

**FINAL PEER-REVIEWED REPORT**

**EXECUTIVE SUMMARY**

**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), 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.

## **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 Mfirs	No. of Samples	Low Wt (g)	High Wt (g)	Avg Wt (g)	Avg Wt in lb per 10,000 units
<b>16 oz Hot Cups</b>						
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
<b>32 oz Cold Cups</b>						
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
<b>9 inch Plates - High Grade</b>						
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
<b>Sandwich-size Clamshells</b>						
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
<b>16 oz Hot Cups</b>						
EPS Foam						
Mfr 1	500		37.7	70.3		
Mfr 2	500		40.8	63.9	37.7	<b>70.3</b>
PE-coated Paperboard						
Mfr 1	500			44.6	44.6	<b>50.4</b>
Mfr 2	500			50.4		1.4
<b>Unbleached Corrugated Cup Sleeves</b>	1200			35.2	35.2	<b>35.2</b>
						no data available
<b>32 oz Cold Cups</b>						
EPS Foam						
Mfr 1	500		70.6	108.5		
Mfr 2	500			95.4	70.6	<b>108.5</b>
PE-coated Paperboard	480	62.5			62.5	<b>62.5</b>
Wax-coated Paperboard	480	62.5			62.5	<b>62.5</b>
<b>9 inch High-Grade Plates</b>						
GPPS Foam - Laminated Coated Paperboard	500		43.8	74.0	43.8	<b>74.0</b>
Mfr 1	500			41.4		0.7
Mfr 2	500			41.4	41.4	<b>41.4</b>
Uncoated Molded Pulp						
Mfr 1	500			42.3		0.8
Mfr 2	500			37.8	37.8	<b>42.3</b>
<b>Sandwich-size Clamshells</b>						
	<b>actual case</b>					
5 inch GPPS Foam	500		35.8	71.9		3.4
5 inch Corrugated Paperboard	702		25.6	29.9		1.6
	<b>normalized</b>					
5 inch GPPS Foam	600			66.0	35.8	<b>71.9</b>
5 inch Corrugated Paperboard	600			33.4	25.6	<b>33.4</b>

(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 and 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)

	<u>ENERGY</u>	<u>SOLID WASTE - WEIGHT</u>	<u>SOLID WASTE - VOLUME</u>	<u>GHG</u>
<b>16 OZ HOT CUPS</b>				
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)
<b>32 OZ COLD CUPS</b>				
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
<b>9-INCH HIGH-GRADE PLATES</b>				
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
<b>5-INCH SANDWICH-SIZE CLAMSHELLS</b>				
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**

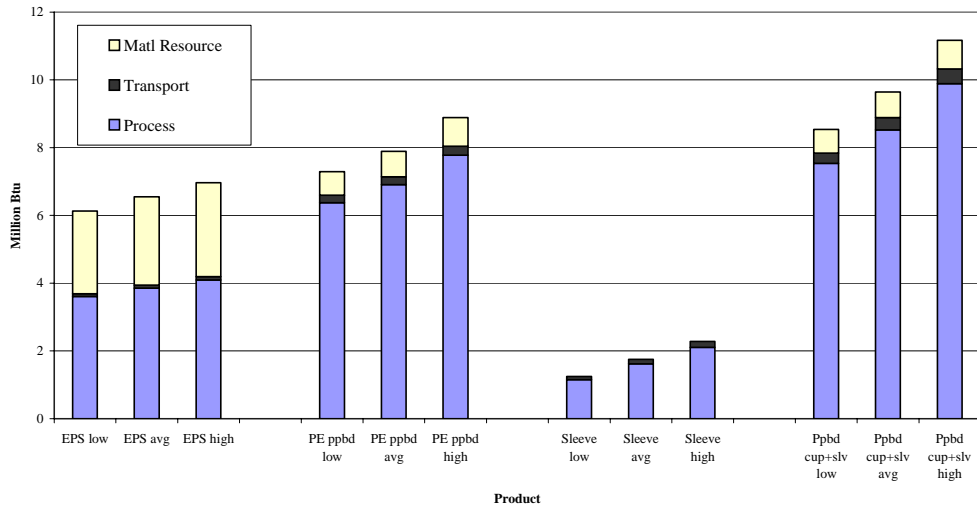
For all foodservice materials in all categories, two percent recycling or composting reduces total environmental burdens by two percent or less. The percent reduction for recycling is less than one percent, since some of the savings in virgin material production burdens are offset by the burdens for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

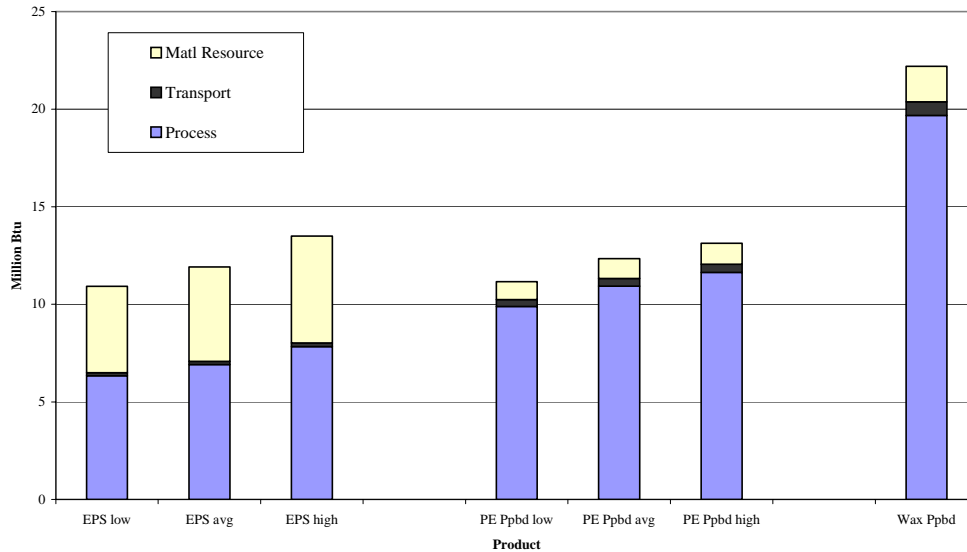
Although the methodology for this study is compliant with ISO standards, it was not possible to meet some of the ISO data quality requirements due to the limited participation by some industries. In particular, this study does not meet all the stringent data quality requirements set out in the ISO 14040 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)**



