table D-6. Water is also a raw material on Table D-7 for sodium chlorate.

  Table D-6: Our chlorine/caustic table is an average table based on data provided by four manufacturers, representing two electrolysis technologies. The data reported by manufacturers did not include water inputs. Including water use based on stoichiometry brings the mass balance within two percent. Water input based on stoichiometry has been added to Table D-6.

  Table D-7: Sodium chlorate data is based on primary data collected from confidential sources that did not report water use. Water input based on stoichiometry has been added to Table D-7.

- Considerable CO_2 is produced as a coproduct to make ammonium hydroxide fertilizer, Table D-9. The fate of the CO_2 should be stated. Water is also consumed.

  Table D-9: Our sources don't show CO_2 emissions from nitrogen fertilizer production processes. In the paperboard models, the amount of nitrogen fertilizer per output product is so small (on average, about 0.5 lb per 1,000 lb of paperboard product) that even large amounts of CO_2 emissions from fertilizer production would have a negligible effect on conclusions and product comparisons.

- In Appendix E, Table E-3 shows a total input of raw material of about 4,500 pounds of roundwood and wood chips to make 1,100 pounds of linerboard and emissions. Either the 4,500 is in error, or about 3,400 pounds are unaccounted for.

  Table E-3: See response for Table D-14. Table E-3 has been revised to provide a better understanding of the composition and fate of the input roundwood and wood chips.

  Table E-4, production of semichemical paperboard, shows 1,194 pounds fed and about 1,025 pounds of product and emissions.

  Table E-4: This data set represents an average of data sets collected in the early 1990s with material balances that were not corrected at that time. A slight adjustment to the inputs was made in 1997. Based on market data, the roundwood input varies between 70 and 80 percent of wood inputs and the OCC input varies between 20 and 30 percent of input. Table E-4 has been revised to provide a better understanding of the composition and fate of the input roundwood (e.g., moisture content, fuel use).

  There is some recycled material involved on Table E-4, and a clear statement of burden of the recycled paper shared with the original use is needed.

  Each appendix table is a "stand-alone" representation of a unit process. The environmental burdens shown in each appendix table are those that have been allocated to the output of that unit process, in this case the production of semichemical paperboard, with no consideration of what happened to the inputs previously or what happens to the outputs subsequently. Thus, the appendix table reports the total mass of recycled inputs without making any allocations for previous uses of the material. When the unit process data sets are assembled and linked in the modeling process, the upstream burdens for production of recycled material inputs are allocated among the previous use(s) of the material and the postconsumer use of the material. For the corrugated box system, this is a complicated interrelationship, making it difficult to provide a clear statement about the allocation of burdens.

  Recycled content inputs to semichemical paperboard production include postconsumer corrugated containers (composed of postconsumer fiber, preconsumer recycled fiber, and virgin fiber) and recycled preconsumer kraft clippings, which in turn are produced from semichemical medium and virgin linerboard. Because of the complex interrelationships between the various types of fiber inputs and outputs, the allocation of burdens is also dependent on the corrugated box recycling rate. Some of the recycled fiber in the corrugated box has already gone through multiple use cycles, for example, as corrugated boxes *that were recovered and used as inputs to the production of semichemical paperboard, which became an input to kraft paperboard, which became linerboard for a corrugated box, and so on. That fiber is modeled as closed-loop recycling, while the virgin fiber in corrugated boxes that are recovered and recycled is modeled as open-loop recycling. See also the earlier response discussing the corrugated box model.*

The same need of inclusion of shared burden for the recycled component is seen on Table E-7, cup sleeves. The cup sleeves appear to be about 43% recycled content. Again, the input is about 1,320 pounds to produce 1,007 pounds of product and waste. While much of the unaccounted for material is probably used as fuel, the reader is left to guess at that. Specific statements about raw materials used as fuel are needed.

A check of Table E-7 shows a total of 1116.7 pounds of inputs, not 1320 pounds, so the difference between inputs and outputs is about 110 pounds. The table footnote states that inputs are based on assumption of 10% converting scrap, so the remaining unaccounted for imbalance is about one percent. No inputs materials are used as fuel in the converting process. See preceding response regarding allocation of burdens in corrugated model.

- Table E-6 also has 2,000 pounds of raw material to make 1,000 pounds of “linerboard and medium”. The title should say “1,000 pounds of linerboard and 1,000 pounds of medium”. Overall, 2,000 pounds fed result in about 2,065 pounds of product and emissions.

  Table E-6: Title has been changed to indicate that 2 processes (linerboard and medium) are shown. The data are based on confidential industry data and the material balance issue was not identified and resolved at the time of data collection and averaging. It is likely that the solid waste reported consists largely of non-paper(board) contaminants of the input recovered paper(board) supply that are not included in the reported weight of fiber input, and/or sludge (containing short fiber losses and paper coatings) with a high percentage of water.

