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Dov Brachfeld, Tad Dritz, Shinsuke Kodama, Alan Phipps, Elyse Steiner
Gregory A. Keoleian, Project Director

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The Center for Sustainable Systems
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Center for Sustainable Systems
The University of Michigan
430 East University, Dana Building
Ann Arbor, Michigan 48109-1115
Phone: 734-764-1412
Fax: 734-647-5841
Email: css.info@umich.edu
http://css.snre.umich.edu

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ABSTRACT

A life cycle assessment was conducted to evaluate the total environmental burdens of the yogurt product delivery system (PDS) for Stonyfield Farm. A life cycle model was used to develop recommendations for enhancing environmental performance of the PDS by Stonyfield Farm and their suppliers. The PDS consists of primary and secondary packaging and transportation links required to deliver the packaging and products between the system model components. The current PDS consisting of polypropylene (PP) cups was compared to the following four alternative systems:

- A PDS that uses high density polyethylene cups;
- A PDS that uses a thermoforming process instead of injection molding;
- A PDS that uses coated unbleached paperboard cups; and
- A PDS that uses corn-based polylactide (PLA) cups.

The PDS energy intensity was correlated to the size of the containers, mass of the materials used, manufacturing processes, and the material composition. The total energy consumption for the current 2, 4, 6, 8 and 32 oz. containers were 3800, 4080, 4760, 4020, and 2930 MJ per functional unit, respectively. The 32 oz. containers consumed 27% less energy than the 8 oz. containers, and if all Stonyfield Farm yogurt were sold in 32 oz. containers, the annualized energy savings would be equivalent to 11,250 barrels of oil.

Significant amounts of energy are consumed at the Material Production phase, as well as Distribution 3 (yogurt delivery to distributors/retailers), which alone accounted for 1/3 of the life cycle total energy. Key recommendations for reducing environmental burdens include switching to thermoformed cup manufacturing, minimizing the distance traveled from Stonyfield Farm to retailers by opening a second yogurt production facility, and optimizing of the ratio of primary packaging to corrugated board as well as further investigating of renewable packaging materials.

EXECUTIVE SUMMARY

Stonyfield Farm's concern for the environment prompted it to consider the impacts of its product delivery beyond the traditional focus on container disposal and solid waste. Stonyfield Farm sponsored this study, which applies a life cycle approach to assessing the total environmental burden of its yogurt product delivery system (PDS), in recognition that adopting a life cycle approach would enhance decision-making regarding environmental performance. Polytainers Inc., Stonyfield's container supplier, also contributed funding and provided data for the study of the current PDS.

This study provides a methodology for quantifying the life cycle environmental burdens of yogurt delivery systems. The methodology was used to evaluate Stonyfield's current PDS and four alternative PDSs. Recommendations were made that would result in significant reductions of environmental burdens and areas for further study were identified that have the potential for additional reductions.

Product Delivery System Model

The PDS consists of primary packaging (yogurt containers), secondary packaging (corrugated boxes, pallets, etc.) and all transportation links required to deliver the materials, packaging and yogurt products between the system model components. In this study five different systems were modeled and analyzed:

- The current PDS, which uses injection molded polypropylene (PP) cups,
- A PDS that uses high density polyethylene (HDPE) in place of PP cups,
- A PDS that uses a thermoforming manufacturing process instead of injection molding,
- A PDS that uses polylactide (PLA) in place of PP cups and LDPE lids, and
- A PDS that uses coated paperboard in place of PP cups.

A life cycle based model to assess the PDSs' environmental burdens and impacts has been developed to support further research. The model incorporated data collected from 21 primary sources with more than 8,000 data input items.

Life Cycle Inventory

The Stonyfield PDS was divided into nine phases as described in Figure ES-1 and all inputs and outputs associated with each phase were inventoried according to the data categories in the left-hand column of Table ES-1 and characterized using the impact categories shown in the right-hand column of Table ES-1.

Figure ES-1: Life Cycle Inventory Phases

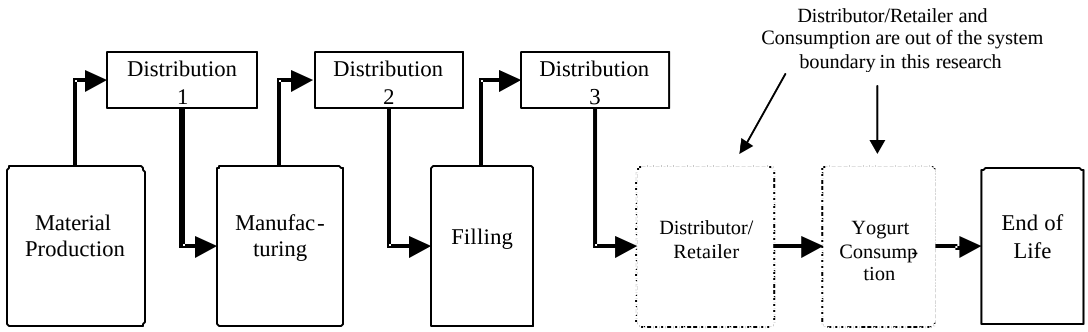


Table ES-1: Data Categories and Impact Categories

Data Categories	Impact Categories
❑ Energy ❑ Material Use ❑ Water Use ❑ Air Pollutant Emissions ❑ Water Pollutant Emissions ❑ Solid Waste	❑ Global Warming Potential ❑ Ozone Depletion Potential ❑ Maximum Allowable Concentrations

Results and Interpretation

The analysis quantified the correlation between life cycle environmental burdens and container size. It also identified significant differences between the current PDS and the four alternative PDSs.

Container Size Analysis

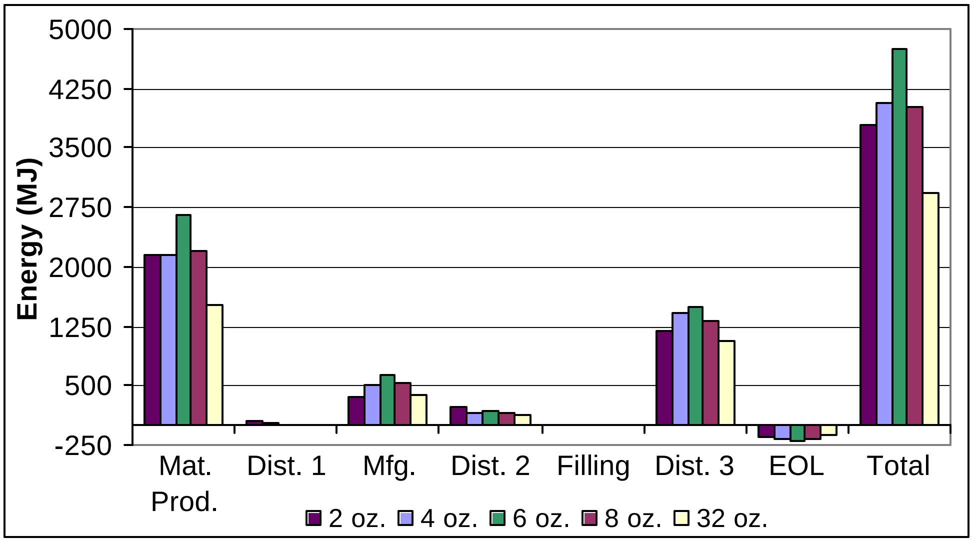
Two major findings from the analysis of the five container sizes were:

- ❑ The quantification of environmental burdens for each container size confirming that, overall, larger containers result in lower environmental burdens.
- ❑ The configuration of the primary packaging has a significant effect on the environmental burdens.

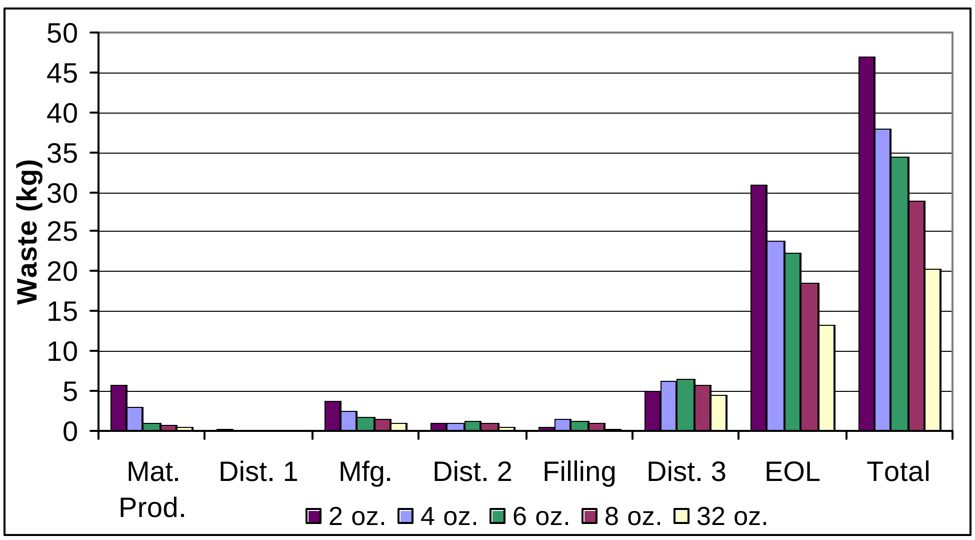
As shown in Figure ES-2, larger containers have lower energy and solid waste burdens. The PDS using 32 oz. containers consumes 27% less energy than the PDS utilizing the more popular 8oz. containers. In fact, if all Stonyfield Farm yogurt were sold in 32 oz. containers, the annualized energy savings would be equivalent to 11,250 barrels of oil. The effect that the primary packaging configuration has on environmental burdens is demonstrated in both the energy and solid waste comparisons. The 4 oz. PDS, which uses paperboard wraps instead of plastic lids, is 14% less energy intensive than the current 6oz. PDS, which uses plastic lids that were originally designed for 8 oz. containers. The downside of the 4 oz. PDS is that the use of paperboard results in significantly more solid waste, 86% more than the 32 oz. PDS.

Figure ES-2: Current PDS Cup Size Comparison

Energy by Phase



Solid Waste by Phase



Alternative PDS Analysis

The analyses of the alternative PDSs demonstrated that the choice of cup material composition and manufacturing process had significant effect on environmental burdens. The major findings of these analyses are:

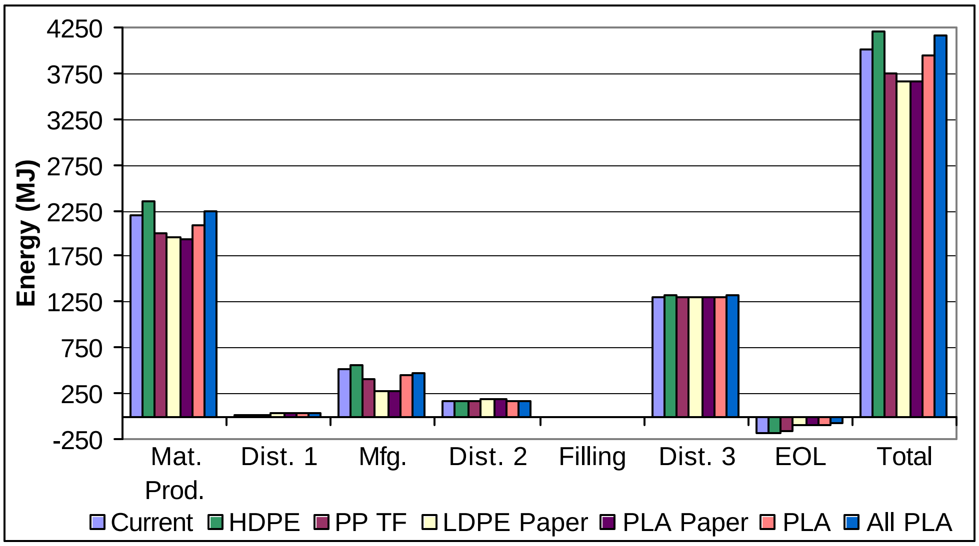
- The PDS using PP cups had lower environmental impacts than one using HDPE cups.
- The thermoforming manufacturing process had bwer environmental impacts than injection molding, primarily due to the lower cup weights.

- The PDSs using coated unbleached paperboard and PLA had the lowest energy consumption values and the highest percentage of renewable energy. However, they also had the highest solid waste.

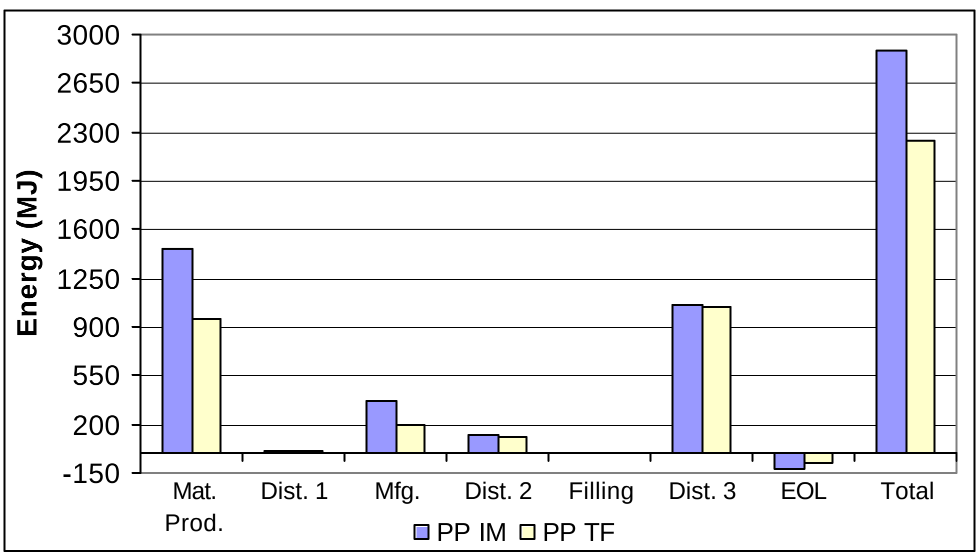
Due to the lower weight of PP cups compared to HDPE cups, a 5.3% savings in energy and a 4.3% reduction in solid waste are realized. Annually, Stonyfield's choice of PP over HDPE saves 104 tons of solid waste when the entire life cycle is considered. The top graph in Figure ES-3 shows the energy comparison between the PP and alternative 8 oz. PDSs. Note that the majority of the differences occur in the material production and manufacturing stages where the quantity of plastic material has the greatest impacts.

Figure ES-3: Alternative PDS Comparisons

Energy: 8 oz. PP vs. Alternative Materials



Energy: 32 oz. Injection Molding vs. Thermoforming



Results from the comparison of thermoforming versus injection molding also show the value of decreasing the weight of primary packaging. This is most clearly demonstrated with the 32 oz. cups because they are expected to have the largest weight savings (31%) when compared to their injection molded counterparts. Considering Stonyfield's current sales figures, if only the 32 oz. cup was thermoformed, a savings equivalent to the energy content of 2,085 barrels of oil per year would be realized. The bottom graph in Figure ES-3 shows the energy by phase for the 32 oz. thermoformed and injection molded PDSs.

Evaluation

To identify the areas recommended for further improvement, the scoring system shown in Table ES-2 was developed. On the scorecard, one check mark indicates that the life cycle phase contributes a moderate amount to the total burden in each category and two check marks indicate that the phase contributes more significantly. A high number of check marks (i.e., Material Production and Distribution 3) indicate that a life cycle phase accounts for a high portion of the total environmental burdens.

Table ES-2: Life Cycle Phase Scorecard for Current Composite PDS

Life Cycle Phases	Energy	Solid Waste	Air Emissions	Emissions to water	Water Use
Material Production	✓✓	✓	✓✓	✓	✓
Distribution 1					
Manufacturing	✓	✓	✓		✓
Distribution 2				✓	✓
Filling					
Distribution 3	✓✓	✓	✓✓	✓✓	✓✓
End-of-life		✓✓	✓		

The systematic life cycle analysis also revealed complex interconnectedness among the components of Stonyfield's yogurt PDS. For example, the light-weighting of corrugated boxes could result in a necessary increase in the weight of primary packaging to compensate for a decrease in the structural performance of the boxes. Another example of the complexity of the system is that an increase in the recycling rate of the plastic containers might increase the burdens that would be otherwise offset by the combustion of discarded plastic containers at energy recovery plants.

Recommendations and Areas of Further Study

- Educate consumers regarding the effect that container size has on environmental burdens.

- Improve performance related to product transport and distribution.
- Optimize the mix of primary and secondary packaging for environmental performance.
- Evaluate alternative primary packaging materials and configurations.
- Analyze impact of using more efficient or lower impact manufacturing processes.

This research found that it is imprudent to focus on one segment of the system in efforts to reduce specific environmental burdens. The life cycle assessment approach, which takes into consideration the PDS as a whole, will be a reliable and comprehensive tool in the further study to improve the total environmental performance of Stonyfield's product delivery system.

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1. INTRODUCTION

Stonyfield Farm's concern for the environment prompted it to consider the impacts of its product delivery beyond the traditional focus on container disposal and solid waste. Stonyfield Farm sponsored this study, which applies a life cycle approach to assessing the total environmental burden of its yogurt product delivery system (PDS), in recognition that adopting a life cycle approach would enhance decision-making regarding environmental performance. Polytainers Inc., Stonyfield's container supplier, also contributed funding and provided data for the study of the current PDS.