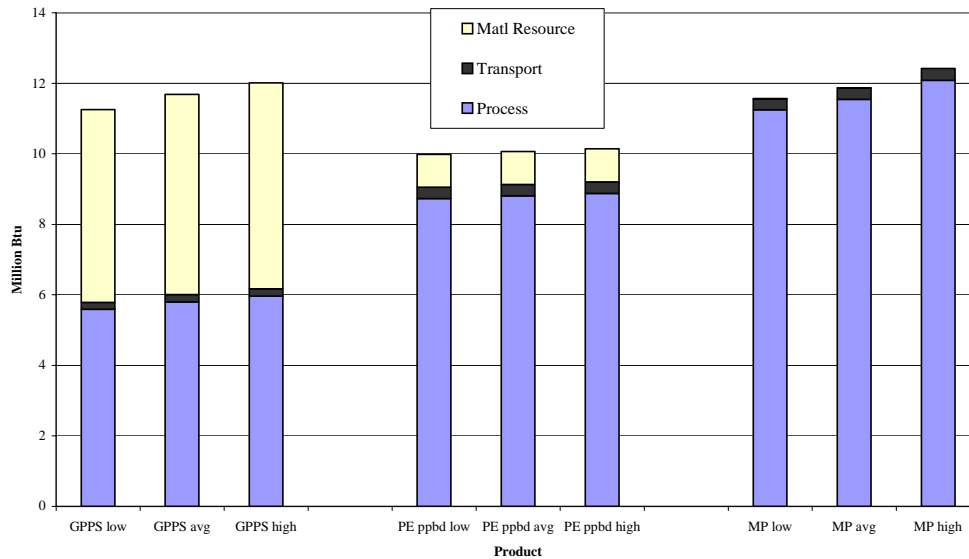
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in energy results for products in different material categories or for different weight products in the 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)**



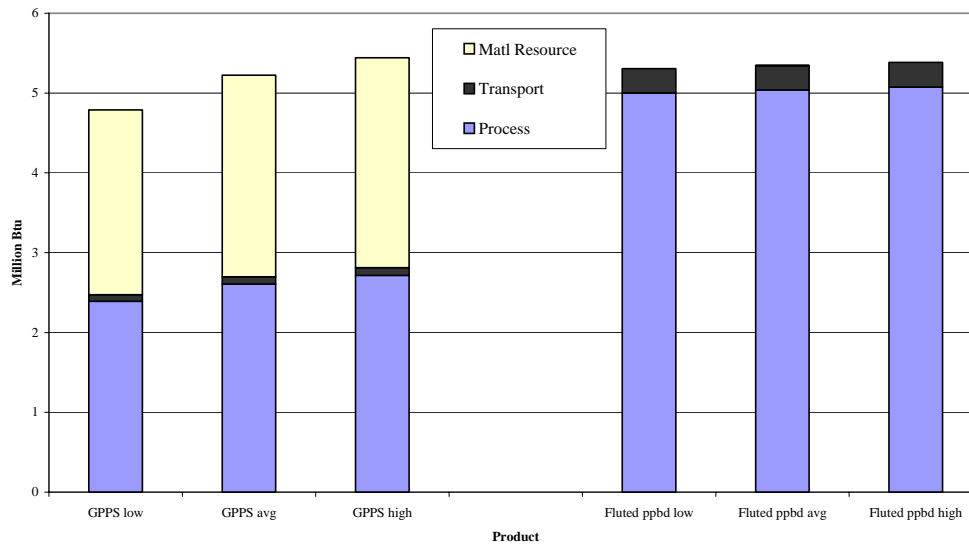
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in energy results for products in different material categories or for different weight products in the 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)**



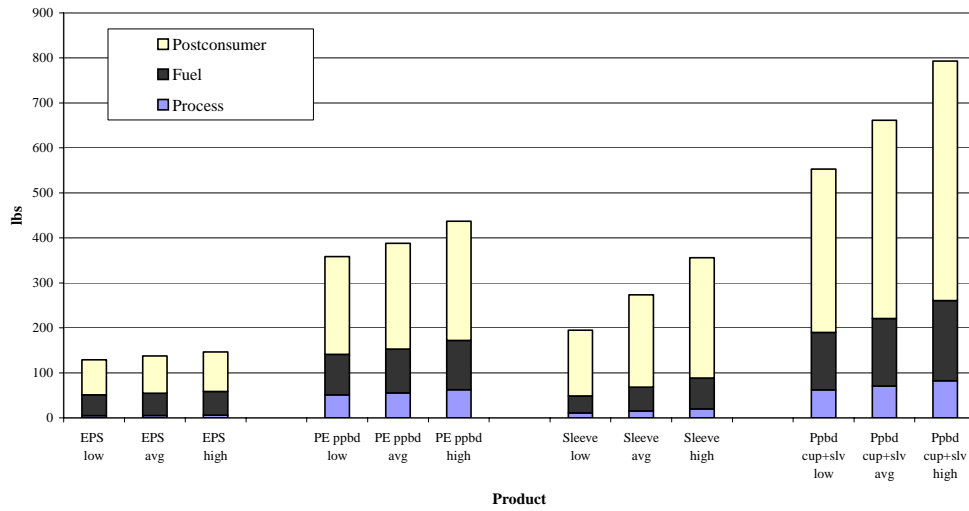
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in energy results for products in different material categories or for different weight products in the 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)**