Report

The panel found the study report to be generally transparent and consistent, but recommends the following to improve the report:

- One of the more surprising findings of this life cycle inventory is that the global warming gas emissions for products such as molded pulp plates and fluted paperboard clamshells are comparable to polystyrene-based equivalent products (Figures ES-15 and ES-16). This finding is surprising since process energy use dominates the life cycle energy profile for these products (Figures ES-3 and ES-

4); roughly 50% of the process energy is wood-based (Table 2-7); and the wood-based energy is not assigned any global warming gas emission burden (page ES-9). The only plausible explanation the panel could find for these results is the release of CO_2 from lime manufacturing (Table D-4). However, the amount of lime use does not seem large enough to account for the results shown in Figures ES-15 and ES-16. FAL should provide some additional explanation in support of this surprising finding.

This is a very insightful question by the peer reviewers. The reviewers are correct in their assessment of the energy sources for the paperboard and plastic systems and the fact that the wood-based process energy for the paperboard systems is assigned no global warming burden. The LCI energy models for clamshells show that more natural gas and electricity are required to make 1,000 pounds of GPPS clamshells compared to paperboard clamshells, while there are significant process coal requirements reported for papermaking but not for the plastic clamshells. The net effect of these fuel profiles is that the GPPS clamshell produces 65 percent more fossil CO_2 emissions per 1,000 pounds of product than paperboard clamshells. However, the average weight paperboard clamshell is more than twice as heavy as the average weight GPPS clamshell. Thus, when the emissions per pound of product are multiplied by the pounds per 10,000 units of product, the total fossil CO_2 is lower for 10,000 units of polystyrene product. The same situation applies to the molded pulp and GPPS plates. Explanation has been added to the report.

- While the panel found the technical approach used in assessing recycling options to be sound, it suggests that FAL provide additional analyses concerning the findings. Specifically, FAL found that a 2% recycling rate produced generally small reductions in the inventoried quantities—not at all surprising for such a small recycling rate. It would be more informative if FAL reported on the ratio of change in inventory requirements to the recycling rate. For example, Table 4-12 shows that for a 2% recycling rate, the reductions in polystyrene and paperboard greenhouse gas emissions are 0.1% and 1.7%, respectively. So, for paperboard, reductions in greenhouse gas emissions scale almost linearly with recycling, while there is almost no reduction for polystyrene. In contrast, Table 4-4 shows that for a 2% recycling rate, the reductions in polystyrene and paperboard energy requirements are more similar, 0.6% and 0.9%, respectively. What are the causes of these differences? Additional explanation for these, and similar findings reported in Chapter 4 would be valuable.

  *For both polystyrene and paperboard systems, the virgin material production burdens and the end-of-life disposal burdens for postconsumer product that is recycled or composted are divided between the initial foodservice use and the secondary use of the material, as explained on page 4-2 in the sections titled **Recycling** and **Composting**. This would suggest that for a 2% recycling or composting rate, there would be a 1% reduction in burdens credited to the* *foodservice product and a 1% credit to the secondary product. However, the reductions in raw material production and disposal requirements are offset by the requirements for collecting and reprocessing the postconsumer foodservice products. The offsetting factors and their differing effects on the net reduction in burdens for polystyrene recycling and paperboard composting are explained in the individual results sections. Net reductions in burdens are summarized at the bottom of Table 4-13.*

- The publicly available 1997 Boustead report for APME, "Eco-policy of the European Plastics Industry; Report 4: Polystyrene" shows 82 MJ/kg of EPS pellet, compared to FAL's 146.3 MJ/kg of molded EPS hot cups. (FAL calculated 6.55 million Btu/104 lb = 146.3 MJ/kg.) Using data available in the current report and drawing unavailable data from older FAL studies, the panel calculated polystyrene values very close to the APME study. This number leads to the surprising, and illogical, conclusion that EPS formation and molding are very energy intensive steps. Since other readers could also perform these calculations, additional explanation would be desirable.

  Based on information provided by EPS product manufacturers, the energy requirements for EPS molding are quite high, as the reviewers suggest. EPS molders were asked to verify the reported energy before the data were used in the LCI. The molding energy data provided and confirmed by manufacturers for this study were also similar to molding energy data from previous LCIs of molded EPS products.

- It is intuitively obvious that any environmental impact of the 16-oz PE-coated paperboard hot cup with sleeve will be higher than that of the cup alone. In fact, the report explains that the impacts of the separate cup and sleeve are added to get the impact of the combination. Therefore, calling a comparison of the two alternatives—cup with sleeve and cup without sleeve—"inconclusive" undermines the credibility of considering data variability in analyzing results. Such comparisons would be better left out of the report.