1.1 Yogurt Packaging Background

1.1.1 History of Yogurt Packaging

Prior to the 1980's, dairy product manufacturers generally sold yogurt in wax coated paper containers. However, in the 1980s, most companies switched to lighter polypropylene (PP) and high density polyethylene (HDPE) plastics in an effort to reduce packaging weight and materials. Dannon led the trend in the industry when it moved from wax coated paper cups to plastic cups in the mid-1980s.[1] During the same period, the company developed tamper-proof covers, and several other brands soon adopted this practice, as well.[2] This initial switch to plastic from paper reduced packaging weight by an average of 18% for an 8 oz. cup of yogurt, according to Montell, a manufacturer of polyolefins.

Benefiting from significant advancements in technology, today's PP yogurt cups are 45% lighter than the original wax coated paper cups.[3] Thin-walled cups measure 0.016 inches in thickness and 8 oz. containers weigh approximately 9 grams. Furthermore, the PP meets manufacturers' cost, durability, and labeling criteria. Other recent developments in the yogurt industry have included smaller sized multi-packs, a two-piece spoon that can be popped out from the lid and snapped together, and even a yogurt that is sold in a tube in place of the standard cup and lid.

1.1.1.1 Recyclability

Plastics: The functionality and variety of plastics have contributed to the material's success, yet these same characteristics have been keeping the recycling rate of post-consumer plastics low. The Society of the Plastics Industry (SPI) has developed a voluntary coding system to facilitate the manual sorting of plastics. [4] However, the SPI code does not necessarily mean that the container is made from recycled material or that the container will be recycled. While it is possible to recycle clean post-consumer #5 PP or #2 high-density HDPE yogurt containers, recycling rates are low and few communities will accept them in their curbside collection programs. Recycle rates for plastic packaging are shown below in Table 1-1. The rates reported are for all plastic packaging and include both industrial and post-consumer plastics.

Table 1-1: Recycling Rates of Plastic Containers and Packaging[5]

Material	Recycle Rates: Soft Drink & Milk Bottles	Recycle Rates: Other Containers	Recycle Rates: Total
Polyethylene terephthalate (PET)	37.3%	10.4%	24.3%
High density polyethylene (HDPE)	31.3%	18.5%	10.1%
Polystyrene (PS)	N/A	Neg.	4.8%
Low density polyethylene (LDPE)	N/A	Neg.	3.5%
Polypropylene (PP)	N/A	Neg.	2.1%
Polyvinyl chloride (PVC)	N/A	Neg.	Neg.
Other resins	N/A	Neg.	Neg.

Source: U.S. EPA Characterization of Municipal Solid Waste, 1998 Update

Since each plastic resin has specific properties, it is advantageous to keep them separate in the recycling stream in order to maintain those properties. To add further complexity, resins are tailored to specific applications by adjusting properties such as melt temperature and by including additives. The result is that even resins within a given SPI code designation can have very different physical properties. Mixing different grades of a resin during the recycling process lowers the value of the resin since it often becomes unsuitable for the intended applications. HDPE is a good example of a resin whose recyclability is affected by the fact that it is produced in several different grades. The HDPE material used for blow molding milk and laundry detergent bottles has a different melt temperature than the HDPE material used for injection molded dairy product containers. Since mixing the different grades of HDPE would decrease the value of the recycled material and processors prefer the blow-molding grade, the injection molding grade of HDPE is not recycled in most communities.

Another characteristic that makes recycling yogurt containers difficult is the addition of pigments and inks for graphics and labeling. Dyes and pigments can be undesirable in recycling because once they are in plastic they are difficult to remove. This limits the number of recycled products in which colored plastic materials can be used. It is no coincidence that the most recycled plastics, HDPE milk bottles and polyethylene terephthalate (PET) soda bottles, are typically produced without pigments and inks.

Paper: Recovery of paper and paperboard reached 42% (35 million tons) in 1997, accounting for more than half of the total municipal solid waste recovered[6]. However, when paperboard is coated with plastic, as it is for many packaging applications, it is no longer accepted in most recycling programs. Paperboard containers and packaging, including plastic coated paperboard packages, made up less than 0.05% of municipal solid waste in 1997.[7]

Recycling of plastic coated paperboard packaging is possible but is largely limited by market and capacity factors in the U.S. There is currently too great a difference between what processors are currently willing to pay and the price that is needed to attract an adequate supply. A 1994 study by the Clean Washington Center outlined conditions required to make recycling of plastic coated paperboard packaging to be feasible: (1) reprocessed pulp must flow into high-value end-use markets such as printing and writing papers; (2) the full value of the feedstock must be realized so that mills are willing to pay enough to attract adequate supplies; (3) capital costs for processing must be minimized; (4) municipalities must be willing to collect and handle plastic coated paperboard packaging and pay some of the cost of the reprocessing effort.[8]

1.1.1.2 Recycled Content

There are restrictions regarding how recovered and recycled paperboard and plastic may be used. Packaging that comes in direct contact with food may not contain post-consumer recycled content without special approval from the Food and Drug Administration (FDA) due to public health and safety concerns. There are several general methods by which plastic packaging can be recycled, for example, and each presents distinct concerns regarding the contaminant residues that may exist in post-consumer material. The FDA's main safety concerns with the use of recycled materials in food-contact articles are: 1) that contaminants from the post consumer material may appear in the final food-contact product made from the recycled material, 2) that recycled post-consumer material not regulated for food-contact use may be incorporated into food-contact packaging, and 3) that adjuvants in the recycled material may not comply with the regulations for food-contact use.[9] [10]

With an increased public awareness of environmental issues and waste generation, there has been some support for allowing recycled content in more food packaging. In response, the FDA now has 52 letters of no objection on file for a number of PET and HDPE food applications. However, the FDA has not issued any letters of no objection for other resins such as PP, polyvinyl chloride (PVC) and polystyrene.[11] As plastic recycling technologies become more economical and as supplies increase, the use of recycled plastic may increase for other food products as well.[12]

1.1.2 Past Studies

There have been several studies conducted comparing packaging systems in terms of environmental impacts. According to a packaging study undertaken by the Tellus Institute, over 95% of the product packaging environmental costs are from the production of the package with the disposal of the packaging representing less than 5% of the environmental costs. Additionally, the study suggests that the lightest weight package per unit of delivered end product is generally the lowest impact product. *Guidance for Improving Life-cycle Design and Management of Milk Packaging* by Gregory Keoleian and David Spitzley is an example of a packaging life cycle assessment (LCA) that analyzed seven packaging systems including single-use and refillable glass bottles, single-use and refillable HDPE bottles, paperboard gable-top cartons, LLDPE pouches, and polycarbonate refillable bottles.[13] The study noted the extent to which refillable and low energy packaging systems were environmentally preferable. Franklin Associates has also published several packaging studies including *Total Energy Consumption for the Production of Plastic Products in 1995*, *Resource and Environmental Analysis of Polyethylene Milk Bottles and Polyethylene- Coated Paperboard Milk Cartons*, and *An Energy Study of Plastics and Their Alternatives in Packaging and Disposable Consumer Goods*.[14] Many of the Franklin Associates LCA results accent the trade-offs and complex considerations that manufacturers and consumers must face when they make purchasing decisions.

1.2 Stonyfield Farm Background

Stonyfield Farm is a dairy product manufacturer located in Londonderry, NH with 170 employees making high quality refrigerated yogurts, frozen yogurts, and ice creams while striving to make a difference through social and environmental programs. Founded in 1983 as an organic farming school with a few Jersey cows, Stonyfield Farm currently has 3.8% of the refrigerated yogurt market share in the United States.

1.2.1 Business Profile

Stonyfield Farm, Inc. is a privately held company with an average annual growth rate of 36% for the eight-year period ending in 1997, making it the fastest growing yogurt company in America.[15] For the 52-week period that ended July 18, 1999, Information Resources Inc. reports that Stonyfield Farm yogurt cup sales in U.S. grocery stores totaled $47 million, up from just $90,000 during its first year of operation and $3 million in 1990.[16] Sales for 2001 were $72 million. Stonyfield products are sold in all 50 states.

Due to its position in the market, Stonyfield Farm yogurt commands a 4-5% price premium on average.[17] Several of Stonyfield's products are made from certified organic ingredients and all are free of bovine growth hormone (rBGH). The yogurt products all contain live and active cultures reputed to enhance digestion, stimulate the immune system and suppress the growth of harmful bacteria. The yogurt is available in 4 oz., 6 oz., 8 oz., and 32 oz. container sizes and in a 2oz. squeezable product called "YoSqueeze". Stonyfield's "YoBaby" multi-pack product line was the first organic whole milk yogurt packaged in baby-portioned 4 oz. cups. Another product line, Planet Protectors, is a refrigerated yogurt product that is marketed for children and sold in six-pack and quart configurations.

1.2.2 Environmental and Social Responsibility

The company has demonstrated a strong commitment to environmental stewardship and corporate citizenship ever since its inception. It has set high standards for the quality and taste of all its products with quality control and careful monitoring occurring throughout the production process. In 1999, Stonyfield received recognition from the President's Council on Sustainable Development and Renew America for integrating economic, environmental and community sustainability programs into the business. Another example of the company's commitment is the fact that Stonyfield Farm gives 10% of profits to efforts that help protect and restore the earth.

Stonyfield is a charter member of WasteWise, a voluntary Environmental Protection Agency (EPA) program in which member companies examine their operating and purchasing practices to identify cost-effective opportunities for waste reduction. As a WasteWise member, Stonyfield Farm focuses on reducing the environmental burdens of its operations and has been successful in recycling or reusing 70% of the waste stream.[18]

The company also participated in ClimateWise, a voluntary EPA partnership program that promoted a comprehensive approach to industrial energy efficiency and pollution prevention. The company was named a 1998 ClimateWise Partner Achievement Award winner, which recognizes "outstanding innovation, leadership, results, and planning in reducing greenhouse gas emissions through cost effective energy management and technology projects."[19]

The company recognizes the environmental impact of its product packaging and considers all aspects, including recyclability, in its packaging decisions. The packaging, specifically the yogurt container lids, is used to communicate with customers about issues that are of importance or interest to the company. Packaging design is most visible to customers and conveys the company's vision of health, nutrition, taste, and environmental responsibility.[20]

The company has modified its yogurt packaging to take advantage of new and improved technologies that reduce the weight of containers, such as a switch from HDPE cups to PP cups. In addition to weight, characteristics such as strength, quality, safety, and color labeling are important in container selection. Stonyfield Farm purchases 4 oz., 6 oz., 8 oz., and 32 oz PP cups and lids from Polytainers, a Toronto based container manufacturer. Stonyfield's cups come in two colors: white and a beige tone called "cotton fluff" used to distinguish organic ingredient yogurts from the conventional yogurts.

1.2.3 Study Sponsorship Motivation

Stonyfield chooses to use PP plastic yogurt containers made by Polytainers as a preferable option over HDPE based on requirements for value, product quality, environmental impact, and energy and material use. The life cycle assessment is one more tool to help with understanding environmental impacts and strategic decision–making. It provides a systematic approach to evaluating all environmental burdens throughout the product delivery system (PDS). A comprehensive LCA can guide Stonyfield's business decisions regarding its packaging in the future. The LCA results will be instrumental in selecting both primary and secondary packaging materials as well as yogurt container configurations and sizes. By making decisions based on life cycle assessment, Stonyfield Farm has the potential to reduce its energy and material consumption and its solid waste, air, and water emissions, thereby improving the environmental performance of its product delivery system over time.

Furthermore, a communication gap regarding packaging materials exists, especially with environmentally conscious consumers. Many customers have requested that

Stonyfield use HDPE because it is recycled in their communities and PP is not.[21] However, most communities accepting HDPE plastic for recycling actually recycle small-mouthed, blow-molded HDPE bottles only (i.e., milk and laundry detergent bottles), not wide-mouth injection molded containers such as yogurt containers.

Stonyfield uses its Internet web site (www.stonyfield.com), daily plant tours, and other mediums to educate consumers about its packaging decisions and efforts to improve environmental performance. Making its message understood has proven to be a challenging task, and the company continues to search for better ways to close the communication gap and to respond to consumer concerns.

1.3 Polytainers Background

Polytainers manufactures thin-walled rigid plastic containers and lids for the dairy industry. Polytainers commenced operations on December 14, 1967, with three molding machines and two printing machines. By 1981, Polytainers was located at its current site in Toronto, a 250,000 square foot plant, running 54 molding machines and 39 printing machines. In 1990, Polytainers opened a Kansas City, Missouri plant, and in 1997 acquired another facility in Los Angeles, California. The company is owned and directed by Mr. Robert Barrett, President.

1.3.1 Business Profile

Polytainers' products include containers manufactured from HDPE and PP, in round and rectangular shapes, and ranging in capacity from 4 oz. to one-half gallon. Lids, typically made of linear low-density polyethylene (LLDPE), are also produced to match all stock containers. The company distinguishes itself by the quality of the printing produced on the containers. Polytainers can print in eight colors using a true color printing process.

Polytainers' image and reputation for integrity within the business community is a priority for the company. It pursues business activities in an environmentally responsible manner within the community and the injection molding industry. As an example of its stewardship, Polytainers maintains membership in EPIC, the Environment and Plastics Industry Council. Because Polytainers is privately held, financial data and market share information is not publicly available.

1.3.2 Study Sponsorship Motivation

Polytainers joined the project with the University of Michigan after being approached by its customer, Stonyfield Farm. Polytainers is committed to exceeding customer expectations, and works towards developing a progressive packaging partnership with customers wherever possible.

1.4 Overview of Life Cycle Assessment

Life Cycle Assessment (LCA) is an environmental management tool of increasing importance that serves to promote sustainable business decisions. An LCA study describes and measures environmental impacts and burdens throughout the life of a specified product "from cradle to grave." The phases of a product life cycle typically include Material Production, Manufacturing, Distribution, Use and End-of-Life. For each phase, the study measures material and energy flows, emissions, and waste generation. Potential impacts to natural resources, to the environment and to human health are assessed based on the results. The LCA tool is useful for new product development, goal-setting, benchmarking, and performance measurement.

The International Standards Organization (ISO) has defined standards for the required components of LCA studies within its ISO 14000 environmental management series. ISO 14040 addresses overall LCA principles and framework, while ISO 14041 – 14043 concern the various LCA phases. The ISO standards define terminology, the required elements, and guidelines to follow when conducting an LCA. This LCA study uses the ISO framework and makes every effort to adhere to the ISO standards.

In the ISO framework the four required phases in an LCA are Goal and Scope Definition; Life Cycle Inventory Analysis; Life Cycle Impact Assessment; and Life Cycle Interpretation.

1.4.1 Goal and Scope Definition

Before starting any LCA study, it is critical to clearly articulate its purpose. This step identifies the intended application, boundaries, assumptions, function of the product system, and the functional unit under consideration. The function states performance characteristics of the product system. The functional unit is a "measure of the performance of the functional outputs of the product system" [22] whose purpose is to provide a common reference to which the inputs and outputs are related. The LCA scope definition specifies the initial inputs and outputs selected for inventory and criteria for inclusion based on mass, energy requirements, or environmental relevance.

1.4.2 Inventory Analysis

The inventory analysis takes stock of material and energy resources consumed, as well as environmental releases produced throughout the life of the product. The Life Cycle Inventory (LCI) methodology entails data collection on flows that occur during each process within the system. The application of allocation principles and procedures should be explained in the LCI, and additional elaboration may be required in recycle or reuse situations. The inventory must be as inclusive and accurate as possible to provide data that is relevant for management decisions. The procedures for data collection and sources of the data are provided to ensure transparency in this phase. Data quality and completeness are often issues in conducting an LCA.

1.4.3 Impact Assessment

The Life Cycle Impact Assessment (LCIA) is aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system. An ISO 14040 compliant LCIA consists of data categories, which represent environmental issues of interest to which LCI results can be assigned, and impact categories, which are methods employed to condense and explain LCI results. There may also be an optional valuation performed to normalize data, data quality analysis, weighting of the results and/or critical review. "There are no generally accepted methodologies for consistently and accurately associating inventory data with specific potential environmental impacts," according to the ISO.

1.4.4 Interpretation

The final step, Life Cycle Interpretation, evaluates the outcomes and recommends changes to improve environmental performance. In other words, this is where the information provided by the inventory analysis and the impact assessment is interpreted in relation to the goal of the study. It identifies the significant issues based on the results from the previous phases, evaluates the completeness, sensitivity, and consistency of the results, and makes conclusions and recommendations.

The LCA is still evolving into a robust methodology. There are limitations and challenges associated with conducting and applying results from LCA studies. Gaps in the data, assumptions, and spatial, temporal, and technological differences all affect the accuracy of the final results. In some cases, cost, length of time required, complexity and reliability of data are barriers to implementation. However, it has been successfully applied in many organizations to reduce environmental burdens associated with product life cycles and to drive sustainable business decisions.

2. GOAL

2.1 Purpose of Study

The primary purpose of this report is to provide Stonyfield Farm with a life cycle assessment of the current yogurt product delivery system (PDS) and four alternatives. The PDS, which includes all primary and secondary packaging as well as all transportation required to deliver Stonyfield products, is described in more detail in Section 4.1. This study also identified segments of the PDS that contained the highest environmental burdens and those that represented opportunities for improvement.