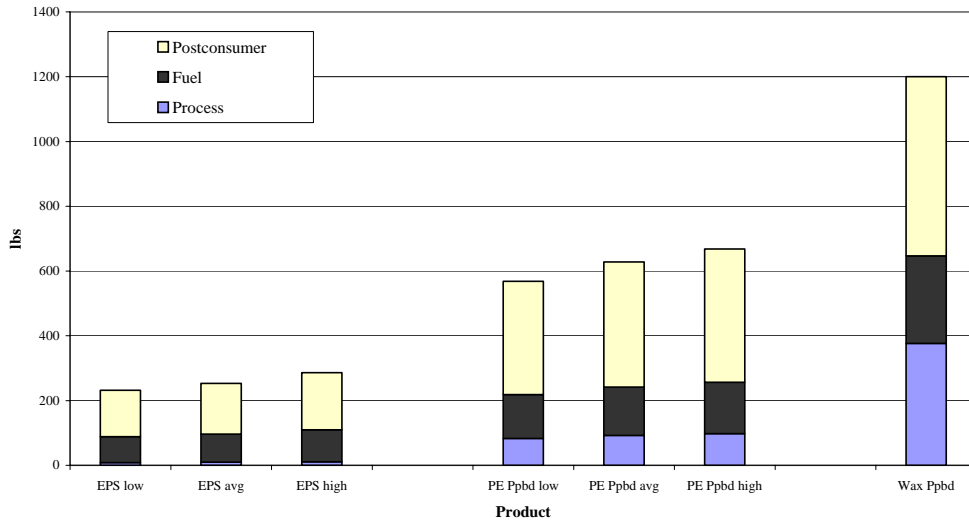
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in energy results for products in different material categories or for different weight products in the 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)**



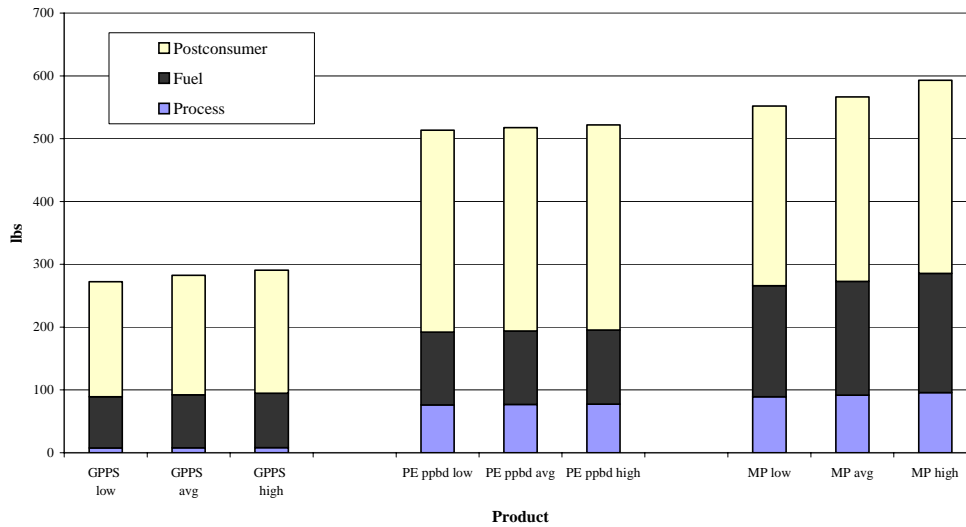
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in 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)**



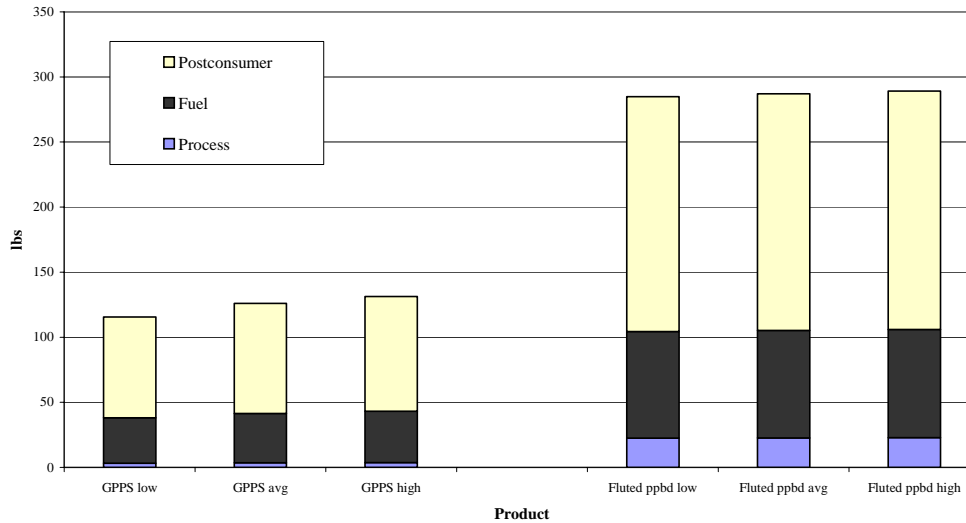
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in 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)**