  Although it is intuitively obvious that a cup with a sleeve would have higher burdens than the same cup without a sleeve, considering the full range of cup weights shows that a cup with a sleeve does not necessarily have higher burdens than a different cup without a sleeve. As shown in Table 2-2, the energy results for the lightest cup with the lightest sleeve are lower than the results for the heaviest cup without a sleeve. The emission comparison table for the average cup with sleeve and the same average cup without sleeve has no value and has been removed from the report.

- By its nature an "Executive Summary" is distributed to a much larger audience than a full report. While this "Executive Summary" does an excellent job of condensing the full report, expanding it to include some additional information from the full report would improve the reader's comprehension. For example, the following report portions might be added: p.1-12, para.4; p.1-14, para.2; p.1-16, para.3; p.1-20, para.3; p.1-22, para.1; p.2-12, para.2; p.2-32, para.2, last sentence; p.2-33, para.2; p.2-42, para.2 and 4; and p.4-16, para.6.

The suggested sections have been added to the appropriate sections of the Executive Summary, with rewording as necessary to fit into the original text. One section, p. 1-14, para.2, was not added, as there did not appear to be a good place in the Executive Summary to insert the suggested discussion of data accuracy without interrupting the flow.

- On page ES-3, replacing the list of products analyzed with the Appendix B "Introduction" list, which is grouped by product category, would help the "Summary" reader understand the categories.

  Suggested replacement has been made.

- Page ES-4 states, "The results include production of foodservice materials…and end-of-life disposal." Unfortunately, the omission of incineration emissions (p.2-33, para.3) is not explained to the reader of the "Summary" only.

  Sentence has been added.

- On page ES-12 the following sequential statements seem in conflict: "The authors discourage the use of this study to make general comparative assertions…" and "The use of this study to make public comparative assertions is limited."

  Language has been added to the ***Conclusions and Observations*** *and* ***Study Limitations*** *sections to clarify the distinction between general comparative assertions of environmental superiority (not appropriate and discouraged by authors) and specific comparative statements supported by study results.*

- Both the executive summary and report need to provide the reader an understanding of the use of post-consumer recycled paper fiber, de-inking technologies and emissions, and bleaching methods used.

  Detail on postconsumer paper and paperboard collection and processing are provided in Appendices E and F. Further description of the paperboard product modeling assumptions relating to recycled fiber has been added in a new subsection, ***Paperboard Product Assumptions****, in the* ***Systems Studied*** *section of Chapter 2.*

- The reader could more easily follow the conclusions in the "Executive Summary" if they were presented in a chart form, such as that shown under "Analysis" in Table 2-32.

Table ES-3 has been added to the Executive Summary, containing the "Analysis" results from the Chapter 2 summary tables.

- The percentage of post-consumer recycled content in the paperboard products should be stated. The use of clay sizing materials and colorants for the paperboard needs to be included or explained why not included. The use of virgin Kraft paper for food contact, or recycled substrate if wax or PE-coated, should be noted as complying with US Food & Drug Administration regulations.

  As noted in the report, the paperboard industry declined to participate in any way in this study, including providing information on the composition of paperboard products and their secondary packaging, process data for bleached and unbleached paperboard production, process data for fabrication of paperboard products, etc. In the absence of such information from the paperboard industry, the following approach was used to model paperboard foodservice products:

  - *All paper products with the potential to have direct contact with food were modeled with no postconsumer content. This includes the bleached paperboard used in cups, plates, and the inner and outer surfaces of the clamshell, and the unbleached corrugated medium layer of the clamshell. The recycled pulp used in molded pulp plate production is clean preconsumer scrap that does not require deinking.*
  - *Composition of non-food-contact paperboard products (external cup sleeves and the corrugated boxes used for secondary packaging) was modeled using paperboard industry statistics on recovered paper and paperboard inputs to corrugated linerboard and medium.*
  - *Bleached paperboard production was modeled as using elemental chlorine free technology, based on recent paperboard industry publications.*
  - *No data were available on quantities and composition of colorants, sizing, fillers or printing inks used in the various foodservice products, so no inputs of these materials were modeled. Previous studies of paperboard foodservice products have not indicated use of clay sizing. Previous studies of similar products also indicate that printing inks and colorants generally comprise a very small weight percent of the product with negligible effect on results.*

  *This text has been added as a new subsection, **Paperboard Product Assumptions**, in the **Systems Studied** section of Chapter 2.*

- FAL reports energy consumption data as material resource, transport, or process energy. The same should be done for air and water emissions. Often a choice of fuel is possible so that at least some of the emissions cited are discretionary. The reader should know which emissions are inherent to the subject being studied and which emissions might be reduced through other choices of fuel or transportation.