2.1.1 Evaluation of Current Product Delivery System

A life cycle inventory of the current PDS, which utilizes injection molded PP yogurt cups, was conducted in accordance with ISO 14040. This entailed gathering comprehensive data on the material and energy flows of the system (energy consumption, material inputs, waste outputs, and pollutant emissions). Where practicable, actual plant specific data were used, while other burdens were calculated using published figures. The results of the existing PDS are to be used as a benchmark with which to compare alternatives.

2.1.2 Evaluation of Alternative Product Delivery Systems

In addition to creating an LCI of the current PDS, this study also investigated alternative delivery systems. For this report the following alternative systems were modeled:

- PDS utilizing HDPE cups to address customer queries about the potential use of this material commonly used to package dairy products.
- PDS utilizing thermoformed cups in place of injection molded cups to investigate a competing plastic forming technology.
- PDS utilizing plastic coated unbleached paperboard cups to investigate the use of renewable material feedstocks.
- PDS utilizing polylactide (PLA) cups and lids to investigate the use of renewable material feedstocks. PLA is a polymer that is typically derived from corn or sugar beets.

2.1.3 Recommendations

In addition to compiling LCI results, this report suggests recommendations as to which aspects of the PDS offer the best opportunities for improvement. Conclusions have been drawn regarding the preferable packaging material or process based on energy, solid waste, pollutant emissions and other key environmental metrics.

2.1.4 Calculation Model

This study also set as a goal the development of a calculation model that could be used to evaluate the PDSs considered in this study, as well as PDSs in future studies. The calculation model is programmed into a Microsoft Excel-based spreadsheet with the functionality to calculate environmental burdens of existing and hypothetical PDSs.

2.2 Intended Use of Study

The primary application of this study's findings is to guide Stonyfield Farm and Polytainers in strategic decisions involving environmental matters. More specifically the intended uses are:

- Establish a baseline of environmental performance for a PDS in order to compare alternative materials and processes
- Assist with the identification of opportunities for process and packaging improvements to the current PDS
- Present an LCA methodology that can be translated to other segments of the food industry
- Provide information to yogurt customers and other interested groups about the life cycle burdens associated with product delivery

Although it is a useful tool, the information in this study should not be used or considered as:

- The sole source of information regarding the environmental performance of the materials investigated and product delivery as a whole, due to the inherent limitations of the LCA methodology.
- An appropriate instrument for assessing individual processes, particularly where the facilities are modeled as a single process.

2.3 Target Audience

2.3.1 Primary Audience

As the two entities funding this study, Stonyfield Farm and Polytainers are the primary audience for this report. Therefore, information was organized and presented for maximum utility to a yogurt producer and container manufacturer.

2.3.2 Internal and External Stakeholders

By providing this essential information, Stonyfield can confirm or improve its yogurt packaging choices and communicate its progress in reducing environmental impacts generated by its business activities with its internal and external stakeholders.

2.3.3 Industry and Academics

A third segment considered was academia and others in the dairy product and packaging industries. It is hoped that the methodology utilized for this study will be useful to other research teams investigating similar processes. Moreover, container manufacturers and companies that purchase the containers may use this document to comprehend the life cycle consequences of their food packaging decisions.

3. SCOPE

3.1 Function and Functional Unit

3.1.1 Definition of Function

The system function was delivery of the Stonyfield Farm refrigerated yogurt products to market. For the purpose of this study, "market" is defined as the first destination after being shipped from Stonyfield Farm's yogurt production facility.

3.1.2 Definition of Functional Unit

The functional unit for this study was 1,000 lbs. of yogurt delivered to market (distributor/retailer).

3.2 Product Delivery System Definition

The Stonyfield Farm PDS was defined as the system employed for the distribution of the company's yogurt product line to consumers. As such, it included not only the yogurt container materials, but also all manufacturing, transportation, and secondary packaging associated with the function of the system.

3.2.1 Primary Packaging/Containers

The yogurt containers were considered the primary packaging for Stonyfield Farm's product. Stonyfield Farm specified the traditional container sizes of 4 oz., 6 oz., 8 oz., and 32 oz. at the outset of the investigation and subsequently added its newly introduced 2 oz. tube container. The container sizes and their components are listed in Table 3-1 below.

Table 3-1: Yogurt Container Sizes and Components

Size	Cup	Lid	Seal	Tube	Wrap/Carton
2 oz.				✓	✓
4 oz.	✓		✓		✓
6 oz.	✓	✓	✓		
8 oz.	✓	✓	✓		
32 oz.	✓	✓	✓		

2 oz. container. Stonyfield Farm's newest packaging configuration sold under the product name "YoSqueeze" consists of eight 2oz. single-serve tubes placed in a carton. The tubes consist of two pieces of plastic film, the tube material and a sealing tape. The film for the tube consists of LLDPE (56.7%), oriented PET (OPET) (22%) and polyethylene (21.2%). The polyethylene contains a white pigment. The film is printed with solvent-based inks. The film for the sealing tape consists of LLDPE (75.4%), OPET (18.4%) and solvent-based adhesives (6%). The carton is constructed out of clay coated, unbleached paperboard, which is printed with oil based inks and has a water base acrylic coating.

4 oz. container. When packaged in the 4 oz. containers, Stonyfield Farm yogurt is delivered in a six-pack arrangement. The six-pack consists of six individual 4oz. cups, each with a plastic film seal, and an unbleached paperboard wrap, which encases the six-pack. The current 4oz. cup is PP and is manufactured using an injection molding process. During the injection molding process, color concentrate is added to the PP resin to color the cups. Color concentrate is added to the resin for the white cups at a rate of 2%, while the color concentrate for the cotton fluff colored cups is added at a rate of 3%. The wrap is constructed out of clay coated, unbleached paperboard, which is printed with oil based inks and has a water base acrylic coating. The seal is a co-extruded PE/PET film.

6 oz., 8 oz., 32 oz. containers. When packaged in the 6 oz., 8 oz., or 32 oz. containers Stonyfield Farm yogurt is delivered in cups, each with a lid and film seal. The current 6 oz., 8 oz. and 32 oz. cups are PP and are manufactured using an injection molding process. The lids are injection molded using LLDPE. During the injection molding process, color concentrate is added to the PP and LLDPE resins to color the cups and lids. Color concentrate is added to the resin for the white cups at a rate of 2%, while the color concentrate for the cotton fluff colored cups is added at a rate of 3%. The seal is a co-extruded PE/PET film.

3.2.2 Secondary Packaging

The delivery of materials for the manufacture of the containers, the transport of the containers themselves for filling, as well as the delivery of the yogurt-filled containers to market involves the use of secondary packaging. The PDS included the secondary packaging materials such as corrugated boxes, box liners, stretch-wrap, and pallets.

3.2.3 Transportation

Shipping for the deliveries described above is executed by either truck or rail. All such transportation comprised a fundamental element of the PDS.

3.2.4 PDS Composition

Table 4-16 in Section 4-7 provides the material composition of Stonyfield's current PDS listed by container size. Table 3-2 below provides a description of the current PDS using a composite delivery system based on the sales of the five container sizes for fiscal year 2000. The mass and fraction-of-total for each material used in the composite PDS is listed.

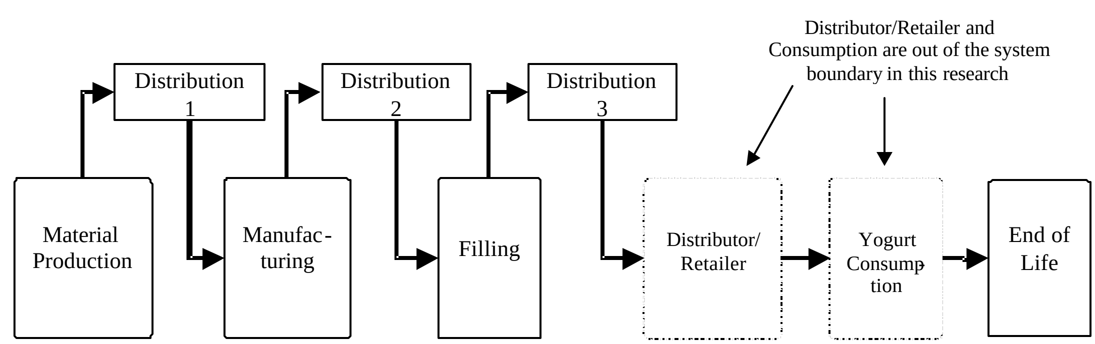
Table 3-2: PDS Composition

Material/Mode	Mass (kg)	Fraction
Primary Packaging		
Coated Paperboard	6.86	12.2%
LLDPE	5.62	10.0%
PE	1.11	2.0%
PET	0.67	1.2%
Color Concentrate	0.53	0.9%
PP	15.98	28.3%
Total	30.77	54.5%
Secondary Packaging		
Corrugated	24.16	42.8%
LDPE	0.18	0.3%
LLDPE Film	0.30	0.5%
Paperboard	0.15	0.3%
Wood	0.90	1.6%
Total	25.67	45.5%
Transportation (1000 kg-km)		
Rail	13.83	2.7%
Truck	503.23	97.3%

3.3 System Model Overview

The system model overview section describes how the entire product delivery system was divided into unit processes. A system model consisting of nine phases – Material Production, Distribution 1, Manufacturing, Distribution 2, Filling, Distribution 3, Distributors/Retailers, Yogurt Consumption and End-of-Life – was developed in order to evaluate the life cycle environmental impacts of the yogurt product delivery system. Figure 3-1 shows the overview of the LCI system model.

Figure 3-1: Overview of System Model



The Distributor/Retailer and Yogurt Consumption phases are excluded from the system model and formal LCA study. However, in the interest of comprehensiveness and to allow Stonyfield the opportunity to educate consumers on potential behavior modifications, a summary assessment of environmental burdens associated with the refrigeration of the yogurt and washing of bowls and spoons during the Yogurt Consumption phase are presented in Appendix B. Section 4.2 describes the modeling of each phase in detail.

3.4 System Boundaries

The following section outlines the boundaries that defined the system for this study.

3.4.1 Material Production

- The Material Production phase includes the extraction of the raw materials as well as the materials manufacture, which is the processing of the raw materials into intermediate materials. This phase also includes transportation of raw materials to the location where they are processed into intermediate materials.
- Material Production includes only production of materials used in the primary packaging. Material production of secondary packaging is included in the Distribution phases.
- The PP, LLDPE, HDPE, PE and PET materials used for the primary packaging contain proprietary additives which represent a very small percentage (less than 0.5% for PP) of the mass according to the supplier. The Material Production burdens associated with these additives were excluded from the system model and since the quantities of these additives were unknown, the materials were modeled as 100% plastic resin. The supplier of PLA indicated that additives would not be required so PLA was also modeled as 100% plastic resin.
- Color concentrate is added to the plastic resin during the manufacturing phase and is therefore modeled as a material input for the primary packaging. Color concentrate is composed of pigments and a carrier resin. The color concentrate used in the cups and lids utilizes titanium dioxide and calcium carbonate for pigments and LLDPE for a carrier resin. The white color concentrate is 59% pigment by weight and is added to the PP resin at a rate of 2%. The cotton fluff color is 53% pigment by weight and is added to the PP resin at a rate of 3%. The Material Production burdens associated with these pigments were excluded from the system model. This exclusion resulted in the white color concentrate having lower Material Production energy (37.3 MJ/kg) than cotton fluff color (41.7 MJ/kg).

3.4.2 Distribution 1

- Distribution 1 includes the transportation of primary packaging input materials from the location where materials manufacture takes place in the Material Production phase to the manufacturing location.
- Material production and manufacturing of the secondary packaging used to ship materials between the Material Production phase and the Manufacturing phase were considered to be outside the boundaries of this study. Most of the shipments in this phase utilize bulk trucks or railcars and therefore do not

require secondary packaging. Where secondary packaging is used, its weight was included in calculating transportation burdens.

3.4.3 Manufacturing

- The Manufacturing phase includes only manufacturing of the primary packaging. Manufacturing of secondary packaging was included in the Distribution 2 and 3 phases.
- Burdens associated with the production of the manufacturing equipment are excluded from the system model. These burdens were expected to be small relative to the burdens associated with the processes that were inventoried. The one exception was that road transport in many of the published data modules contained the burdens associated with the construction of the vehicles and replacement parts such as tires and batteries.
- Burdens associated with the construction of the manufacturing facilities are excluded from the system model.
- Burdens associated with human activities, including driving to and from work, are excluded from the system model.
- Printing inks are excluded from the system model due to lack of data. However the chemical compounds of the inks were considered in the Human Health Impacts discussion in Section 5.1.2.

3.4.4 Distribution 2

- Distribution 2 includes the transportation of primary packaging materials from the manufacturing location to Stonyfield Farm where the filling takes place. The environmental burdens associated with material production and manufacturing of the secondary packaging used during this leg of transportation were included. The burdens associated with the transportation of the secondary packaging, from the supplier to the manufacturing facility, were also included.
- Materials required for the shipment of the secondary packaging were considered to be outside the boundaries of this study.

3.4.5 Filling

- Energy and emissions burdens associated with the filling process were excluded from the system model. The facility in which the Filling occurs is also used for the yogurt production and therefore burdens associated with the PDS could not be distinguished from the burdens associated with yogurt production. For this reason, Filling was determined to be outside the project scope by Stonyfield Farm. The only exceptions were the solid waste generated from the sealing process and losses of primary packaging during the filling/sealing/packing processes, which were directly related to the PDS and therefore included.

3.4.6 Distribution 3

- Distribution 3 includes the transportation of yogurt and its primary and secondary packaging from the filling location (Stonyfield Farm) to the distributors/retailers. The environmental burdens associated with material production and manufacturing of the secondary packaging used during this leg of transportation were included. The burdens associated with the transportation of the secondary packaging, from the supplier to the filling facility, were also included.

- Materials required for the shipment of the secondary packaging were considered to be outside the boundaries of this study.
- Distribution 3 includes only the burdens associated with transportation to the first destination. In the event that the yogurt is shipped from Stonyfield to a distributor and then to a retailer, the transportation leg between the distributor and the retailer would be excluded.

3.4.7 Distributor/Retailer

- Environmental burdens associated with activities in the Distributor/Retailer phase were excluded from the system model. Disposal of secondary packaging used in the Distribution 3 phase is counted in the Distribution 3 phase.

3.4.8 Yogurt Consumption

- Environmental burdens associated with the transportation of the yogurt from the retailer to the consumer and consumption of the yogurt were excluded from the system model. Burdens associated with the refrigeration of the yogurt and the washing of bowls and spoons are calculated and discussed in Appendix B.

3.4.9 End-of-Life

- Environmental burdens associated with the End-of-Life phase include transportation from the consumer to final disposal and burdens of landfilling and incineration.

3.5 Introduction to Data Categories

This section will introduce the six data categories that were used to classify the items inventoried throughout the study. The data categories were intended to reflect the emissions or resource use for each area of interest. The data categories and their components, listed below (Table 3-3), were felt to be consistent with the goal and scope of this study and are adequate to make overview statements pertaining to the environmental impacts of the PDS.

Table 3-3: Data Categories

Energy
❑ Total Primary Energy
❑ Renewable
❑ Non-Renewable
Material Use
❑ Total
Water Use
❑ Total
Air Pollutant Emissions
❑ All Air Pollutants Tracked by DEAM[23] (See Appendix C)
❑ Criteria Air Pollutants
❑ Other Toxic Air Pollutants (See Appendix D)
Water Pollutant Emissions
❑ All Pollutants Tracked by DEAM (See Appendix C)
❑ Water Quality Concern Chemicals (See Appendix D)
Solid Waste
❑ Total Solid Waste
❑ Incinerated Solid Waste
❑ Recycled Material

3.5.1 Energy

The study tracked total primary energy consumed at each life cycle phase. Additional sub-components of primary energy were selected to offer supplementary information on the PDS energy use: Renewable, Non-Renewable, and Feedstock energy. Renewable and Non-Renewable refer to energy generated from renewable fuels (hydroelectricity, wood and biomass) and non-renewable fuels (coal, lignite, oil, natural gas or uranium) respectively. Feedstock energy is the part of total primary energy that is embedded within used material such as combustible fuel material. The importance of including feedstock energy is that it accounts for the decision to use the energy source as a material input, foregoing its use as a fuel. An example of feedstock energy is energy contained in petroleum, which is a raw material for making plastics.[24] The total primary energy data category is the aggregation of Renewable and Non-Renewable energy, minus any energy offset through electricity generation from solid waste incineration.

3.5.2 Material Use

The total mass of materials used was tracked at each phase of the PDS life cycle.

3.5.3 Water Use

The data category for total water use referred to the tracking and aggregation of water used at each phase of the life cycle measured by volume.

3.5.4 Air Pollutant Emissions

The data category air pollutant emissions refers to the aggregation of all pollutant emissions to air tracked by the DEAM modules at each phase of the life cycle measured by mass. The components of the data category are listed in Appendix C.

In addition, specific emissions were classified together to offer supplementary information on the PDS emissions to air: Criteria Air Pollutants (SO_X, NO_X, CO, hydrocarbons and particulate matter) and Other Toxic Air Pollutants (listed in Appendix D).

3.5.5 Water Pollutant Emissions

The water pollutant emissions data category refers to the tracking and aggregation of emissions to water at each phase of the life cycle measured by mass. The components of the data category are listed in Appendix C.