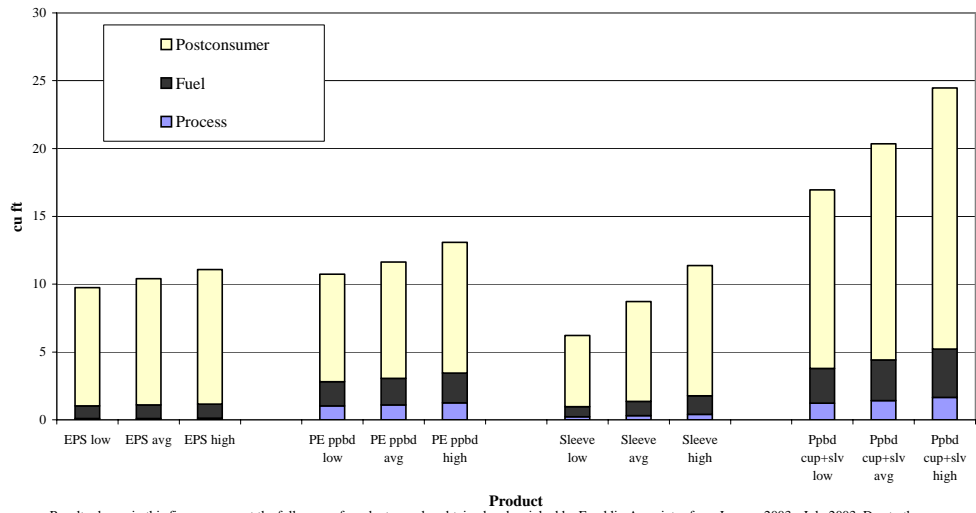
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in 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)**



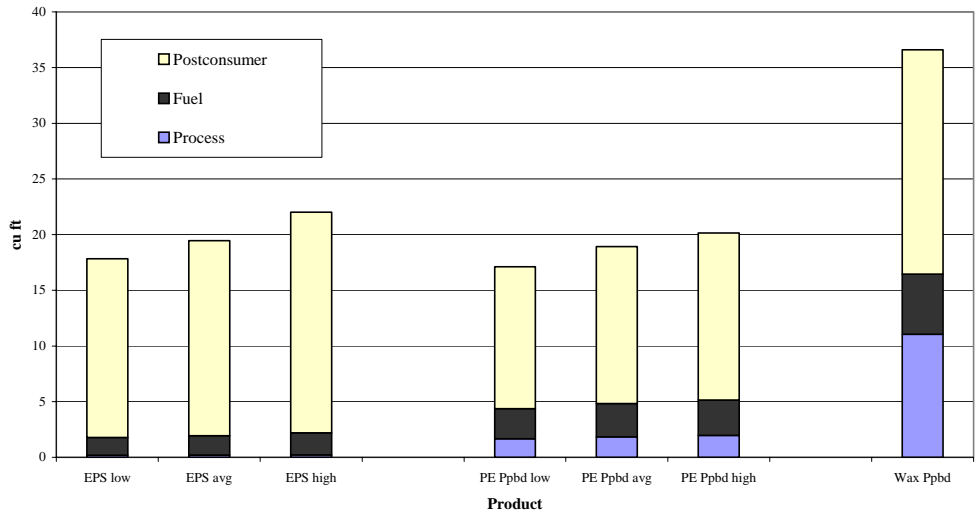
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in 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)**



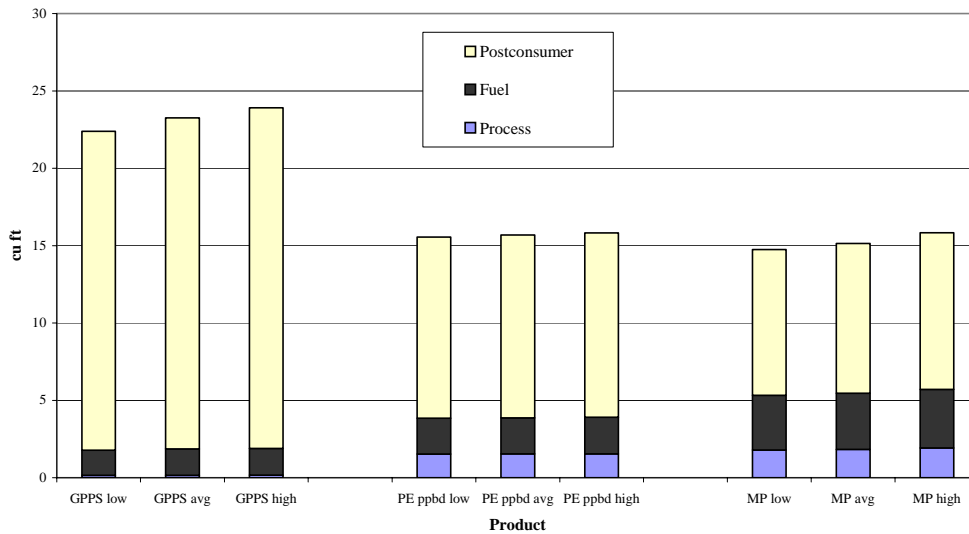
**Product**  
 Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight 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)**