Our LCI models are set up to separately quantify life cycle emissions released directly from processes and life cycle emissions associated with the production and combustion of fuels. The fuel-related emissions include the emissions associated with both process energy and transportation energy. Emissions tables have been added showing the percentages of process emissions and fuel-related emissions for each substance.

- Since maximum secondary packaging weights were selected for use in analyses, why were average weights included in Tables ES-2, 3-1, and B-2? Average weight inclusion is confusing to the reader.

  Agreed that the average weights shown do not serve a useful purpose and have been removed from the tables.

- Tables 2-22 through 2-31 present an interesting assessment of the data, but a flawed one. The summaries make the implicit assumption that all emissions are of equal weight and that is obviously not true. The text needs to state that the comparisons shown on these tables are not a life cycle impact assessment and only one simplistic way of examining the data.

  Agreed that reader may make implicit assumption described by reviewers. Text has been added to clarify the intent and caution the reader against drawing overall environmental performance conclusions based on these tables.

- Most of Appendix B is already in the body of report. The remainder of Appendix B should be moved into the report and Appendix B deleted. Including in the report the methodology for calculating secondary packaging weights would answer many report reader questions.

  The Appendix B description of the process by which the range of sample weights was determined has been added to the ***Systems Studied*** *section of Chapter 2. The Appendix B discussion of secondary packaging weight data has been incorporated under the* ***Systems Studied*** *section of Chapter 3.*

- It would also be helpful to the reader if the paper plate grade definitions on page D-27 were included in the report.

  This has been added under the ***Systems Studied*** *section of Chapter 2.*

CONCLUSIONS

The panel finds the study to generally comply with ISO 14040 series standards. FAL has clearly delineated the goals, scope, and boundaries of the project. Overall, the data sources are appropriate and generally reliable. The methodology is transparent, and scientifically technically sound. The results are data-based. Recognizing data uncertainty in the interpretation of results is particularly welcomed. FAL has appropriately based its conclusions on the data and analysis.

INITIAL PEER REVIEW
FRANKLIN ASSOCIATES, LTD.
FOODSERVICE PACKAGING LCI

Peer Review Comments
And
Franklin Associates, Ltd. Response

Prepared for

Polystyrene Packaging Council
(PSPC)

by

Dr. David Allen
University of Texas

David Cornell
D. D. Cornell Associates, LLC

Beth Quay (Chair)

and

Franklin Associates, Ltd.

August 28, 2002

At first glance this page is confusing. "…and Franklin Associates, Ltd." makes it appear FAL helped write the report. We suggest that we (1) return to the original cover page submitted; (2) drop "Prepared for…(PSPC)"; (3) change "by" to "Report Prepared By"; and (4) add "Response Prepared By Franklin Associates, Ltd.".

INTRODUCTION

At the request of the Polystyrene Packaging Council (PSPC), the consulting firm of Franklin Associates, Ltd. (FAL) is expanding and updating a life cycle study FAL conducted for the Council of Solid Waste Solutions in 1990. This foodservice packaging life cycle inventory (LCI) will focus on cups, plates, clamshells, and trays.

In accordance with ISO 14040, FAL has retained a panel to independently peer review its work. To improve study quality, FAL has asked this panel to review the following five areas at the beginning of the study: goal, target audience, scope, boundaries, and data collection approach. A copy of the initial information provided to the panel for review is attached at the end of this document. The panel will later be asked to review any assumptions before modeling begins and the draft report after FAL completes the LCI.

Following are the peer review panel comments on each area. FAL's responses to each comment are italicized.

COMMENTS

Goal

FAL states that the goal is to update the 1990 study to include more recent data on materials originally considered, to consider newly developed materials, and to complete the study in accordance with current ISO standards. Though the information provided to the panel infers that the study may be used to make comparative assertions, this goal is not explicitly stated. ISO 14040:1997 includes more stringent requirements for an LCI making comparative assertions. If part of the study's goal is to make such assertions, it should be decided and explicitly stated at the beginning of the study.

The goal of the study itself does not include using study results to make comparative assertions, and PSPC has in fact given its members the following guidelines: "Study sponsors may use the final report to make specific statements about their product systems only if the statements are supported by the Life Cycle Inventory (LCI) results and are accompanied by a reference to the publicly available full report. Use of the study results for advertising purposes (e.g., public assertions or comparative assertions) must comply with Federal Trade Commission (FTC) Guides for the Use of Environmental Marketing Claims (16 CFR Part 260) and ISO guidelines. ACC, APC, PSPC and its members and Franklin are not responsible for use of the study results by any party in a way that does not conform to the guidelines described herein."