3.5.6 Solid Waste

The mass of solid waste materials was tracked at each phase of the PDS life cycle. The solid waste data category is the aggregation of those materials that exit the system to be disposed of by landfilling. Total incinerated solid waste refers to those waste materials that exit the system yet are disposed of through incineration. Those materials that exit the system to be recycled for use in another product system do not accrue any of the burdens associated with disposal and are counted in the recycled material sub-category only. The analysis did not account for credits (in Material Use or Energy for example) for the recycling of material at end-of-life, however a credit was given for the reduction of total solid waste. For example, if out of 10kg of materials discarded at End-of-Life 3kg are recycled for use in another system, these burdens would be counted as recycled material while only the remaining 7kg of the waste would be counted in total solid waste.

3.6 Impact Categories

Using the information from the above data categories, the environmental impacts and burdens of the PDS were classified into the three environmental impact categories listed below.

- Global Warming Potential
- Ozone Depletion Potential
- Maximum Allowable Concentration

3.6.1 Global Warming Potential (GWP)

Global Warming Potential is the category indicator measuring possible contribution by the PDS to the "greenhouse effect." The greenhouse effect refers to the ability of some atmospheric gases to retain heat that is radiating from the earth. The measurement of GWP employed in this report is based on the model compiled by The Intergovernmental Panel on Climate Change (IPCC).[25]

The GWP index is defined as the cumulative radiative effect between the present and a chosen time horizon (here 100 years is used) caused by a unit mass of emitted gas, expressed relative to that for some reference gas (IPCC and this study use CO_2).

A single indicator is produced for the greenhouse effect, in which:

$$E = \sum GWP_i * m_i$$

Where, for a greenhouse gas “i”, m_i is the mass of the gas released (in grams), and GWP_i is its Global Warming Potential, expressed in CO_2 equivalents.

Although the GWP calculation is one of the most accepted of all life cycle impact assessment index methodologies, it is limited in so far as GWP assumes an even distribution of the gases being tracked, and indirect GWP effects, such as the emission of one greenhouse gas leading to the formation of another greenhouse gas, are not considered. (However, the indirect effects of methane are accounted for in its equivalency factor.)

3.6.2 Ozone Depletion Potential (ODP)

A layer of ozone in the Earth’s stratosphere serves as a protective shield from the Sun’s harmful ultraviolet radiation. Deterioration of the ozone layer allows more radiation to reach the Earth’s surface, potentially destabilizing ecosystems as well as causing adverse effects on agricultural productivity, human health and climate. ODP is an impact category measuring possible contribution by the PDS to deterioration of the stratospheric ozone layer.

The most accepted ODP model, developed by the World Meteorological Organization, is employed in this study.[26] The impact category is evaluated as follows:

$$\text{Ozone Depletion} = \sum ODP_i * m_i$$

Where, for an ozone depleting gas “i”, m_i is the mass of the gas released (in milligrams), and ODP_i is its Ozone Depletion Potential. Ozone depletion is expressed in milligrams of CFC-11.

As in the case of Global Warming Potential, the ODP characterization method has limits. For example, the ozone depletion potentials that are employed in the World Meteorological Organization model are subject to uncertainty and periodic modification. Also, the influence of greenhouse gases on the level of ozone occurs not only directly through chemical reaction but also indirectly through global warming. This influence is not built in to the model due to the complexity of the dynamics involved.

Also, the actual ODP is likely to be lower than that shown in the Results section figures due to federal legislation and EPA regulation of ozone-depleting substances in the U.S. The chemicals included in the ODP calculations are halon 1301 (CF_3Br), methyl bromide (CH_3Br), and carbon tetrachloride (CCl_4). Both halon 1301 and carbon tetrachloride have been identified as Class I substances under Title VI of the Clean Air Act, which means that they have an ODP of 0.2 or higher.[27] Responding to scientific findings, the U.S. announced that the phaseout of the production of Class I substances including CFCs, halons, carbon tetrachloride, and methyl chloroform would be accelerated and that these substances would be phased out by December, 31, 1995.[28] Methyl bromide was later added to the list as a Class I ozone-depleting substance and is to be phased out gradually between 1999 and 2005.[29]

3.6.3 Maximum Allowable Concentration (MAC)

A maximum allowable concentration model for air pollutant emissions measurement permits the normalization of air emissions in terms of human health risk. A volume of air at the maximum allowable concentration of toxicity can be determined by adding together air pollutant emissions divided by factors based on air quality standards for human health.[30]

The Maximum Acceptable Concentration model is evaluated as follows:

$$\text{volume of air at maximum allowable concentration} = \sum m_i / MAC_i$$

Where, for an air pollutant "i", m_i is the mass of the gas released (in grams), and MAC_i is its maximum allowable concentration factor. MAC is expressed in cubic meters of polluted air. Table 3-4 lists the air pollutants included in the MAC value calculations.

The MAC results should be interpreted with caution because of signification limitations of the MAC characterization method.[31] Overall, the limitations of the MAC methodology are that (1) spatial and temporal characteristics of pollutants are not addressed, including the location and duration of releases, and that (2) the fate, transport, and exposure routes are not taken into consideration. Populations exposed, density, and type of exposure (i.e., skin contact, inhalation, etc.) are important factors in assessing human health risks not treated in a MAC characterization. In addition, MAC values may be set based on political or economic factors. Other methods of human health assessment for specific pollutant releases such as Toxicity Equivalency Potentials are available. MAC values were used because they address general classes of pollutants including hydrocarbons and particulates.

Table 3-4: Maximum Allowable Concentration Factors[32]

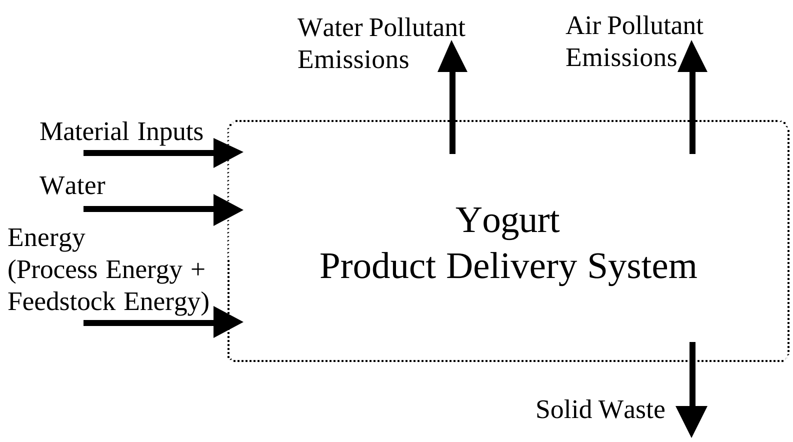
Pollutant	MAC Value ($mg\ m^{-3}$)
Dust (PM)	10
CO	29
NO_x	9
SO_2	13
Hydrocarbons	500

4. LIFE CYCLE INVENTORY

4.1 Overview

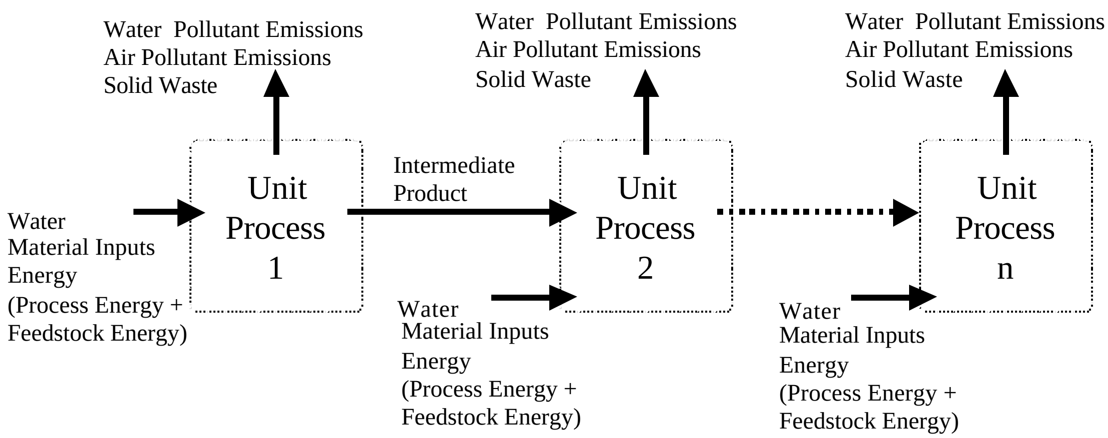
Life cycle inventory analysis mainly consisted of data collection and calculation procedures to quantify relevant inputs and outputs of total system to be analyzed. As shown Figure 4-1, this research analyzed the service system that provided delivery of one functional unit (1,000 lbs.) of yogurt to consumers.

Figure 4-1: Yogurt Product Delivery System LCI Overview Diagram



In order to facilitate the data collection and calculation, the whole system was divided into several unit processes; the inputs and outputs of each unit process were inventoried as shown in Figure 4-2.

Figure 4-2: Generic LCI Unit Process Material and Energy Flow Diagram



4.2 System Introduction

The following sections describe the model of each phase in detail. Data modules obtained from secondary data sources are described below each phase in table format.

4.2.1 Material Production

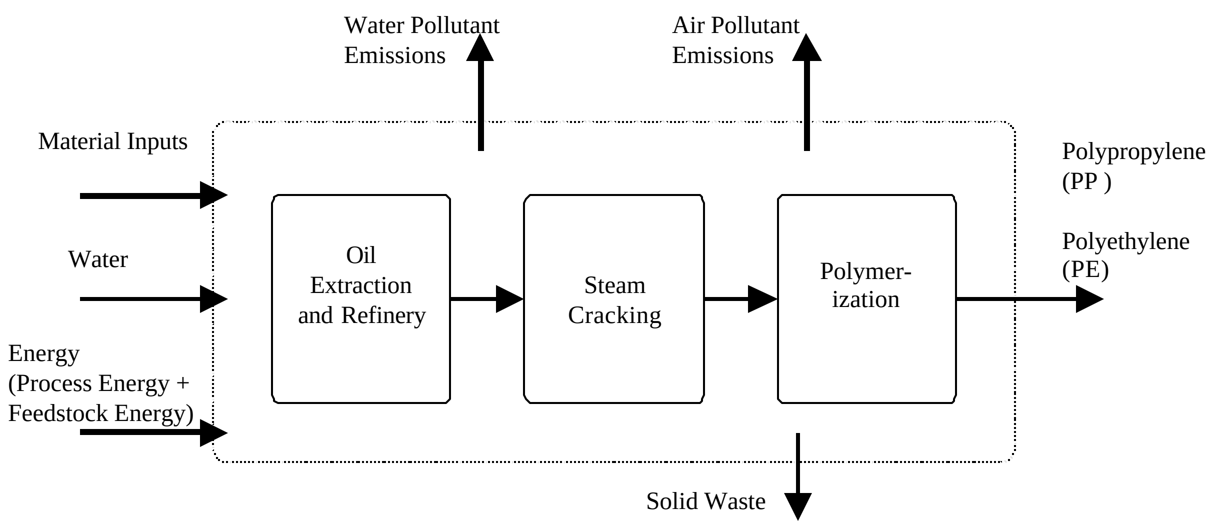
The Material Production phase represents the material production activities for primary packaging. The primary packaging of the current PDS uses PP for cups, LLDPE for lids, polyethylene (PE) and PET for seals, coated unbleached paperboard for 2 oz cartons and 4 oz. multi-pack wraps, inks and color concentrate.

Three alternative primary packaging materials were also modeled including high density HDPE, coated unbleached paperboard and PLA. Each of these three materials was modeled to replace the PP currently used for the cups. PLA was also modeled as a replacement for LLDPE for the lids.

4.2.1.1 Polyolefins (PP, HDPE, PE, LLDPE)

The life cycle processes of the production of polyolefin resins are illustrated in Figure 4-3 below. The production of these materials includes Oil and Natural Gas Extraction, Petroleum Refining, Cracking of naphtha, and Polymerization. The difference between PP production and PE production is the intermediate produced in the cracking process. The interim monomer ethylene (C_2H_4) is polymerized into polyethylene and propylene (C_3H_6) is polymerized into polypropylene.[33]

Figure 4-3: Polyolefin Material Production Process Model



The detailed system model of the material production process depends on the data modules obtained from secondary data sources. The following table contains the sources and brief explanation about the data modules used in this study.

Table 4-1: Polyolefin Material Production Data Module Descriptions

Material	Source	Description
PP Production	DEAM module name - Polypropylene: Production.1 Original source - Eco-Profiles of the European plastics industry Report 10: Polymer Conversion, by I. Boustead.[1]	Technology – Production of 1 kg polypropylene (PP) Temporal – Report published in 1997 Geographical – Data from European plastics industry.
HDPE Production	DEAM module name - High Density Polyethylene (HDPE): Production.1 Original source – Eco-Profiles of the European plastics industry, Report 10: Polymer Conversion, by I. Boustead.	Technology – Production of 1 kg polyethylene (HDPE) Temporal – Report published in 1997 Geographical – Data from European plastics industry.
LDPE Production	DEAM module name -Low Density Polyethylene (LDPE): Production.1 Original source – Eco-Profiles of the European plastics industry, Report 10: Polymer Conversion, by I. Boustead.	Technology – Production of 1 kg polyethylene (LDPE) Temporal – Report published in 1997 Geographical – Data from European plastics industry.
LLDPE Production	DEAM module name - Low Density Polyethylene (LDPE): Production 1. Original source – Eco-Profiles of the European plastics industry, Report 10: Polymer Conversion, by I. Boustead.	Technology – Production of 1 kg polyethylene (LDPE) Temporal – Report published in 1997 Geographical – Data from European plastics industry.

4.2.1.2 PET

As shown in Figure 4-4, the production subsystem of PET includes an oxidization hydration process and a poly-condensation process instead of the polymerization process shown in the PP and PE production process.

[1] Material production data from United States is not publicly available. European data has been used in its place.

Figure 4-4: PET Material Production Process Model

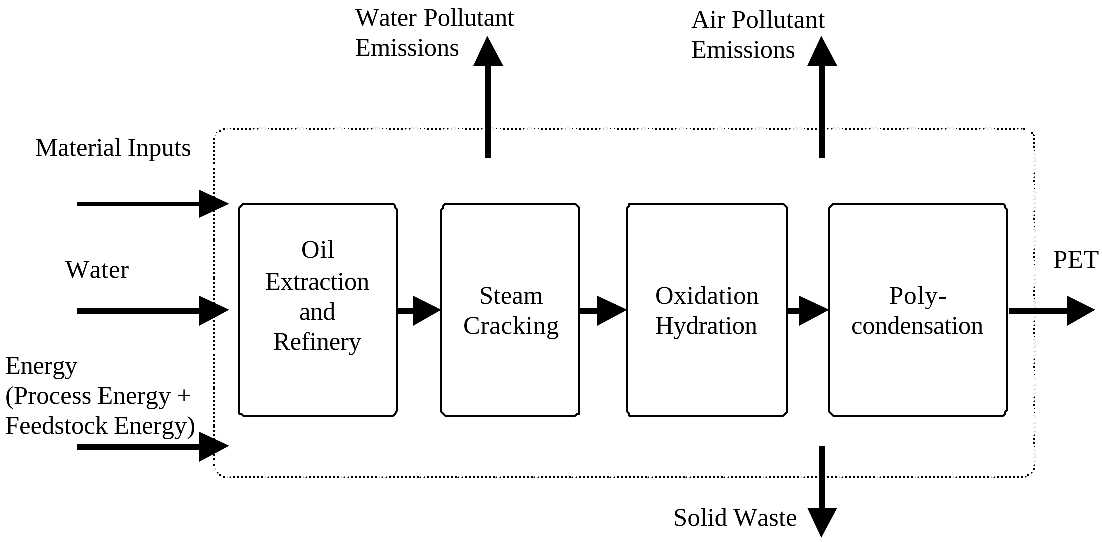


Table 4-2: PET Material Production Data Module Description

Material	Source	Description
PET Production	DEAM module name – Polyethylene Terephthalate (PET, Resin): Production.1 Original source - Eco-profiles of the European plastics industry, Report 8: Polyethylene Terephthalate (PET), by I. Boustead Primary source for energy - IEA (Int'l Energy Agency)	Technology – Production of 1 kg of PET resin. Temporal – Data published 1998. Geographical – Data on PET production processes have been supplied for six plants operating in Europe.

4.2.1.3 Polylactide

Polylactide (PLA) is a polymer derived from renewable carbohydrates such as corn and sugar beets. PLA is not currently produced in large-scale commercial quantities in the U.S. and therefore life cycle data were not readily available. Cargill Dow Polymers (CDP) is scheduled to begin PLA production in 2002 using corn grain as the raw material. This study assumed that PLA would be produced at CDP's Blair, Nebraska facility, which is scheduled to be operational in 2002.

Material production of PLA includes Corn Farming, Corn Wet Milling and Polymer Production. Corn Farming involves activities such as tilling, planting, irrigating, fertilizing and harvesting the corn. Corn Wet Milling involves steeping the corn in warm water and a series of grinding, washing and screening operations. Drying, refining and fermentation processes are also performed as required for the desired product outputs. The Corn Wet Milling process can yield 14.5 kg of starch, 5.2 kg of

20% gluten feed, 1.4 kg of 60% gluten meal and 0.7 kg of corn oil from one bushel of corn (25.4 kg).[34] It is the starch that is used to produce PLA.

Polymer Production involves converting the starch into dextrose and then using a fermentation process to turn the dextrose into lactic acid. The lactic acid is converted into lactide through a condensation process. Lactide is purified using vacuum distillation and then polymerized using a solvent-free melt process.