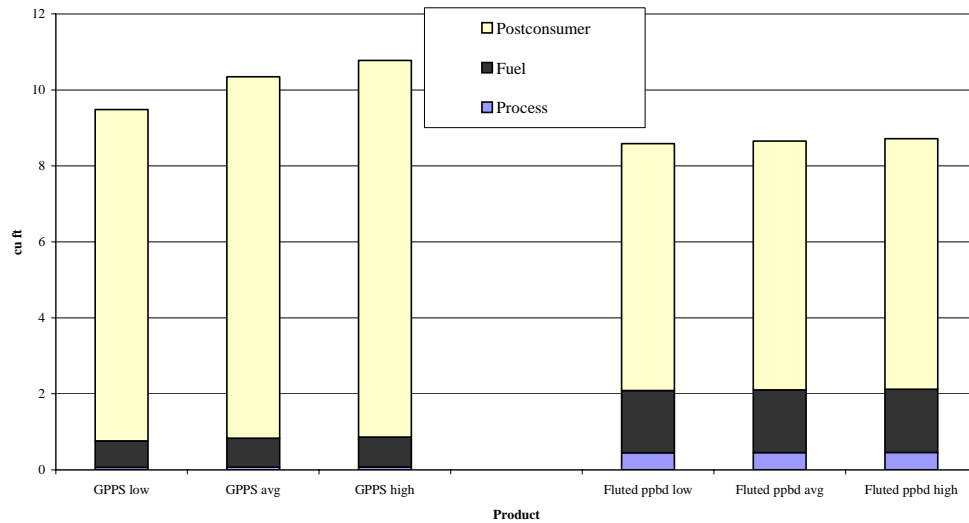
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in 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)**



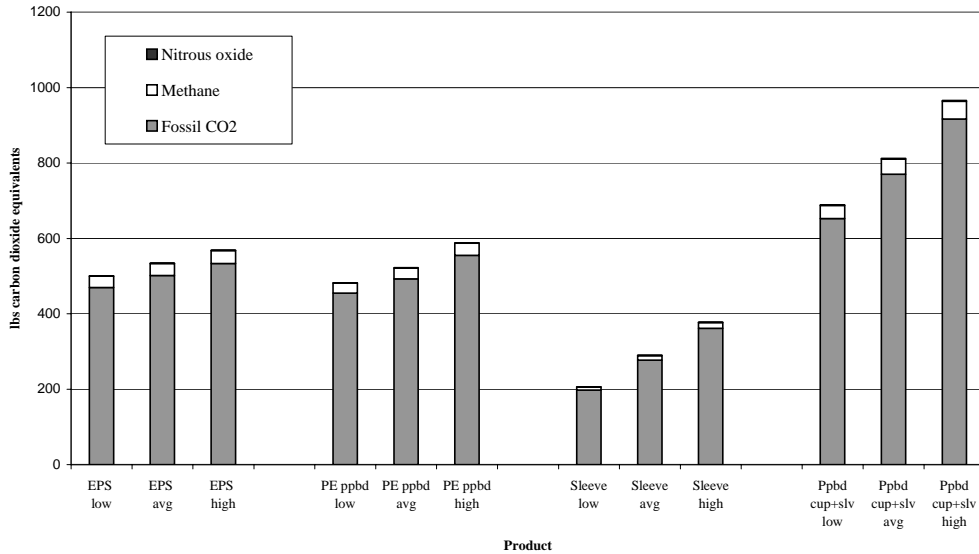
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in 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)**



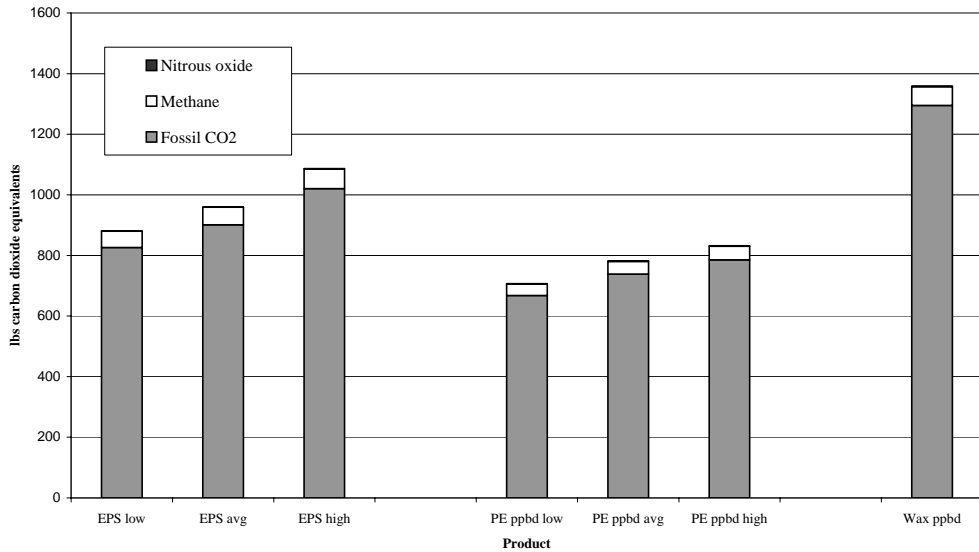
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in solid waste results for products in different material categories or for different weight products in 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.