PSPC is part of the American Chemistry Council (ACC), and it is ACC policy to make publicly available any reports sponsored by a member organization; thus, the necessity of a peer review was predetermined. It is likely that the study results, when made publicly available, may be used by interested parties to make comparative assertions. The study *will therefore include a section similar to PSPC's guidelines for responsible use of study results by interested parties.*

Based on FAL's response the panel feels the study must conform to ISO requirements for LCI studies making comparative assertions.

Target Audience

FAL clearly states two intended audiences: food industry stakeholders and interested public parties.

Scope

FAL establishes the scope of the study as four package types—hot and cold cups, plates, clamshells, and meat/poultry trays—made of three materials (polystyrene foam, paperboard, and bio-based products). Why packages made of other plastic materials and why reusable cups/plates are not included in the study is not clear. Omission of such alternatives may open the study to public criticism.

The package types evaluated in the study were selected by the study sponsor. The sponsor selected the products that were of interest to them based on the original 1990 study and the currently predominant competing and emerging products in disposable foodservice markets.

FAL also does not indicate what the "bio-based product(s)" is. If more than one bio-based material is currently being marketed, or is anticipated to be marketed, the justification for choosing a specific product needs to be included.

The bio-based product to be evaluated is EarthShell, which is the only bio-based product that currently has any notable penetration in the marketplace. Only EarthShell plates and clamshells are commercially available at this time.

FAL notes the study will cover a range of product weights—results essential to performing ISO 14041:1998,7 required sensitivity analyses. However, FAL notes that only one weight will be evaluated for each of the bio-based containers. The panel questions this approach since at the very least the next generation of light-weighted bio-based packages should be forecast and evaluated.

The scope of the study does not include forecasting lightweighting trends for bio-based products. If lightweighting projections were to be made for bio-based products, similar projections would have to be made for all competing material products.

FAL states that consumer use patterns will not be considered in this study due to scope and budget constraints. However, how can an equivalent functional unit be selected without considering such information? Personal experience indicates a consumer will probably use only one cold cup, clamshell, or meat/poultry tray on a given occasion, so study results for these packages are not affected by use patterns. But use patterns among different types of plates and hot cups can vary significantly. It would seem consumer use data must have already been collected by large food chains/managers such as McDonald's, ARA, and Marriott to forecast purchasing requirements, and should be solicited and considered.

We agree that use patterns for plates and hot cups are much more variable than for cold cups, clamshells, and meat/poultry trays. However, we have not been able to find any performance standards for plates and hot cups that could be used for developing equivalent use definitions (e.g., standards for use based on maximum load strength of paper plates before failure or insulating properties of paper cups that would indicate at what beverage temperature insulating sleeves or double-cupping is required to protect consumers). In the absence of such standards, empirical observations of equivalent use would be based on specific use applications, e.g., a certain load of food, or beverage at a certain temperature. Equivalent use definitions would differ for different specific applications. For example, at load A, plates 1, 2, and 3 may all perform acceptably, while at load B, plates 1 and 2 hold up to the load, but plate 3 fails or must be doubled.

We will solicit consumer use data from the sources recommended by the peer review panel; however, the scope of the project does not include development of consumer use data. In the event that such data are not readily available, the study systems have been set up to facilitate likely equivalent use comparisons to the extent possible. For example, the heaviest weight (thicker) hot paper cup results can be compared to results for lower weight (thinner) paper cups with insulating sleeves or double-cupping.

Particularly for hot cups, results need to be presented in a "building block" style. For example, present the results for the basic cup, then additional requirements for insulating sleeves, instead of one result with sleeve use assumed. Such secondary packaging use is a very real issue for hot cups. Seattle's Finest provides a roll of butcher block paper customers can tear from to wrap their "too-hot-to-handle" paper cups. The company has obviously evaluated consumer use and found the paper to be cheaper than a second cup. In fact, this company might be a good source of consumer use data.

A subtle additional issue regarding functional unit arises. Are different amounts of ice used for cold drinks in different cup types because of different insulating properties? Are hot drinks heated hotter for one type of cup versus another? Energy use implications could be significant. If not to be treated by the LCI, these should be noted as areas for future study.

It is expected that users will not adjust the properties of the beverage delivered to suit the properties of the cup, but will select the cup with properties to accommodate the beverage delivered. The range of results for each product will be accompanied by information on the range of weights represented so that study participants and interested parties can identify approximately where the products they produce or use fall in the range of results.

The second sentence of this paragraph does not clearly relate to the original comment.

Boundaries

FAL provided very little information on boundaries, probably because of its extensive experience and databases. We list the following issues to ensure they are being considered:

- Farming practices to support the bio-based product may vary significantly among producers. How will this variability be handled? How will the information on farming processes be obtained? Will pesticides, herbicides, fertilizers, and other chemical agents used in farming be included in the bio-based analysis? Will the study attempt to estimate the material flows associated with erosion, water use, or land use requirements to support the bio-based product?