Figure 4-5: PLA Material Production Process Model

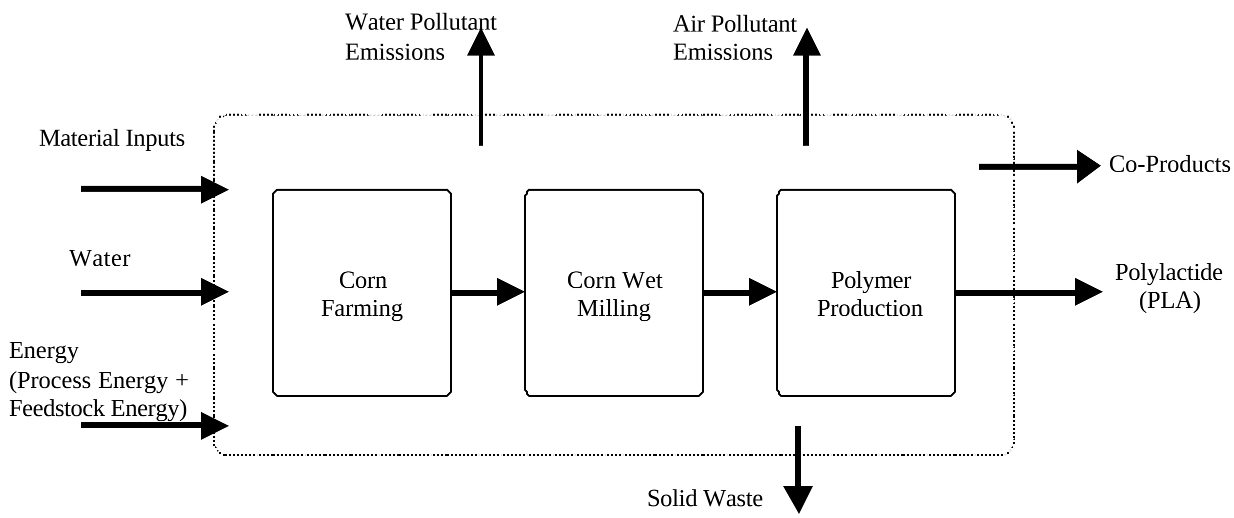


Table 4-3: PLA Material Production Data Module Description

Material	Source	Description
PLA Production – Corn Farming, Corn Wet Milling and Polymer Production	Corn Farming 1. Limestone (US, CaCO3): Quarrying.1 2. Nitrogen (US, N2): Production.2 3. Potash (KCl): Production.1 4. Superphosphate (Normal): Production.1 5. Natural Gas (US): Production.2 6. Natural Gas (US, Industrial Boiler): Combustion.2 7. Petrochemical Feedstocks (US): Production.2 8. Electricity (US, average): Production.2 9. Diesel Oil (US): Production.2 10. Diesel Oil (US, tractor):	Technology – ❑ Farming, Milling and Polymerization data all from U.S. sources. 1. Limestone quarrying Energy production included 2. Separation from air via cryogenic distillation. 3. Production of Potash. 4. Production of superphosphate (normal) which contains (18% P2O5). 5. Natural gas production includes: Recovery of natural gas, dehydration, sweetening, pipeline transport including compressor station energy. 6. Natural gas combustion considers no waste or water effluents, Heating value: 52 MJ/kg, density: 0.022 kg/scf. Natural gas boiler. EPA AP-42 emissions factors for large industrial boilers and small industrial boilers (averaged together)

	Engine Combustion.2 Original source -- 1. Swiss Federal Office of Environment, Forests and Landscape (FOEFL or BUWAL) Environmental Series No. 132 Bern, February 1991 energy requirements page A35 air/water/waste page A36 2. U.S. Department of Energy/ Office of Industrial Technologies/ Nice 3 and Praxair Distribution, Inc. 3. The Fertilizer Handbook 4. Bo Weidema, LC screening of Food Products. Danish Academy of Technical Sciences (p. 51) 5. DeLuchi, Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, Volume 2: Appendix G, Tables G1 and G2., 1987 U.S. Census Bureau data-- Diesel Oil Combustion of equipment used for natural gas recovery: data from AP-42 6. U.S.-EPA AP-42, October 1998 -- Argonne National Laboratory, IL, U.S. Department of Commerce, Nov. 1993. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity. Energy Information Administration. Electric Power 7. Sources: Crude Oil Production:--Energy Requirements: 'Energy Technology Characterizations Handbook' (DOE, 1983)-- Air Emissions: (EPA, AP-42), VOC Air emissions: U.S. Environmental	7. The module includes domestic and foreign crude oil production (onshore conventional, advanced recovery and offshore conventional recovery), transportation to the refineries in the U.S., crude oil refining into petrochemical feedstock and transportation from refinery to end-user 8. This module includes the production, combustion (at a utility), and waste (ash, slag, etc.) management of the five main fuels in the U.S. electricity grid (the percentage of each fuel in the grid is in parentheses): Coal (56.6%), Natural Gas (8.6%), Heavy Fuel Oil (2.2%), Nuclear (22%) and Hydroelectricity (10.6%) 9. This module includes domestic and foreign crude oil production (onshore conventional, advanced recovery and offshore conventional recovery), transportation to the refineries in the U.S., crude oil refining into Diesel oil transportation from refinery to end-user 10. Diesel oil combustion in a farm tractor Temporal -- 1. February 1991 2,3,4 Data unavailable 5,6,7 Refer to original data source 8. 1996 9. Refer to original data source 10. Data unavailable Geographical – 1. US data 2. US data 3. Data unavailable 4. Data taken from Danish publication 5. US data 6. US data 7. US data 8. US data 9. US data 10. US data

	Protection Agency (EPA, 1990) --Total Wastewater and Composition: (EPA,1987)--Solid Waste: (Tyson et al., 1993) Oil Refinery: --Raw materials and energy: EIA 'Petroleum Supply Annual 1994' --Air Emissions: EPA AP-4 fifth edition (Methane and N2O from Deluchi 1993)--Wastewater: EPA 'VOC emissions from Petroleum Refinery Wastewater Systems-Background Information for Proposed Standards' (1985), DOE 'Energy Technologies and the Environment' (1988) --Solid Waste: API 'The Generation of Wastes and Secondary Materials in the Petroleum Refining Industry' (1991)Transport from Refinery to Utility:--DeLuchi, Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, Volume 2: Table E1a and Appendix H (specifically, EIA Petroleum Supply Annual data) 8. EIA-759, U.S. Department of Energy, 1996 Electric Utility Net generation by NERC Region and Fuel Type.--EIA Coal Industry Annual 1996, Table ES4—U.S. DOE Energy Technology Characterizations Handbook: Environmental Pollution and Control 9. Crude Oil Production:--Energy Requirements: 'Energy Technology Characterizations Handbook' (DOE, 1983)--Air Emissions: (EPA, AP-42), VOC Air emissions: U.S. Environmental	

	Protection Agency (EPA, 1990) --Total Wastewater and Composition: (EPA,1987)--Solid Waste: (Tyson et al., 1993)Oil Refinery:--Raw materials and energy: EIA 'Petroleum Supply Annual 1994'--Air Emissions: EPA AP-4 fifth edition (Methane and N2O from Deluchi 1993)--Wastewater: EPA 'VOC emissions from Petroleum Refinery Wastewater Systems-Background Information for Proposed Standards' (1985), DOE 'Energy Technologies and the Environment' (1988) --Solid Waste: API 'The Generation of Wastes and Secondary Materials in the Petroleum Refining Industry' (1991)Transport from Refinery to Utility:--DeLuchi, Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, Volume 2: Table E1a and Appendix H (specifically, EIA Petroleum Supply Annual data) 10. Argonne National Laboratory for the GREET model.	

4.2.1.4 Inks

Environmental burdens of ink production were not included in the system model due to a lack of data.

4.2.1.5 Color Concentrate

Color concentrate is added to the resin to create the desired white and cotton fluff colors for the cups and lids. The color concentrate is added to the resin during the molding process at a rate of 2% for the white color and 3% for the cotton fluff color. Color concentrate consisted of pigments and an LLDPE carrier resin. The percentage of pigment mass included in the color concentrate is 59% for white containers and 53% for cotton fluff containers. The production of pigments was not included in the system due to a lack of data. The material production of LLDPE carrier resin and the extrusion/pelletizing process of color concentrate pellets were included in the system. Color concentrate extrusion and pelletizing process burdens were obtained by subtracting the HDPE material production module from the HDPE pipe manufacturing module. The two assumptions made here were that the energy requirements for extrusion of HDPE were equivalent to that of LLDPE and that the burden of pipe extrusion was equivalent to that of pellet extrusion. The following table includes a description of the data modules used in this area.

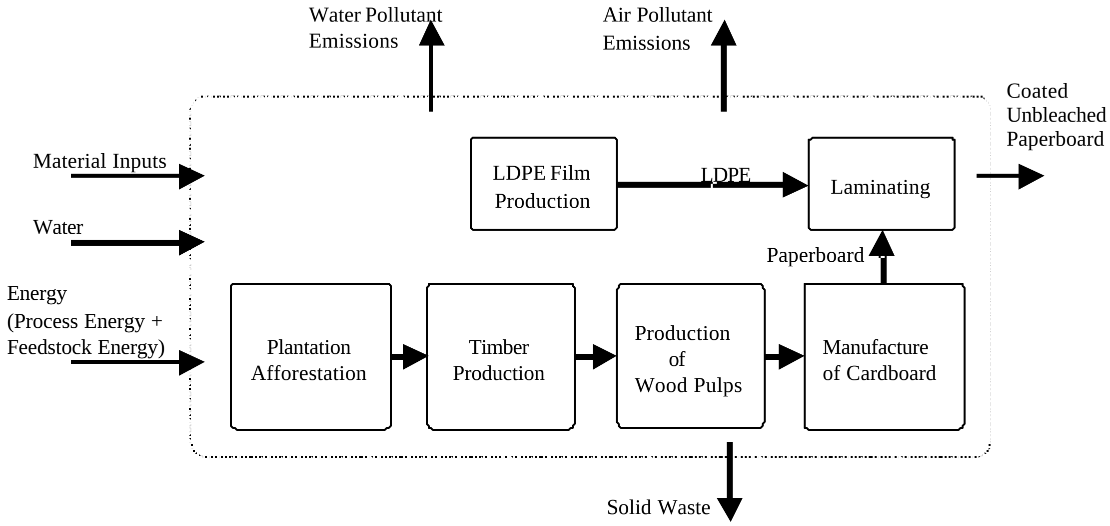
Table 4-4: Color Concentrate Material Production Data Module Description

Material	Source	Description
Cotton Fluff Color Concentrate – Coloring of plastic lids and cups	DEAM module name - 1. High Density Polyethylene Pipe: Production.1, 2. High Density Polyethylene (HDPE): Production.1, 3. Linear Low Density Polyethylene (LDPE): Production.1 Original source - Eco-Profiles of the European plastics industry, Report 10: Polymer Conversion, by I. Boustead.	Technology – ❑ Pigment component of the color concentrate is proprietary and the Material Production burdens were omitted from the model. ❑ The remaining 47% of the color concentrate is LLDPE. (LDPE data was used for LLDPE) 1. Data have been obtained from 3 factories operating in the Nederlands and producing both PVC and PE pipe. All of the weight of the pipe is assumed to be PVC homopolymer. Temporal – Report published in 1997 Geographical – Data from European plastics industry
White Color Concentrate	DEAM module name - 1. High Density Polyethylene Pipe: Production.1, 2. High Density Polyethylene (HDPE): Production.1 3. Linear Low Density Polyethylene (LDPE): Production.1 Original source - Eco-Profiles of the European plastics industry, Report 10: Polymer Conversion, by I. Boustead.	Technology – ❑ Pigment component of the color concentrate is proprietary and the Material Production burdens were omitted from the model. ❑ The remaining 41% of the color concentrate is LLDPE. (LDPE data was used for LLDPE) Temporal – Report published in 1997 Geographical – Data from European plastics industry

4.2.1.6 Coated Unbleached Paperboard for Yogurt Cups

The coated unbleached paperboard used for yogurt cups is laminated with LDPE. Therefore, the data module for LDPE coated paperboard is created by adding LDPE production and the lamination process to the unbleached kraft paper production module. The material production of coated paperboard for yogurt cups is illustrated in Figure 4-6 below.

Figure 4-6: Unbleached Paperboard (Cup) Material Production Process



The following table contains the description of the data modules that are used to calculate the total burden for producing coated paperboard used for cups.

Table 4-5: Unbleached Paperboard Production Data Module Description

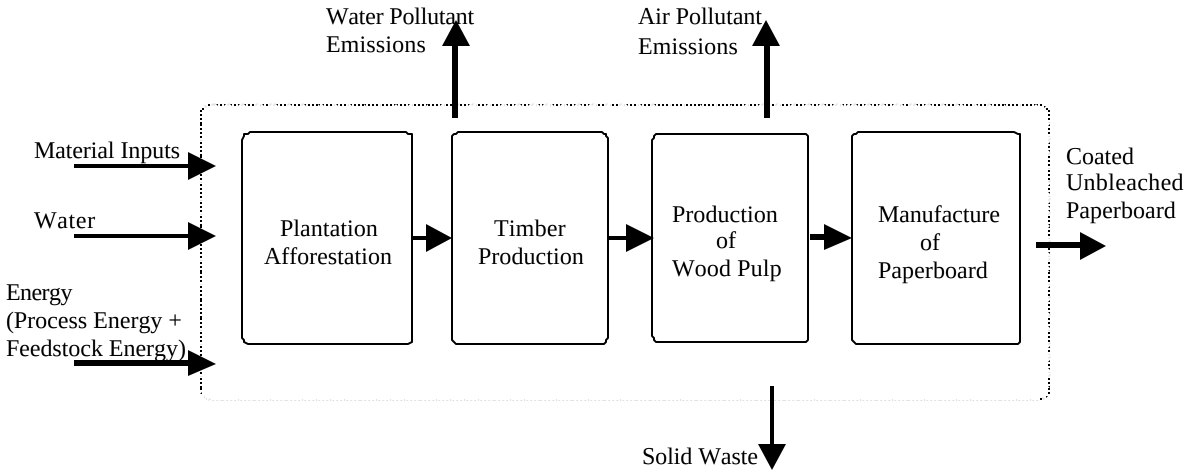
Material	Source	Description
Coated Unbleached Paperboard for Cups.	DEAM module name - 1. Paper (Kraft, Unbleached): Production. 2. Low Density Polyethylene (LDPE,Film): Production.1 3. Lamination of Plastic Paper (14.6.4 SAEFL[35]) 4. Electricity (US, average): Production.2 5. Natural Gas (US): Production.2 6. Natural Gas (US, Industrial Boiler): Combustion.2 Original Data - 1. BUWAL (Bundesamt für Umwelt, Wald und Landschaft) n°250 Band II: Ökoinventare für Verpackungen Bern, 1996 Page 212-213 2. Eco-profiles of the European plastics industry	Technology – 1. Production of 1000 kg kraft (unbleached) from pulp unbleached with sulphate 2. Production of 1000 kg Polyethylene (LDPE) Film 3. Energy requirement for composite film 1000m2 is 13kwh of electricity and 1.28m3 of natural gas. 4. This module includes the production, combustion (at a utility), and waste (ash, slag, etc.) management of the five main fuels in the U.S. electricity grid (the percentage of each fuel in the grid is in parentheses): Coal (56.6%), Natural Gas (8.6%), Heavy Fuel Oil (2.2%), Nuclear (22%) and Hydroelectricity (10.6%) 5. Natural gas production includes: Recovery of natural gas, dehydration, sweetening, pipeline transport including compressor station energy. 6. Natural gas combustion considers no waste or water effluents, Heating value: 52 MJ/kg, density: 0.022 kg/scf. Natural gas boiler. EPA AP-42 emissions factors

	Report 10: Polymer Conversion .Boustead Brussels, May 1997 Page 10. 3. SAFEL Section 14.6.4 4. EIA-759, U.S. Department of Energy, 1996 Electric Utility Net generation by NERC Region and Fuel Type. --EIA Coal Industry Annual 1996, Table ES4— U.S. DOE Energy Technology Characterizations Handbook: Environmental Pollution and Control 5. DeLuchi, Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, Volume 2: Appendix G, Tables G1 and G2., 1987 U.S. Census Bureau data-- Diesel Oil Combustion of equipment used for natural gas recovery: data from AP-42 6. U.S.-EPA AP-42, October 1998 -- Argonne National Laboratory, IL, U.S. Department of Commerce, Nov. 1993. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity. Energy Information Administration. Electric Power	for large industrial boilers and small industrial boilers (averaged together) Temporal – 1. Data collected in 1996 2. Data collected in 1993-1995 3. Data published in 1998 4. 1996 5. Refer to the source data Geographical – 1. Swiss data 2. Data derived from 14 plants in European Union. 3. European publication 4. US data 5. US data 6. US data

4.2.1.7 Coated Paperboard for Wraps and Cartons

The coated paperboard manufacturing model includes the life cycle of paperboard production including plantation afforestation, timber production, wood pulp production and paperboard production itself. Figure 4-7 illustrates the life cycle of coated paperboard production included in the data module used for this study.

Figure 4-7: Paperboard (Wraps and Cartons) Material Production Process Model



The following table contains the description of the clay coated paperboard production data module which is adopted for the paperboard wrap, a component of the 4 oz. primary packaging, and the paperboard carton, a component of the 2 oz. primary packaging.