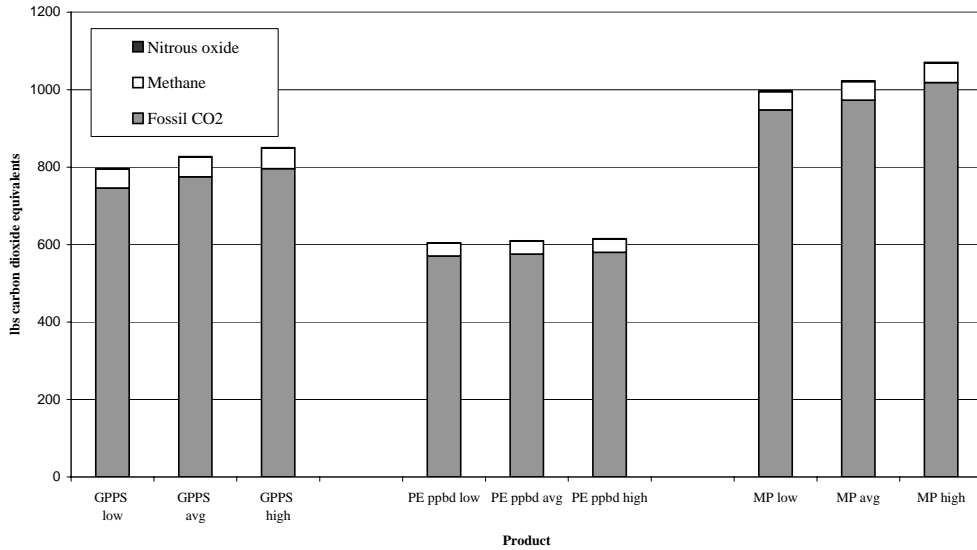
**Figure ES-14. Atmospheric Emissions for 10,000 32-oz Cold Cups  
(lbs carbon dioxide equivalents)**



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.

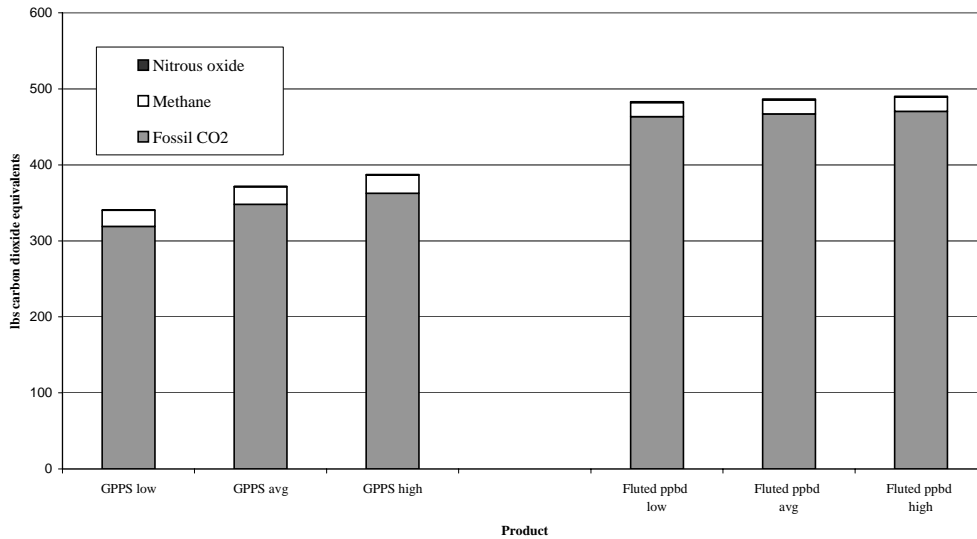


**Figure ES-15. Atmospheric Emissions for 10,000 9-inch High-Grade Plates  
(lbs carbon dioxide equivalents)**



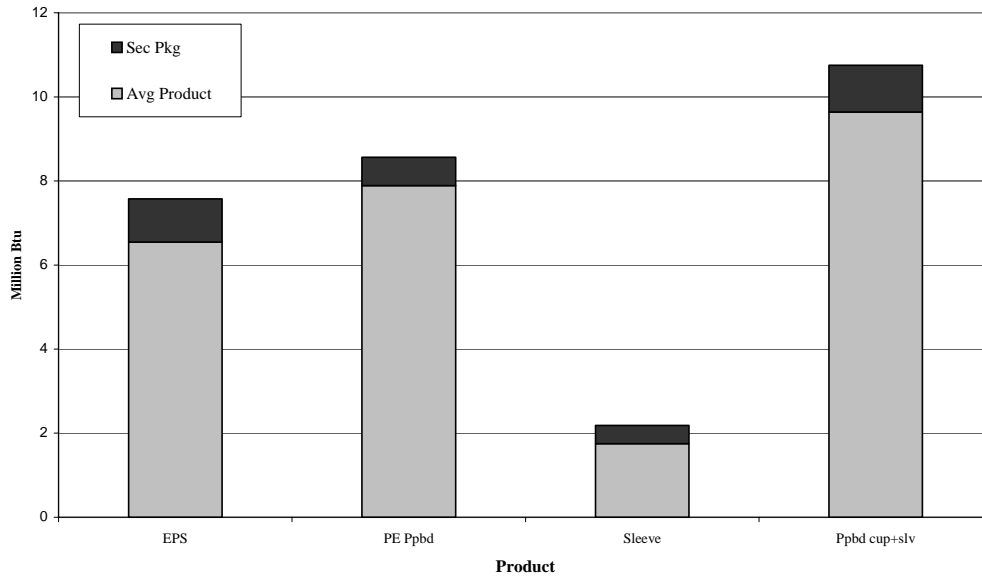
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in GHG results for products in different material categories or for different weight products in the same 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)**