  Unless specific information on supplier farming practices is provided by the bio-based producer, FAL industry average farming data, which include production and use of fertilizers and estimated waterborne emissions of pesticides and herbicides, will be used. Because of the lack of availability of good data on water use for unit processes, the FAL LCI database does not include water use. If the bio-based producer or their suppliers report substantial quantities of water used for irrigation, water use for farming can be reported, although the report must also then note that data are not available on water use for other processes in the life cycles of the foodservice products. FAL farming data do not include land use and erosion.

  It is disappointing that water use will not be covered.

  Another potential data category recently brought to the panel's attention is use of genetically modified plants. If the environmental community has not already expressed interest in this area, it probably will in the future.

- Previous FAL studies have made comparisons between petroleum and paper-based products more complex because of the convention of treating feedstock petroleum as an energy input. What convention will be used in this study? Will wood and inputs to the bio-based product be handled in energy equivalent units or as resource flows?

  FAL will continue to report the energy value of fuel resources used as material inputs. Since wood and bio-based materials are used in this country predominantly as material resources rather than fuel resources, their energy value will be reported only if the materials are actually used as fuel (e.g., use of wood wastes and black liquor as fuel at pulp mills).

It is disappointing that some of the material use data will be embedded in the energy information. The panel hopes that the LCI data can be formatted in a way that will facilitate material use analysis.

- Assumed solid waste disposal methods can significantly affect LCI results. Composting should only be recognized to the extent it is actually practiced on paper and bio-based food service ware. In the same way, only actual food service ware plastics recycling should be considered. Since most products will be landfilled, density differences should be noted. When incinerated, paper and polystyrene will have different Btu values.

  Actual current recycling/composting levels for foodservice products will be determined. If currently practiced at significant levels, recycling and composting will be modeled for the appropriate foodservice products. Landfill densities of each material will be used in developing landfill weight and volume data for disposed products. Systems will be credited with the amount of energy recovered from waste-to-energy incineration of disposed products based on the higher heating values of the materials.

- Paper products can be manufactured from virgin or recycled pulp. Virgin pulp may come from pulp wood farms or mixed forests, and may be imported or US-derived. Recycled pulp may be from pre-consumer or post-consumer waste, and will contribute significant waste streams within the pulp mill. Identifying a reasonable allocation procedure for recycled pulp discharges and waste treatment may be difficult.

  In the data collection process, paper product manufacturers will be contacted for information on the types and sources of pulp used in their products. We will then try to collect data from the supplying mills. If the supplying mills do not provide data, we will use U.S. pulp data from the FAL database, which contains data sets for both virgin and recycled pulp.

Data Collection Approach

FAL does not specifically state the data quality requirements (required by ISO 14040:1997,5.1.2.3), including:

- Time-related coverage
- Geographical coverage
- Technology coverage

This study will consider packages from three very different industries—one in its infancy. From what time periods can data be collected and considered equivalent? What is an acceptable range of years to represent “state-of-the-art” for each material? How far into the future will light-weighting be projected to reflect technology improvements?

Will the data be US-specific? Guidelines need to be set so that all industries can provide comparable data.

All foodservice product industries represented in the study are being given the opportunity to participate in the study and provide state-of-the-art, U.S.-specific data on their product/material. T he study will cover only currently available products; there are no plans to make projections on lightweighting or technology improvements for any systems. We are currently working closely with producers of EPS foam resin and EPS foam products, the bleached paperboard industry, and EarthShell to bring their most current data into the study.

The data quality will thus depend on participation. Should any industry decline to provide current data on their products, FAL's U.S. industry average data for that material will be used. Data quality in terms of time, geographical, and technology coverage will be reported for each material/product; however, data quality may not be equivalent for different systems, depending on industry participation and the quality of the most current existing FAL data. Any such differences in the quality of data used to represent the various product systems, and the reasons for the differences, will be noted in the report.

The panel is very concerned that the data be collected in a way that assures it is comparable across different industries. "State-of-the-art" can mean different things to different people. To some, it will mean the data they collect today on their processes specifically for this study. To others, it will mean the industry data readily available to them, but that is five years old. To still others, it may mean the new process they are installing 9 months from now (with equipment already on order), but have already theoretically evaluated. It is imperative that data guidelines be provided to those from whom data is requested. We recommend these guidelines include specifying data source.