Table 4-6: Coated Paperboard Production Data Module Description

Material	Source	Description
Coated Paperboard– Wrap for 4 oz. 6-packs and cartons for 2 oz. tubes.	DEAM module name - Cardboard (Virgin and Recycled Fibers, Duplex-Triplex Coated): Production.1 Original source - BUWAL (Bundesamt für Umwelt, Wald und Landschaft)	Technology – ❑ Production of 1000 kg Cardboard (Duplex-Triplex) divided by 1000 to produce burdens for 1 kg. ❑ All transport included. Temporal – Data collected in 1993. Geographical – Data derived from 14 plants in European Union.

4.2.2 Container Manufacturing

As described in the Product Delivery System Definition, Section 3.2, 6 oz., 8 oz. and 32 oz. containers each have three components: cups, lids and seals while the 4 oz. containers consist of cups, seals and a wrap that is used to create a multi-pack of six 4 oz. containers. The 2 oz. containers consist of film tubes and a coated paperboard carton. Five models for the Manufacturing phase were created. The first two models are for the production of the plastic container components: injection molding, which is currently used to manufacture cups and lids, and thermoforming, which is an alternate process for manufacturing cups. The other three models are for paperboard container conversion, film extrusion, and wrap and carton conversion. The following section describes each model in detail.

4.2.2.1 Injection Molding

Polytainers facility in Toronto is dedicated to the injection molding and printing of thin walled containers used primarily for dairy products. They use three types of polyolefin materials; PP (50%), LLDPE (28%) and HDPE (20%), as well as Color Concentrate (2%). Graphics are typically printed on both the cups and lids at the Toronto facility. Both the molding and printing processes were included in this Injection Molding model. Electricity, natural gas and water consumption data were collected from Polytainers. Electricity was mainly used for molding and printing machine operations and natural gas was used for the facility space and water heating (i.e., overhead). The electricity and natural gas consumption was translated into corresponding environmental burdens using DEAM to make the Polytainers injection molding model.

For this base model, the Canadian electricity grid was used to calculate the burden of electricity production. The burden of natural gas consumption was calculated considering both natural gas production and combustion. Water consumption at the Toronto facility was also added to the base model. Since the data regarding the solid waste generation at the Toronto facility was not available, the Injection Molding module from DEAM was used to calculate solid waste generation as follows: the mass of solid waste, calculated from subtracting the PP Production module from the PP Injection Molding module, was added to the base model. The air emissions from the injection molding and printing processes other than those caused by natural gas combustion were assumed to be negligible and were excluded from the model. The following table contains the data modules used to create the Polytainers injection molding model.

Table 4-7: Injection Molding Process Data Module Descriptions

Process Module	Source	Description
PP and PE Injection molding with printing.	DEAM modules name - 1. Electricity (Canada, average): Production.2 2. Natural Gas (US): Production.2 3. Natural Gas (US, Industrial Boiler): Combustion.2 Original source- The U.S. Energy Information Agency (EIA) provides most information for the modules.	Technology – 1. Canada electricity grid consists of Coal (.6%), Natural Gas (2.9%), Heavy Fuel Oil (1.6%), Nuclear (16.3%), Hydroelectricity (62.4%), Other Renewable (0.6%) 2. Natural gas production includes: Recovery of natural gas, dehydration, sweetening, pipeline transport including compressor station energy. 3. Natural gas combustion considers no waste or water effluents, Heating value: 52 MJ/kg, density: 0.022 kg/scf. Temporal – Canadian electricity data from 1996. Natural gas production and combustion data from 1998. Geographical – 1. Electricity: average Canadian grid. 2. Both production and combustion of natural gas: US.

4.2.2.2 Thermoforming

The thermoforming model for Polytainers was created assuming that the thermoforming process occurred at the Polytainers Toronto injection molding facility. The model consisted of the burdens of the thermoforming process itself and the burdens that stemmed from natural gas air and water heating at the Toronto facility. A base model was created by subtracting the PS Production module (module #2 in Table 4-8) from the thermoformed PS module (module #1 in Table 4-8). The thermoforming process burden was calculated by subtracting the overhead burdens, which were the production and combustion of natural gas, from the base model. It was assumed that the thermoforming process energy was supplied as electricity. This electricity use was converted to environmental burdens using Canadian grid data. The electricity use calculated by the above logic was verified with a thermoforming data module provided by an additional separate published data source.[36] The solid waste data for thermoforming was taken from the DEAM PS thermoforming module and added to the Polytainers thermoforming model, since primary solid waste data were not available. The following table contains the data modules used to create the Polytainers thermoforming model.

Table 4-8: Thermoforming Process Data Module Description

Process Module	Source	Description
Thermoforming	DEAM module name - Thermoforming energy consumption: 1. Polystyrene (PS): Thermoforming.1 2. Polystyrene (PS, General Purpose): Production.1 Energy consumption: 1. Electricity (Canada, average): Production.2 2. Natural Gas (US): Production.2 3. Natural Gas (US, Industrial Boiler): Combustion.2 Original Source – ❑ Eco-profiles of the European plastics industry Report 10 (PS Thermoforming) and Report 3 (PS Production) ❑ EIA-759 (Electricity) ❑ EPA AP-42 (Natural Gas production and combustion)	Technology – ❑ Canada electricity grid consists of Coal (.6%), Natural Gas (2.9%), Heavy Fuel Oil (1.6%), Nuclear (16.3%), Hydroelectricity (62.4%), Other Renewable (0.6%) ❑ Natural gas production includes: Recovery of natural gas, dehydration, sweetening, pipeline transport including compressor station energy. ❑ Natural gas combustion considers no waste or water effluents, Heating value: 52 MJ/kg, density: 0.022 kg/scf. Temporal – 1. PS Production 1997 2. PS Thermoforming 1993 – 1995 3. Electricity 1996. 4. Natural gas production and combustion data from 1998. Geographical – 1. Polystyrene production: European plastics industry 2. Thermoforming data: Italy 3. Electricity: Canadian grid. 4. Both production and combustion of natural gas: US

4.2.2.3 Paperboard Container Conversion

For the conversion module, the burdens for the conversion of paperboard, including printing process, were derived from process energy requirements reported in the SAEFL study.[37] The published energy requirements (such as diesel oil, natural gas and electricity) for Swiss plants were converted into U.S. environmental burdens using U.S. specific DEAM data modules. The Offset printing of paperboard data set included the conversion processes required for both cup and lid production. Offset printing was assumed rather than gravure printing for containers. The data modules used to create the wrap and carton conversion module are listed in Table 4-9 below.

Table 4-9 Paperboard Conversion Module Descriptions

Process Module	Source	Description
Conversion of Coated Paperboard with Offset Printing	SAEFL module name- Cardboard Offset Printing DEAM module name- 1. Diesel Oil (US): Production.2 2. Electricity (US, average): Production.2 3. Natural Gas (US): Production.2 4. Natural Gas (US, Industrial Boiler): Combustion.2 Original source – Offset printing: Environmental series No. 250/II Waste Life Cycle Inventories for Packagings Volume II by SAEFL 1. Most data from EPA 2. EIA 759 3. EPA-42 4. EPA AP-42	Technology – ❑ Offset Printing: data from 6 plant in Swiss 1. Diesel production includes: crude oil production, transportation to the refineries in the U.S., crude oil refining into Diesel oil, transportation from refinery to end-user 2. U.S. electricity grid consists of Coal (56.6%), Natural Gas (8.6%), Heavy Fuel Oil (2.2%), Nuclear (22%), Hydroelectricity (10.6%) 3. Natural gas production includes: Recovery of natural gas, dehydration, sweetening, pipeline transport including compressor station energy. 4. Natural gas combustion considers no waste or water effluents, Heating value: 52 MJ/kg, density: 0.022 kg/scf. Temporal – Diesel from various data collected from 1983-1994. U.S. electricity data from 1996. Natural gas production and combustion data from 1998. SAEFL report published in 1998. Geographical – ❑ Offset printing data from Swiss plant 1. Diesel includes both domestic and foreign production and U.S. refining. 2. Electricity: average U.S. grid. 3. Both production and combustion of natural gas: US.

4.2.2.4 Film Extrusion

The film extrusion manufacturing data module was created by subtracting the LDPE Production module from the LDPE Film Production module, which contained both the material production and extrusion manufacturing burdens. A lack of data also precluded the use of a single DEAM module containing precise information regarding co-extrusion (i.e., two different materials). The following table contains the description of the data modules.

Table 4-10: Seal Production Process Data Module Description

Process Module	Source	Description
Extrusion – 1) PE/PET film co-extrusion for seal material and 2) film extrusion for tube and tape.	DEAM module name - 1. Low Density Polyethylene (LDPE, Film): Production.1 2. Low Density Polyethylene (LDPE): Production.1 Original source - PE: Eco-Profiles of the European Plastic Industry Report 10: Polymer Conversion, by I. Boustead.	Temporal – PE: Data published 1997 for LDPE film and data collected 1989-1992 for LDPE production. Geographical – 1. Data derived from 15 plants throughout Europe and UK for LDPE. 2. No information available for LDPE Film.

4.2.2.5 Wrap and Carton Conversion

For the conversion (wrap and carton) module, the burden data of the cardboard conversion and printing process provided by the SAEFL report[38] was used as a base model from which the energy requirements (such as diesel oil, natural gas and electricity) were converted to their corresponding environmental burdens using DEAM data modules. The Offset printing of cardboard data set included the conversion processes required for wrap and carton production. Offset printing was assumed rather than gravure printing for wraps and cartons from information obtained from packaging datasheets. The data modules used to create the wrap and carton conversion module are listed in Table 4-11.

Table 4-11 Wrap and Carton Conversion Module Descriptions

Process Module	Source	Description
Conversion of Coated Paperboard with Offset Printing	SAEFL module name- Cardboard Offset Printing DEAM module name- 1. Diesel Oil (US): Production.2 2. Electricity (US, average): Production.2 3. Natural Gas (US): Production.2 4. Natural Gas (US, Industrial Boiler): Combustion.2 Original source –	Technology – ❑ Offset Printing: data from 6 plant in Swiss 1. Diesel production includes: crude oil production, transportation to the refineries in the U.S., crude oil refining into Diesel oil, transportation from refinery to end-user 2. U.S. electricity grid consists of Coal (56.6%), Natural Gas (8.6%), Heavy Fuel Oil (2.2%), Nuclear (22%), Hydroelectricity (10.6%) 3. Natural gas production includes: Recovery of natural gas, dehydration, sweetening, pipeline transport including compressor station energy. 4. Natural gas combustion considers no

	Offset printing: Environmental series No. 250/II Waste Life Cycle Inventories for Packagings Volume II by SAEFL 1. Most data from EPA 2. EIA 759 3. EPA-42 4. EPA AP-42	waste or water effluents, Heating value: 52 MJ/kg, density: 0.022 kg/scf. Temporal – Diesel from various data collected from 1983-1994. U.S. electricity data from 1996. Natural gas production and combustion data from 1998. SAEFL report published in 1998. Geographical – ❑ Offset printing data from Swiss plant 1. Diesel includes both domestic and foreign production and U.S. refining. 2. Electricity: average U.S. grid. 3. Both production and combustion of natural gas: US.

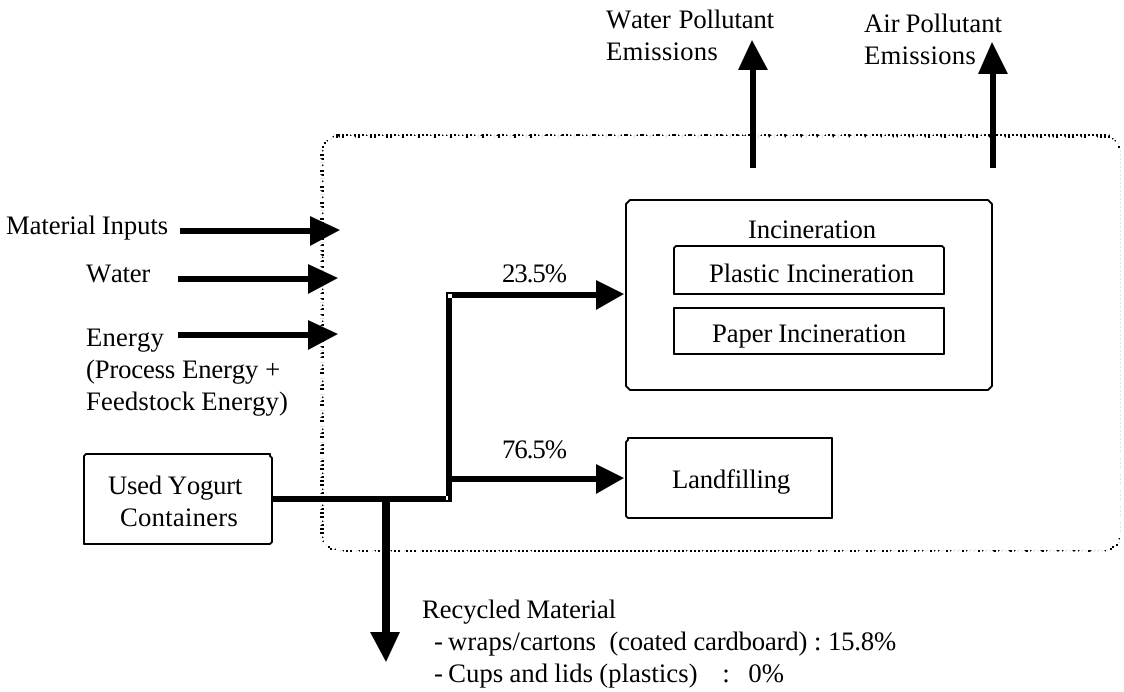
4.2.3 Filling

The burdens of yogurt production and filling processes were not included in the system model, except for scrap produced in the seal and tube trimming processes. The model also accounted for primary packaging damaged in the yogurt filling processes. The detailed calculations for these scrap values are explained in Section 4.5, Calculation Procedures.

4.2.4 End-of-Life

End-of-Life process modeling accounted for the environmental burdens that stemmed from waste treatment of used containers. It was assumed that all of yogurt products produced in the Yogurt Filling phase were consumed at market and all the containers were transported to the waste treatment site. This study adopted the national average ratio of waste treatment methods of 23.5% incineration versus 76.5% landfilling.[39] These percentages were applied to the solid waste remaining after the recyclable materials were taken out. Coated cardboard used for the 4 oz. container wraps and 2 oz. tube cartons was diverted to the Recycled Material data category at the rate of 15.8%.[40]

Figure 4-8: LCI End-of-Life Model



4.2.4.1 Incineration

The incineration model depended on the data modules obtained from the DEAM database. Two incineration data modules – incineration of paper and plastics – were used. The following table contains descriptions of the data modules used in this study. The negative values of fuel energy in the incineration data modules were regarded as the energy recovered for electricity generation. The negative feedstock energy values were disregarded, however, because they were already counted as the recovered energy through electricity generation as described above.

Table 4-12: Incineration Solid Waste Disposal Module Descriptions

Disposal Module	Source	Description
Incineration (Paper)	DEAM module name – Miscellaneous Paper (US, with energy recovery): Incineration.2 Original source – North Carolina State University, 'Waste-to-Energy Process Model.	Technology – ❑ Energy is assumed to be recovered as electricity (heating value is 12,591 MJ/ton) ❑ Landfilling and leachate from the ash is accounted for (leachate for 100 years, treatment for 80 years). Temporal – Data published in 1997. Geographical – Information is from work done for the EPA Waste Management LCA project (US specific).
Incineration (Plastic)	DEAM module name - Plastic (US, with energy	Technology – ❑ Energy is assumed to be recovered as

	recovery): Incineration.2 Original source – North Carolina State University, 'Waste-to-Energy Process Model.	electricity (heating value is 36,133 MJ/ ton). ❑ Landfilling and leachate from the ash is accounted for (leachate for 100 years, treatment for 80 years). Temporal – Data published in 1997. Geographical – Information is from work done for the EPA Waste Management LCA project (US specific).

4.2.4.2 Landfilling

The landfilling model was also from a DEAM data module described in the following table. The data module without energy recovery was used for the landfilling model to be conservative. In the energy category, the DEAM module showed feedstock energy as a negative value to indicate that energy contained in materials buried in landfills can no longer be recovered. This negative value was removed for our calculations to avoid crediting energy for landfilled waste.