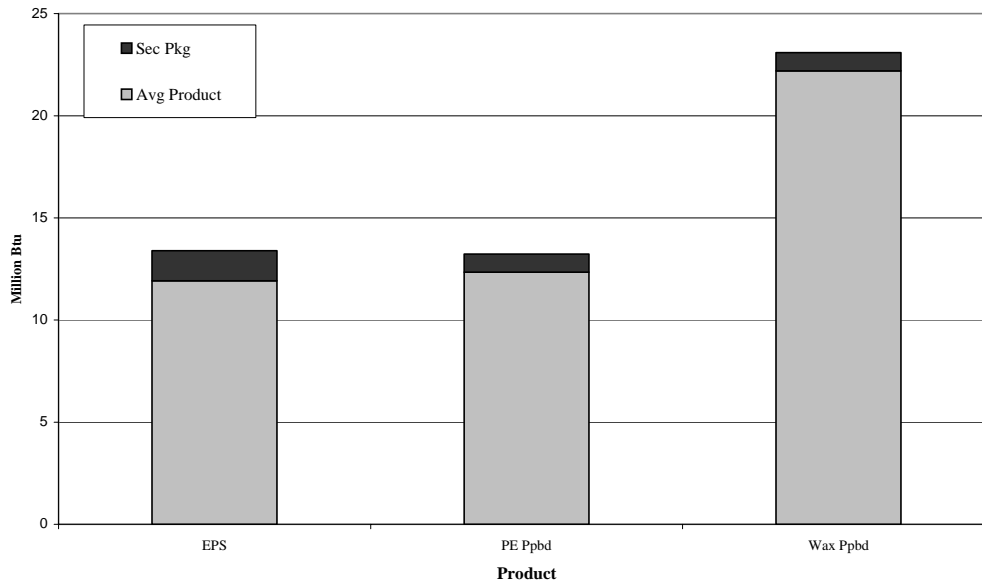
Results shown in this figure represent the full range of product samples obtained and weighed by Franklin Associates from January 2003 - July 2003. Due to the uncertainties in LCI data, differences in GHG results for products in different material categories or for different weight products in the same 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)**



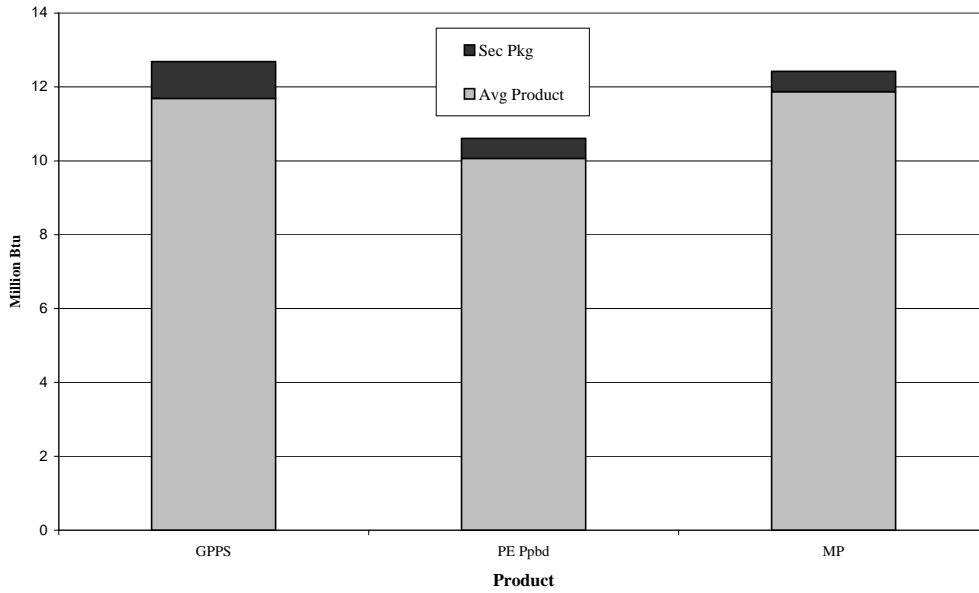
Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of 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)**



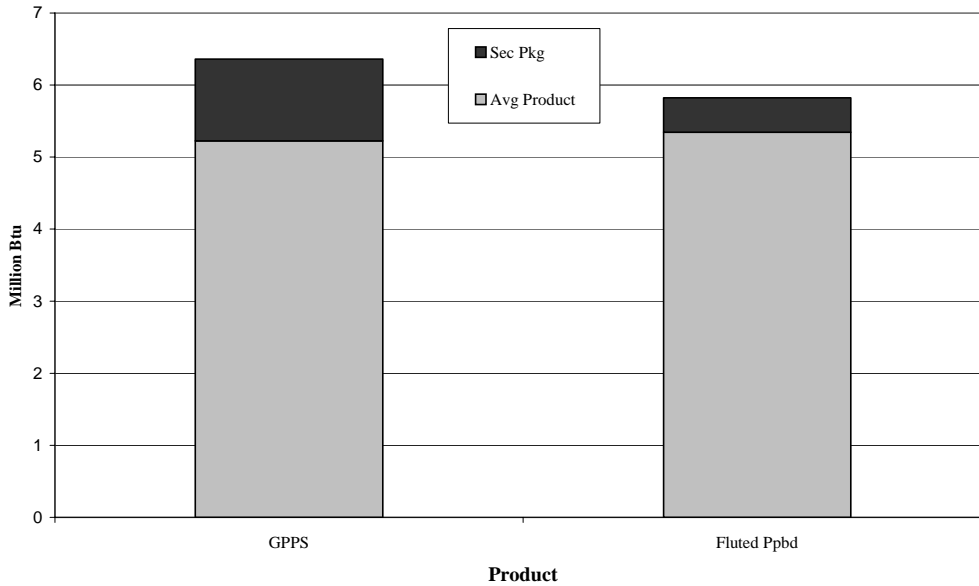
Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of 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)**