For reference, since the study may be used to make comparative assertions, ISO 14040:1997,5.1.2.3 and ISO 14041:1998,5.3.6 also require the following information be included:

- *Data Precision*
- *Data Completeness*
- *Data Representativeness*
- *Data Sources*
- *Data Uncertainty*
- *Consistency of Methods*
- *Reproducibility of Methods*

ATTACHMENT: INFORMATION SUBMITTED TO PANEL FOR REVIEW

FIRST ITEMS FOR PEER REVIEW: REVIEW OF STUDY GOAL, SCOPE AND BOUNDARIES, AND DATA COLLECTION APPROACH

Goal and Intended Audience: This life cycle inventory (LCI) of selected polystyrene foam, paperboard, and bio-based foodservice items is an expanded update of a 1990 LCI on foam polystyrene and bleached paperboard foodservice items. The study is being updated to incorporate the following changes that have occurred since the original study:

- Changes in materials, including the development of bio-based containers
- Improvements in manufacturing processes and energy usage
- Development of ISO standards for conducting life cycle inventory studies
- Limitations on making comparative assessments or claims in the marketplace.

The purpose of the study is to gather the most up-to-date information on these foodservice items and use the data to develop life cycle profiles for the product systems. The profiles developed will provide foodservice industry stakeholders with a fair, accurate, and comprehensive database from which improvements can be made.

The primary intended audience for the report is foodservice industry stakeholders; however, in keeping with ACC policy, the final report will be publicly available upon request to any interested party.

Study Scope and Boundaries: The LCI will analyze polystyrene foam, paperboard, and bio-based foodservice items that are available in each of the following categories: cups for hot and cold beverage applications, plates, sandwich clamshells, and meat trays, as well as any associated ancillary items that are used with certain systems to achieve equivalent functionality (such as fluted paperboard sleeves for paperboard hot cups and absorbent pads for polystyrene foam meat trays). Packaging for shipment of finished products will also be included.

The study will quantify energy and resource use, solid waste, and individual atmospheric and waterborne emissions for the life cycle of each product system, from raw material extraction through ultimate disposal. Current levels of recycling and composting will be evaluated where applicable. The study will not attempt to draw conclusions about the environmental impacts of product systems.

The functional unit is initially defined as an equivalent number of product units of the same size or capacity (see table of products for analysis), along with the corresponding quantity of any ancillary materials used with the product to achieve comparable functionality. For example, 10,000 32-oz polystyrene foam cold cups would serve the same function as 10,000 32-oz coated paperboard cold cups. Ten thousand molded pulp meat trays would provide the same function as 10,000 polystyrene foam meat trays with

10,000 absorbent pads (needed to provide the absorbency that is inherent in the molded pulp trays).

The analysis will evaluate the range of product weights available in each product/material category. (In the case of the bio-based products, there is only one product configuration in each product category, so there will not be a range of product weights.) For example, in the product category of 9" uncompartmented plates, results will be shown for the bio-based plate, for the range of weights of EPS foam plates, and for the range of weights of bleached paperboard plates. The intent of the project is not to select one representative sample from each product/material category to compare against a competing material product, e.g., no single EPS foam plate will be selected for comparison against any single paperboard plate or against the bio-based plate. Differences in performance characteristics within the range of products in each material category will be described if data are available to quantify the differences (e.g., in load strength, capacity, etc.). **The scope of the project does not include testing products for strength, insulating properties, etc., nor developing data on consumer use practices.**

Using the range of product weights for an equivalent number of units in each product/material category appears to be the only practical way to model the systems. It is not practical to attempt to model all possible comparative scenarios in each product category. Using plates as an example, all plates can be compared on a one-to-one basis in light to moderate loading applications where all plates can support the load without failing. However, in heavier loading applications, only certain plates may be capable of supporting the greater load. In this case, the less sturdy plates either could not be used, would have to be used in multiples, or would need to be used with some type of supporting tray or basket. In order to conduct an equivalent functional comparison of specific plates in this type of situation, the loading application would need to be specifically defined, and data would be needed on maximum loading of each plate before failure, as well as data on consumer use practices for weaker plates in heavy load applications (i.e., not used, double plates used, or single plates used with an ancillary supporting container that would then also have to be included in the analysis). The scope and budget of this project does not allow for this type of sensitivity analysis. Presenting the range of results for each product/material category will allow limited sensitivity analysis; for example, a multiplier of two could be applied to results for the lightest plate in a material category to compare double plate use with the results for the heaviest plate within the same material category.

Data Collection Approach: Our goal is to represent each product system as accurately as possible. To that end, we are contacting the major companies that produce each foodservice product and requesting their cooperation in providing data on product fabrication and packaging for use in the study. We will similarly contact the companies that supply the materials used by the product companies (e.g., producers of polystyrene resin, paperboard, wax and polyethylene coatings, etc.).