Table 4-13: Landfilling Solid Waste Disposal Module Description

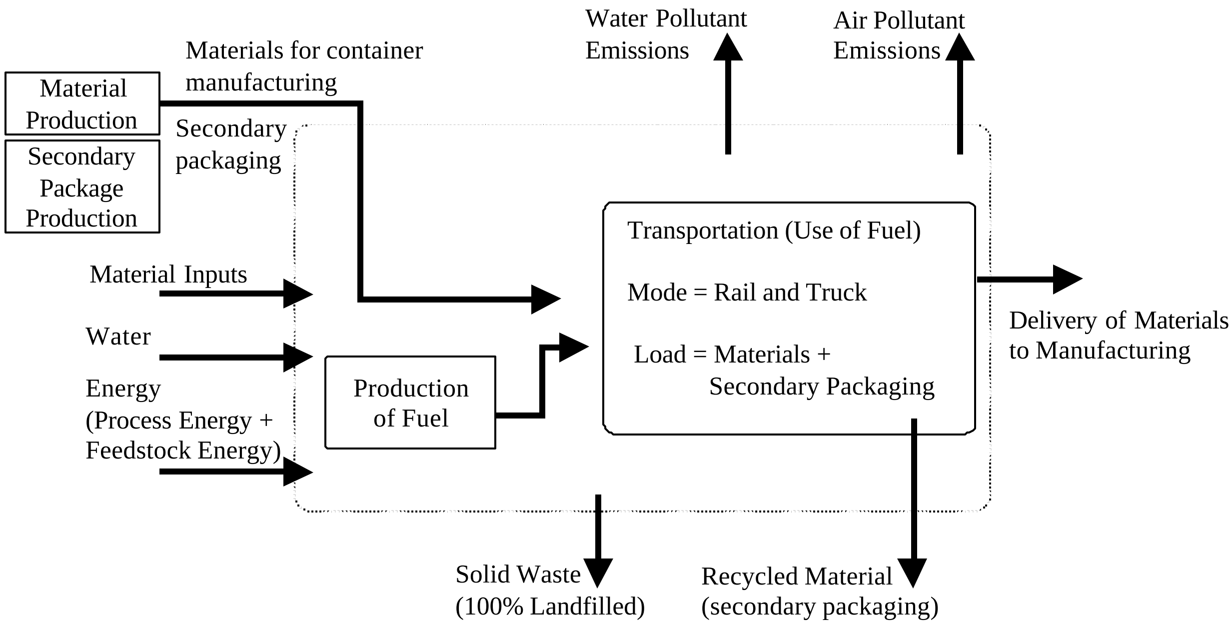
Disposal Module	Source	Description
Landfill (MSW)	DEAM module name - Landfilling without Energy Recovery (US, MSW, average).2 Original source – Unknown to Eco-Balance	Technology – ❑ Disposal of MSW in a Subtitle D landfill. ❑ DOES NOT include energy recovery of the landfill gas (gas is assumed to be flared) ❑ Results for 1000 kg of MSW for 100 years were divided by 1000 to generate burdens for 1 kg. ❑ Heating Value of MSW: 10 MJ/kg, 62% renewable and 38% non-renewable. Temporal – Module not dated. Geographical – No information available.

4.2.5 Distribution

4.2.5.1 Distribution 1

Distribution 1 model includes environmental burdens associated with transportation of materials used for the manufacturing of the primary packaging. As such, the scope of Distribution 1 was the transportation between material producers and the respective container component manufacturers. The burdens of fuel production and fuel use were taken into consideration. The transport load is the sum of the weight of materials for manufacturing of primary packaging (yogurt containers) and the weight of secondary packaging used for the transportation of these materials. Distribution 1 does not include the production of the secondary packaging, however, much of the material was shipped in bulk and therefore the use of non-reusable secondary packaging was very limited. Each material was transported from the producer to the container manufacturer by rail or truck. The configuration of secondary packaging was defined to be unique to the transportation mode of a certain material. The waste associated with the losses of carried materials during transportation was assumed to be landfilled at a rate of 100%.

Figure 4-9: LCI Distribution 1 Model

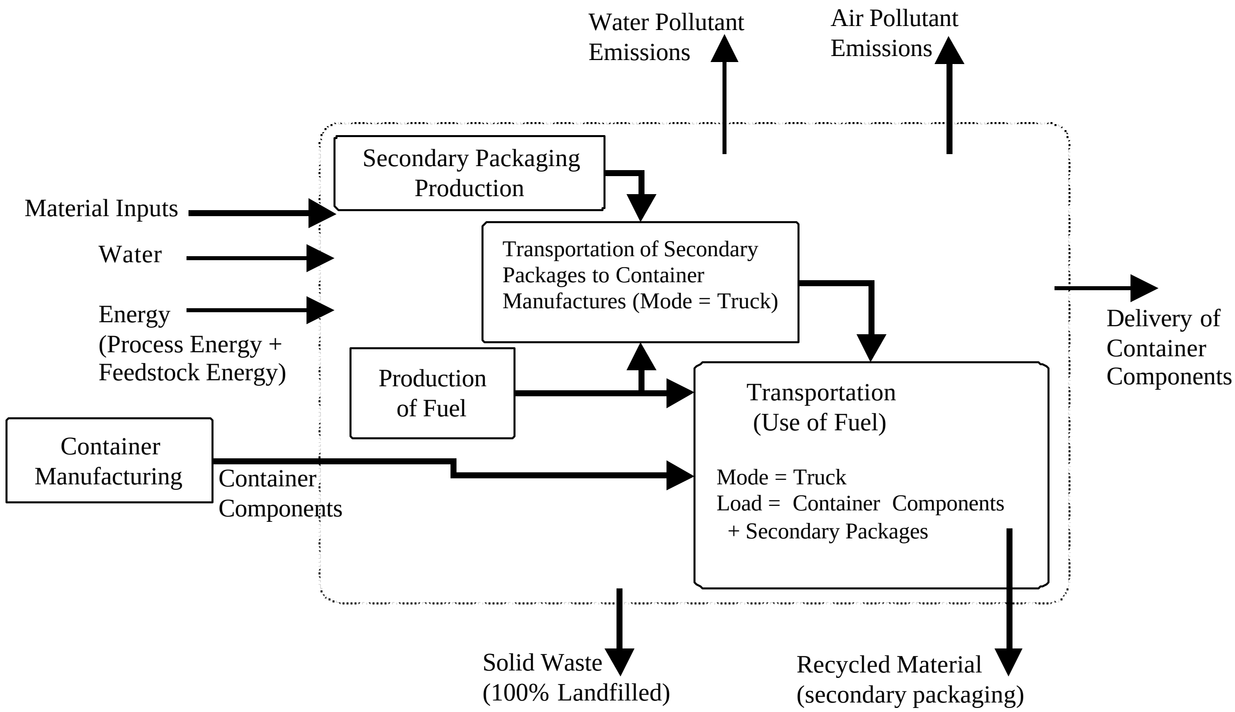


The DEAM data modules for Rail and Truck include both the production of fuel and the use of fuel for transportation. Table 4-14 includes descriptions of the Rail and Truck modules used for the distribution phases in this study.

4.2.5.2 Distribution 2

Distribution 2 modeled the transportation of yogurt container components between container manufacturers and Stonyfield. This transportation took into account the weight of both the primary packaging (yogurt containers) and secondary packaging, such as corrugated boxes, cardboard separators, pallets and the stretch wrap. The burdens of manufacturing of secondary packaging materials are also included in Distribution 2. However, the conversion of these materials into secondary packaging, such as corrugated board into boxes or lumber into pallets, was not included in this model due to lack of data. Table 4-15 contains the description of data modules used to calculate these burdens. In addition, the transportation of secondary packaging from the suppliers to container manufactures was included in this model with the assumption that all packaging is transported by 40-ton capacity truck.

Figure 4-10: LCI Distribution 2 Model



4.2.5.3 Distribution 3

Distribution 3 models the transportation of yogurt products from Stonyfield to retailers. With regard to secondary packaging, their material production and their transportation from the suppliers to Stonyfield were taken into account. As in Distribution 2, the conversion of these materials into secondary packaging, such as corrugated board into boxes or wood into pallets, was not included in this model due to lack of data. The waste of secondary packages and transportation losses of carried materials were assumed to be all landfilled. The recycled secondary packaging was counted as a Recycled Material output.

Figure 4-11: LCI Distribution 3 Model

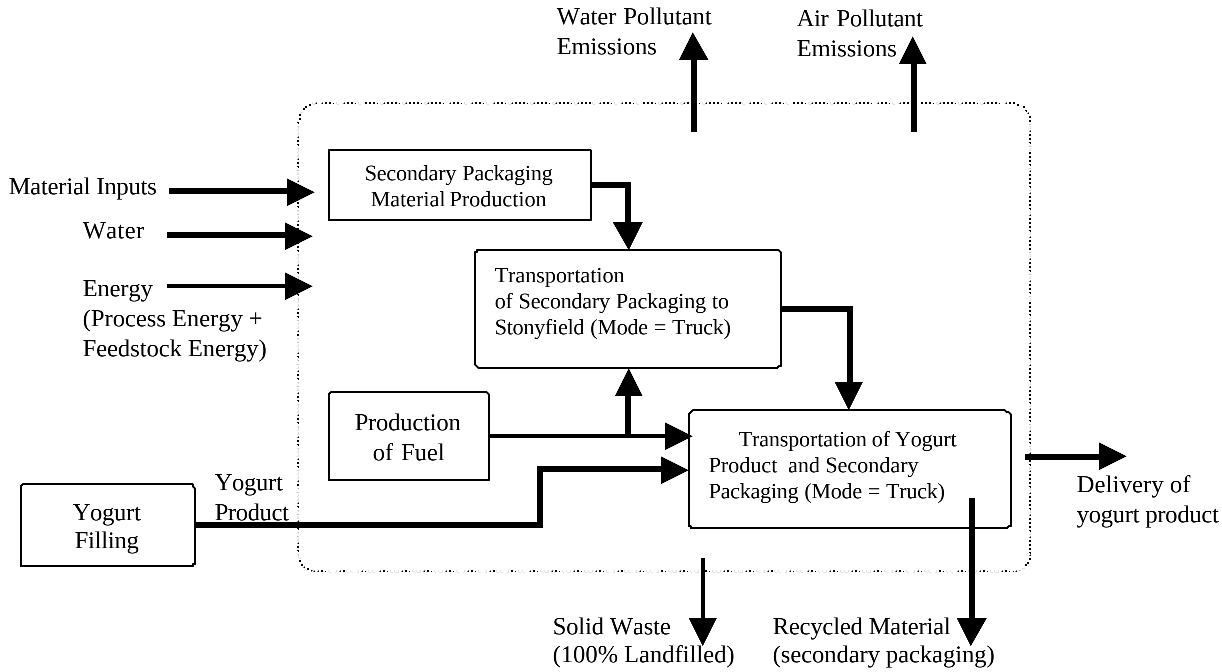


Table 4-14: Transportation Data Module Descriptions

Transport Mode	Source	Description
Rail	DEAM module name – Rail Transport (US, Diesel Oil, kg.km).1 Original source - Laboratorium fur Energiesysteme	Technology – ❑ Consumption of diesel in rail transport (European Data): 0.0056 liter/km metric ton (shipped). ❑ Diesel Oil Production: US data Temporal – Data from 1993-1994. Geographical – 1. Consumption of diesel derived from European average. 2. Diesel production burdens from U.S.
Truck	DEAM module name – 1. Road Transport (Truck 40 t, Diesel Oil, kg.km).1 2. Diesel Oil (US): Production.2 Original source - 1.Anhang B: Strassengutertransport 2. Crude Oil Production: --Energy Requirements: Energy Technology Characterizations Handbook(DOE, 1983) --Air Emissions: (EPA, AP-42),	Technology – 1.Road Transport ❑ Data on combustion derived from diesel truck fuel consumption and emissions (maximum and average load: 40 000kg). ❑ The actual load of the truck is 24 000 kg and the empty return is accounted. ❑ The consumption of the truck with the maximum load is 39 litters per 100 km 2. Diesel Oil ❑ Transport to refineries includes: fluvial, pipeline, rail, sea, and road (only domestic). Oil refinery data is U.S. refinery operations. Transport from refinery to utility includes pipeline (85%,

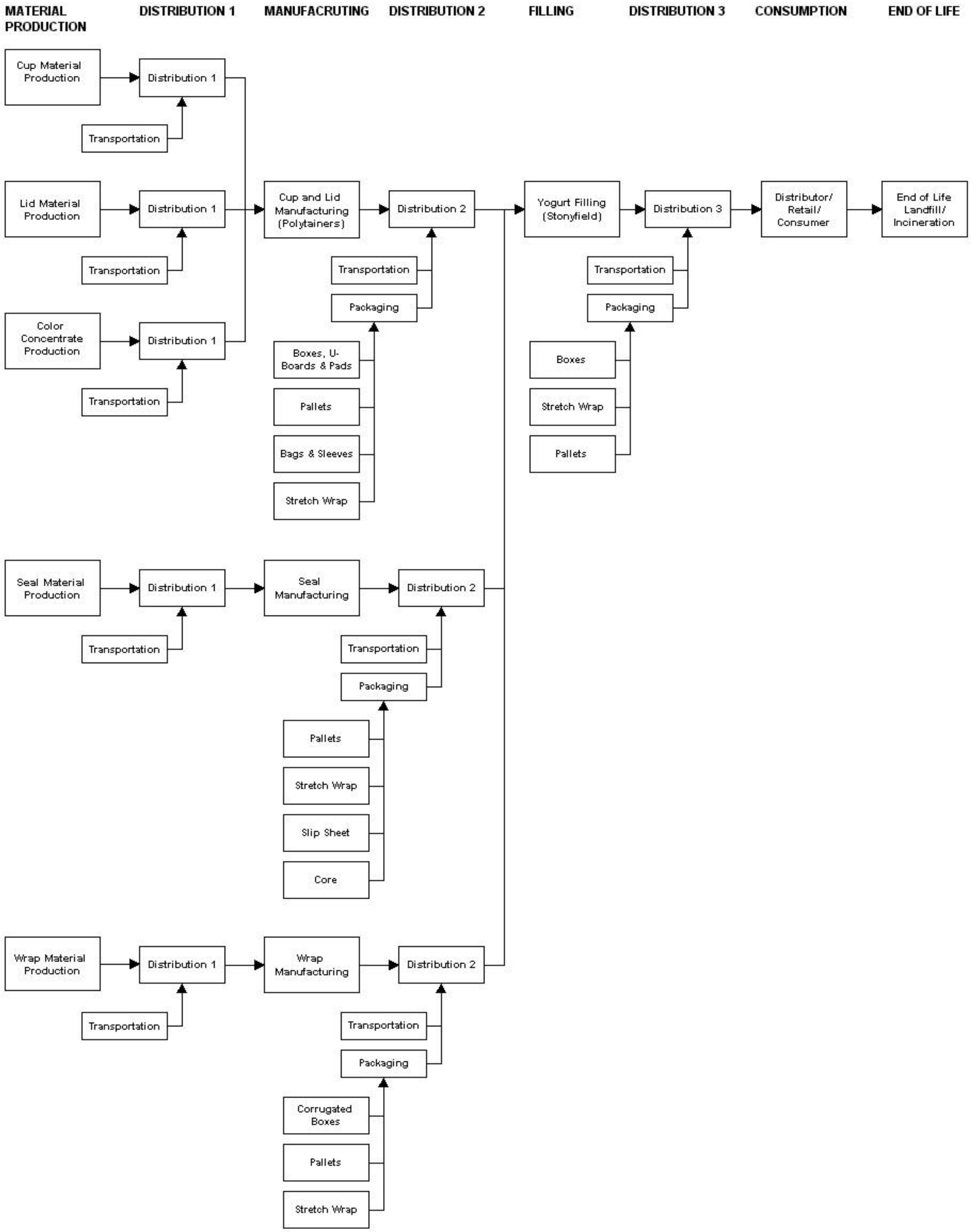
	VOC Air emissions: U.S. Environmental Protection Agency (EPA, 1990) --Total Wastewater and Composition: (EPA,1987) --Solid Waste: (Tyson et al., 1993) Oil Refinery: --Raw materials and energy: EIA Petroleum Supply Annual 1994 --Air Emissions: EPA AP-4 fifth edition (Methane and N2O from Deluchi 1993) --Wastewater: EPA VOC emissions from Petroleum Refinery Wastewater Systems-Background Information for Proposed Standards (1985), DOE Energy Technologies and the Environment (1988) --Solid Waste: API The Generation of Wastes and Secondary Materials in the Petroleum Refining Industry (1991) Transport from Refinery to Utility: --DeLuchi, Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, Volume 2:	800 mi.) and road transport (15%, 75 mi. one way) Temporal – 1. Data published in 1996. 2. Refer to the left column. Geographical – 1. Module models European trucking, data compiled in Zurich, Switzerland.

Table 4-15: Secondary Packaging Data Module Description

Material Module	Source	Description
Corrugated Board Following two types of corrugated board were modeled: Type I : (1.:22% 2. 78%)- Used for Boxes and U-boards Type II: (1.: 100%)	DEAM module name - 1. Corrugated Cardboard (Recycled Fibers): Production.1, and 2. Corrugated Cardboard (Virgin Fibers): Production.1 Original source - BUWAL (Bundesamt für Umwelt, Wald und Landschaft)	Technology – 1. Composition: 67% testliner, 33% medium 2. Composition: 34% brown kraftliner, 33% medium, 33% testliner ❑ All transports included for both Virgin and Recycled modules. ❑ Ratios of Recycled and Virgin Corrugated modules were adjusted to model actual recycled content. Temporal – All data published in 1996. Geographical – 1. Data derived from one plant in Switzerland. 2. Data from one plant in Switzerland.
LLDPE Film	DEAM module name - Low Density Polyethylene (LDPE, Film): Production.1 Original source - Eco-Profiles of the European plastics industry, Report 10: Polymer Conversion, by I. Boustead.	Technology – ❑ Burdens associated with the production of LLDPE Film assumed to be identical to LDPE Film. ❑ Data obtained for the production of 67000 metric tons LDPE film per year. ❑ Production of 1000 kg Polyethylene (LDPE) Film divided by 1000 to generate burdens for 1 kg. Temporal – Data published 1997. Geographical – No information available.
Paper Board	DEAM module name - Cardboard (Virgin Fibers): Production.1 Original source - Eco-Balance DEAM Module. Information from BUWAL (Bundesamt für Umwelt, Wald und Landschaft)	Technology – ❑ Production of 1000 kg cardboard (flat, 100% virgin fiber) divided by 1000 to produce burdens for 1 kg. ❑ Density: 300 g/m2, moisture content: 8% ❑ All transport included. Temporal – Data published 1996. Geographical – Data derived from one plant in Sweden.
Wood	Data name - Kiln-dried lumber. Original source - Life Cycle Inventory of Western Wood Products Association (WWPA) - Scientific Certification Systems, Inc.	Technology – ❑ Resource regeneration, reuse and recycling considered beyond the scope of the study. ❑ Moisture content of wood products assumed to be 0%. Temporal –Data published August 1995. Geographical – Representative sample was taken of 75 sawmills throughout the Western Wood Region (12 states including Alaska).