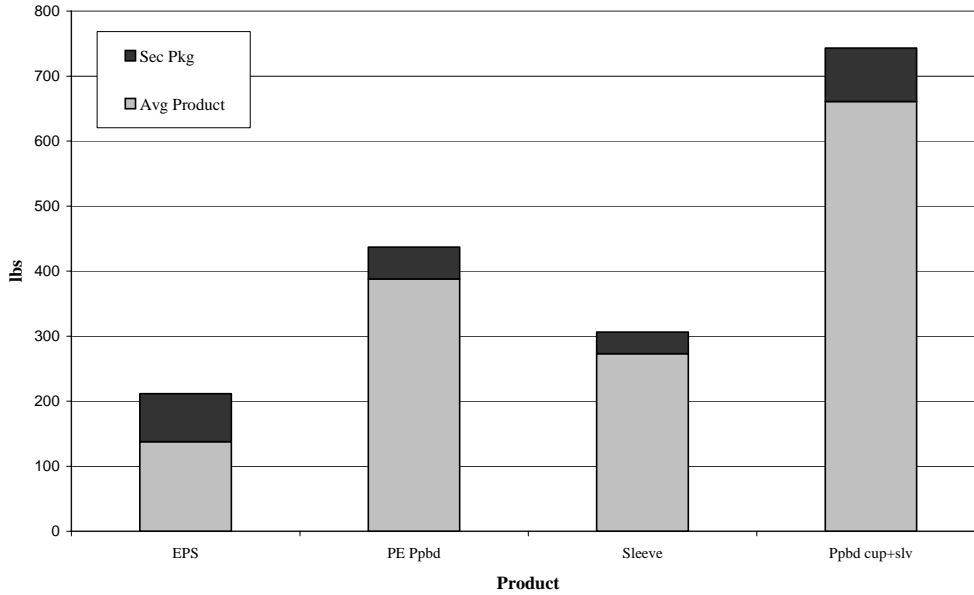
Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of 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)**



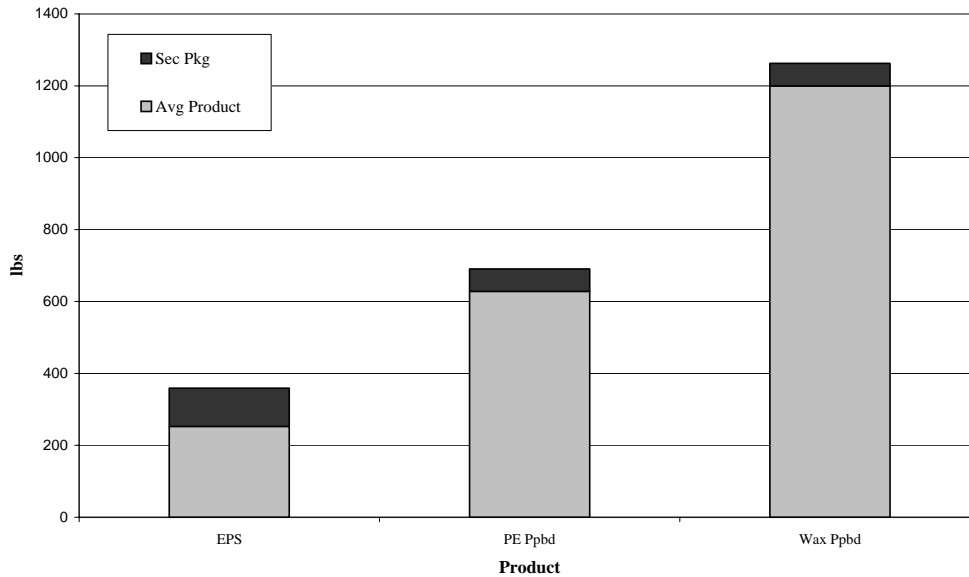
Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of 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)**



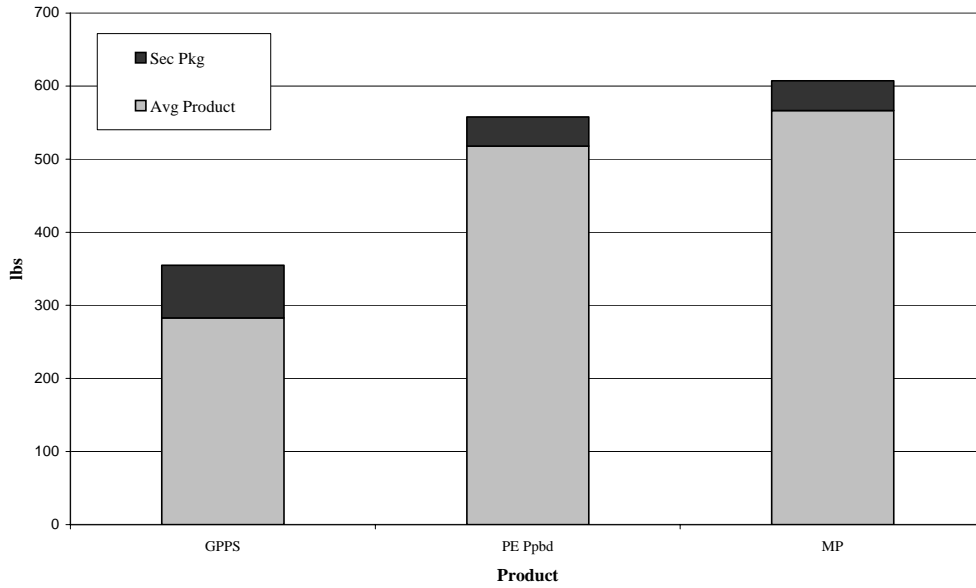
Results in this figure represent average weight product plus secondary packaging. The purpose of this figure is to illustrate the contribution of secondary packaging to the environmental burdens for the average weight product in each material category. Conclusions regarding the relative performance of 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.