Should any foodservice product/material industry decline to provide data on their system for this study, that system will be represented in the study based on an independent compositional analysis of the product and Franklin Associates' industry average life cycle data on the component materials in the appropriate weight percentages. The study will represent the range of product weights available in each product category, based on product weight data obtained through company data sources, including product specifications published on the internet, or weight measurements of product samples. Data quality documentation consistent with ISO 14040 Section 5.1.2.3 will be provided to the extent possible.

QUALIFICATIONS AND LCA EXPERIENCE OF PEER REVIEW PANEL MEMBERS

The panel who performed the peer review of the report **Life Cycle Inventory of Polystyrene Foam, Bleached Paperboard, and Corrugated Paperboard Foodservice Products** consisted of the following members: Beth Quay, chair, Dr. David T. Allen, and David D. Cornell. Their educational backgrounds and professional experience and qualifications are summarized below.

Beth H. Quay

Ms. Quay, formerly Director of Environmental Technical Affairs for The Coca-Cola Company in Atlanta, Georgia is an owner/manager of a family business, Antique & Surplus Auto Parts.

She is also an independent consultant to industry and has chaired five Life Cycle Inventory peer review teams. As chair of peer review teams she reviewed the draft LCI reports and appendices, developed a consensus report for the team, and represented the peer review team on issues raised during the peer review.

Ms. Quay's LCA experience at The Coca-Cola Company included managing and coordinating LCAs of beverage packaging and delivery systems. She participated in the SETAC "Code of Practice" Workshop in Sesimbra, Portugal in 1993, where she chaired the team that developed Chapter 6, "Presentations and Communications." She also served as a member of the U.S. EPA LCA Peer Review Groups on Impact Analysis and Data Quality and participated in the SETAC Workshop, "A Technical Framework for Life Cycle Assessment," in Smuggler's Notch, Vermont in 1990.

Ms. Quay's background at The Coca-Cola Company also included management of environmental issues in company operations worldwide, including evaluation of environmental impacts of proposed packaging designs and development of recycling programs and comprehensive waste management solutions. She represented The Coca-Cola Company at environmental conferences and with industry environmental groups.

Ms. Quay has a Bachelor's Degree in Industrial Engineering (Summa Cum Laude) from Georgia Institute of Technology and has done graduate work in Applied Statistics.

David T. Allen

Dr. David Allen is the Gertz Regents Professor of Chemical Engineering and the Director of the Center for Energy and Environmental Resources at the University of Texas at Austin. His research interests lie in air quality and pollution prevention. He is the author of six books and over 150 papers in these areas. The quality of his research has been recognized by the National Science Foundation (through the Presidential Young Investigator Award), the AT&T Foundation (through an Industrial Ecology Fellowship), the American Institute of Chemical Engineers (through the Cecil Award for contributions to environmental engineering), and the State of Texas (through the Governor's Environmental Excellence Award). Dr. Allen was a lead investigator in one of the largest and most successful air quality studies ever undertaken: the Texas Air Quality Study (www.utexas.edu/research/ceer/texaqs). His current research is focused on using the results from that study to provide a sound scientific basis for air quality management in Texas. In addition, Dr. Allen is actively involved in developing Green Engineering educational materials for the chemical engineering curriculum. His most recent effort is a textbook on design of chemical processes and products, jointly developed with the U.S. EPA.

Dr. Allen has extensive experience in LCA and has served on a number of peer review panels of LCIs. He has taught short courses on LCA for government agencies, private companies and in continuing education programs.

Dr. Allen received his B.S. degree in Chemical Engineering, with distinction, from Cornell University in 1979. His M.S. and Ph.D. degrees in Chemical Engineering were awarded by the California Institute of Technology in 1981 and 1983. He has held visiting faculty appointments at the California Institute of Technology, the University of California, Santa Barbara, and the Department of Energy.

David D. Cornell

Mr. Cornell, P.E. is an independent consultant as D.D. Cornell Associates, LLC. He provides technical assessments, economic modeling and feasibility studies. One specialty of his is providing technical advice on plastic stewardship and environmental issues management to various clients.

Prior to establishing his consulting practice he worked for Eastman Chemical Company where among other assignments he was Manager, Plastics Technology and Recycling. He developed significant expertise in Life Cycle Assessment while at Eastman Chemical Company as part of his assignments in the environmental area, and evaluating plastic containers. At Eastman Chemical he was responsible for diverse assignments including issues management, communication of technical information, and innovative chemical recycling processes. He has received 14 USA patents. He has participated extensively on environmental issues with numerous industry, government and NGO organizations. Prior to joining Eastman Chemical he was a Materials Applications Engineer with General Electric Company.

Mr. Cornell holds three degrees: a BS in Chemical Engineering and a BA in Mathematics from the University of Delaware and an MS in Material Science from the University of Cincinnati.