4.3 Material Flow Diagram

Figure 4-12: Material Flow Diagram Used to Model PDS Life Cycle



4.4 Allocation Procedures

Allocation procedures are used to partition inputs and/or outputs within a product system. An allocation procedure is required when a unit process within a system shares a common pollution treatment infrastructure or where multiple products or co-products are produced in a common unit process.[41] The system on which this research focused was a product delivery system so it did not produce any co-product, except for the electricity generated at municipal solid waste management sites. However, several allocation rules were adopted in each phase; the following sections discuss them phase by phase.

4.4.1 Material Production

4.4.1.1 Co-Product Allocation

Since all the input/output data in the Material Production phase were obtained from secondary data sources, the allocation rules were defined for these data modules in the sections above.

4.4.1.2. Recycling Allocation

As described above, recycling allocation rules also depended on the data modules from secondary data sources.

4.4.2 Manufacturing

4.4.2.1 Co-Product Allocation for Plastic Containers

The Polytainers manufacturing facility in Toronto produces various containers that are supplied to companies other than Stonyfield. The primary data collected, such as energy consumption and water use, were associated with the total production activities conducted at the Toronto facility. Therefore, an allocation procedure was adopted to estimate the portion that accounts for the manufacturing of Stonyfield containers out of the total energy and water consumption. This allocation was made on a mass basis with the assumption that the molding machines' energy consumption is in proportion to the mass of the resins used in those machines. The same allocation rule was applied for water use.

Facility level data were used instead of process level data for two reasons. First, the production of Stonyfield containers was not dedicated to a specific set of molding machines. Polytainers' use of interchangeable molds and a flexible production schedule resulted in the cups and lids being produced on a variety of different sized molding machines. Second, overhead energy consumption, such as that used for air-conditioning and lighting, could not be allocated easily to individual process lines.

4.4.2.2 Co-Product Allocation for Coated Paperboard

As described above, recycling allocation rules depended on the data modules from secondary data sources.

4.4.2.3 Recycling Allocation

In the plastic molding and paperboard conversion processes, there were several losses of materials. Such plastic and paper wastes were sent to recycling companies and recycled in an open-loop system. Since the recycled materials were not recovered within this same system, they were counted in the Recycled Material data category.

4.4.3 Yogurt Filling

4.4.3.1 Co-Product Allocation

There was no co-product in the yogurt filling unit process.

4.4.3.2 Recycling Allocation

No recycling allocation rules are adopted.

4.4.4 End-of-Life

4.4.4.1 Co-Product Allocation

Some incinerators have energy recovery devices that generate electricity by incinerating wastes. Electricity generated in this way at the End-of-Life phase was treated as a co-product, and the environmental burdens that would otherwise occur with normal electricity production were subtracted from the total environmental burden of the End-of-Life phase.

4.4.4.2 Recycling Allocation

There are several materials that were converted from solid wastes to reusable materials in other systems. In this study, we assumed a zero percent recycle rate for cups, lids and seals and 15.8% for the coated paperboard wraps and cartons. Since the recycled cardboard was utilized in an open-loop system, the mass of recycled cardboard was counted in the Recycled Material data category.

4.4.5 Distribution 1

4.4.5.1 Co-Product Allocation

There was no co-product from Distribution 1 phase.

4.4.5.2 Recycling Allocation

There was no recycling allocation in Distribution 1 phase.

4.4.6 Distribution 2

4.4.6.1 Co-Product Allocation

There was no co-product from Distribution 2 phase.

4.4.6.2 Recycling Allocation

100% of the corrugated cardboard boxes used in Distribution 2 was sent to a recycling company to be reused. However, since these boxes were reused outside the

PDS, the mass of the used boxes was classified in the Recycled Material data category.

Pallets have been considered differently than the corrugated cardboard boxes because they are not only recycled but also reused. According to a study cited by Polytainers, pallets are used for 16 round trips on average, which amounts to a reuse rate of 94%. The remaining 6% of pallets are damaged and sent to re-manufacturing facilities (71%) or discarded (29%).[42] The mass of recycled pallets was classified into the Recycled Material data category while the mass of discarded pallets was counted as Solid Waste. The 6% of total pallets, which was replaced with new or rebuilt pallets in each delivery cycle, was counted as the new pallet material (wood) input to the distribution phase under study.

4.4.7 Distribution 3

4.4.7.1 Co-Product Allocation

There is no co-product from Distribution 3 phase.

4.4.7.2 Recycling Allocation

Allocation rules within the Distribution 3 phase were exactly the same as within the Distribution 2 phase.

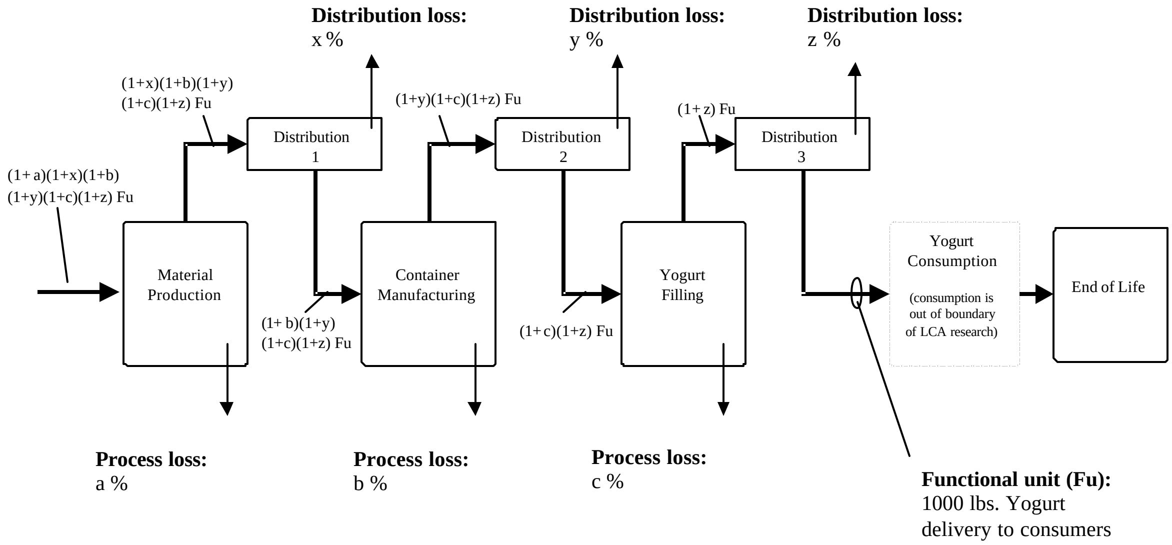
4.5 Calculation Procedures

This section explains the procedures by which inputs and outputs generated from each unit process were calculated. All the calculations of inputs and outputs from each unit process were based on the mass of product output from each unit process. For this reason, it was important to determine how much product output each unit process generates. The following section describes (1) how the product output from each unit process was determined and (2) how the inputs and outputs (burdens) from each unit process associated with the product output was calculated.

4.5.1 Functional Unit and Losses

As discussed in Section 3.1, the functional unit of this system is 1,000 lbs. of yogurt delivery to retailers or distributors. Figure 4-13 illustrates how the product output from each process unit was calculated considering various losses that occurred in the downstream unit processes. For example, if a distribution loss at Distribution 3 was defined as z%, the Yogurt Filling unit process has to produce z% additional functional units of yogurt as its product output, because z% out of 1,000 lbs. is to be lost before it reaches retailers and distributors. The product output from each process unit was calculated by multiplying each of the down stream loss rates by the functional unit.

Figure 4-13: Unit Process Output Calculation Diagram



Distribution loss: (applicable to Distribution 1,2,3)

Each distribution unit process may adopt multiple transportation modes such as truck and rail. The loss rate of each unit process was calculated using a weighted average of the transport mode loss rates. For example, when Distribution 3 had mode 1 and mode 2 in the ratio of R1 and R2 respectively and corresponding loss rates were L1 and L2, the overall loss rate, Z, was calculated with following formula:

$$Z = R1 \times L1 + R2 \times L2$$

Process loss:

Yogurt Filling:

To calculate the total process loss (c) (in Figure 4-13) at Filling, an engineering scrap rate (E) and a filling process scrap rate (F) were defined. The engineering scrap rate (E) is used to calculate the scrap that is generated when round shape seals are cut out of the plastic sheet and when edges are trimmed from tube stock. The filling process scrap rate (F) was defined as the ratio of yogurt containers damaged through the filling process. Since the seals and tubes are also lost in the filling process after they are successfully cut out, the total scrap rate of seals and tubes in the Yogurt Filling phase (c) was defined as follows.

$$c = (1 + E)(1 + F) - 1$$

where E: engineering scrap rate
F: filling process scrap rate

Yogurt containers loss rate through the filling process is represented simply by F.

Container Manufacturing/Material Production:

The scrap rates "b" and "a" (in Figure 4-13) were defined as single scrap rates for the container manufacturing and material production unit processes respectively.

The scrap rate for Material Production is embedded in the individual material production DEAM modules. The scrap rates for Manufacturing are described in further detail in Section 4.7.

Once the product output was determined by the formulas described above, total environmental burdens from each unit process were calculated based on the mass of product output. The following sections describe calculation procedures for all phases in order from downstream to upstream.

4.5.2 End-of-Life

To obtain the mass of yogurt containers sent to municipal solid waste (MSW) management site, it was assumed that the entire functional unit of yogurt products delivered to retailers and distributors were all carried to the MSW facility. In other words, a zero percent loss rate after Distribution 3 phase was assumed. The total mass of waste was classified into three categories; the plastics that are incinerated, the paper incinerated and MSW landfilled. The total inputs and outputs were calculated multiplying the mass of each category and mass based environmental burden data, which corresponds to each category.

For the calculation, three different data modules were used:

1. Paper incineration
2. Plastic incineration.
3. MSW landfill (represents general municipal solid wastes, and it includes paper and plastics)

4.5.3 Distribution 3

In Distribution 3, three categories were taken into consideration to aggregate the total environmental burdens of this phase.

1. Transportation
2. Material production of secondary packages
3. Solid waste

Transportation

In order to calculate the burdens of transportation, total km-kg was calculated by aggregating following pairs of weights and distances.

Weight	*Distance*
Yogurt products	Stonyfield to retailers/distributors
Yogurt containers	Stonyfield to retailers/distributors
Secondary packaging	Stonyfield to retailers/distributors
Secondary packaging	Secondary packaging suppliers to Stonyfield

The weight of yogurt product consisted of the weight of a functional unit of yogurt and the weight of the yogurt containers. Secondary packaging included corrugated boxes, pallets, and stretch wrap.

Material Production of Secondary Packaging

The burdens of the material production were calculated by multiplying the weight of materials used for the secondary packaging and each material's burden data obtained from secondary data sources. The materials included corrugated board for corrugated box, wood for pallet, and LLDPE film for stretch wrap.

Solid Waste

The masses of solid waste from Distribution 3 were calculated in the two categories described below.

> *1. Loss from transportation*
>
> Transportation loss rates were defined as values unique to each transportation mode, and the losses of all transportation modes were aggregated by multiplying the weight of yogurt carried in each mode and the corresponding loss rate.
>
> *2. Secondary packaging*
>
> Some of the secondary packaging was recycled and counted as a Recycled Material output. It was assumed that non-recycled secondary packaging was landfilled.

All wastes other than Recycled Material were assumed to be landfilled and the total burden was calculated by multiplying the mass of waste by the DEAM MSW Landfill module rate.

4.5.4 Yogurt Filling

Solid waste was the only environmental burden considered in the Filling phase. The numbers of container components used in the Filling phase were calculated based on the product output from this unit process.[43] The same filling process scrap rate was defined for all container components. In addition to the filling process scrap rate, the engineering scrap rate was defined for seals and tubes, because they generate scrap when they are cut out from plastic film sheets. The mass of scrap of all container components, other than the seals and tubes, were calculated by multiplying total component weight by the filling process scrap rate. The seal and tube scrap rates were calculated by the formula $(1+E)(1+F) - 1$ as explained in the process loss section. The total burden of these wastes was obtained by multiplying the total mass of waste by the MSW landfill burden module.

4.5.5 Distribution 2

As in Distribution 3, three factors, transportation, material production of secondary packaging, and solid waste were taken into consideration.

Transportation
In order to calculate the burdens of transportation, total kg-km was calculated by aggregating the products of the following weights and distances.

Weight	*Distance*
Yogurt Containers	Container manufactures to Stonyfield
Secondary packaging	Container manufactures to Stonyfield
Secondary packaging	Secondary packaging suppliers and container manufactures

The secondary packaging consisted of corrugated boxes, sleeves, separator cardboard, pallets and the stretch wrap.

Material Production of Secondary Packaging
Calculation procedure was the same as Distribution 3

Solid Waste
Calculation procedure was the same as Distribution 3

4.5.6 Manufacturing

In the Manufacturing phase, environmental burdens were accrued from two categories: the container fabrication process and the solid waste generated from the fabrication processes.

Manufacturing Process
Using the product output of this unit process and mass of each container component, the total mass of each component per functional unit was calculated. Since each component had its own fabrication process, their burdens were calculated by multiplying the mass of the component by the corresponding data module burdens. The data modules used here are listed below:

1. Injection molded components……………PP and PE Injection molding with printing
2. Thermoformed components……………...Thermoforming
3. Paperboard components………………….Conversion of Coated Paperboard with Offset Printing
4. Seals and Tubes………………………….PE/PET Film Co-Extrusion
5. Cardboard Wraps/Cartons……………….Conversion of Coated Paperboard with Offset Printing

Solid Waste
Since scrap rates were defined as values unique to each container component, the waste from different fabrication processes was calculated separately, and the weight was aggregated. It was assumed that all wastes from this unit process were landfilled, with the exception of the waste that was recycled. Therefore the total burden was calculated by multiplying the total mass of waste and the DEAM MSW Landfill module rate.

4.5.7 Distribution 1

The calculation procedure for Distribution 1 was simpler than other two distribution unit processes because the material production of secondary packages and their transportation from secondary packaging suppliers to material manufactures was excluded. The focus was on the transportation from material manufactures to container manufactures, and the waste generated from this transportation.

Transportation

Both the kg-km of different materials and secondary packaging used for the transportation of the materials between material manufactures and container manufactures were aggregated. Total environmental burden was calculated using DEAM Truck and Rail data modules.

Solid Waste

Transportation loss was calculated using transportation loss rates defined for each transportation mode. The weight of wastes from all transportation modes were aggregated and the total environmental burden was calculated using DEAM MSW Landfill module.

4.5.8 Material Production

The mass of all materials required for the functional unit is calculated based on the weight of product output and composition data of each container component. Total environmental burdens were calculated by multiplying the mass of each material and corresponding data modules. Data modules used here are:

1. PP Production – for PP cups
2. HDPE Production – for HDPE cups
3. LDPE Production – for lids and paperboard coating
4. Unbleached Paperboard – for coated unbleached paperboard cups
5. PLA Production – for PLA cups and lids
6. LLDPE Production – for seals
7. PET Production – for seals
8. Coated Paperboard – for wrap for 4 oz. 6-packs and cartons for 2 oz. tubes
9. Cotton Fluff Color Concentrate – for beige cups and lids
10. White Color Concentrate – for white cups and lids

4.6 Data Collection Procedures

Primary data was collected on a total of 20 material producers and manufacturers. Stonyfield and Polytainers provided data on their products and operations at the outset of this study. Additional data was collected through verbal and written correspondences with Stonyfield and Polytainers. The manufacturer of coated unbleached paperboard containers also provided data on their products through verbal and written correspondences. Additionally, nine of the suppliers of the secondary packaging materials were contacted. Data concerning the secondary packaging mass, composition and transportation distances and modes were obtained or verified directly with these suppliers, in most cases.

This study used primary data to model the injection molding of the container cups and lids. To achieve this, data on energy consumption, material inputs and water use were collected from Polytainers' Toronto facility using a data collection sheet modeled after the example suggested in the ISO 14041 document.

4.7 Data Inputs

Information from the tables below was used as inputs to the computer calculation model. The actual input forms have been included in Appendix E.

Table 4-16 Primary Packaging Weights: Current PDS

Component	Material	**2 oz.**	**4 oz.**	**6 oz.**	**8 oz.**	**32 oz.**
Cup[1]	PP	N/A	4.90g	7.80g	9.10g	29.00g
Lid[2]	LLDPE	N/A	N/A	3.90g	3.90g	8.10g
Seal[3]	PE/PET	N/A	0.24g	0.33g	0.33g	0.71g
Wrap/Carton[4]	D/T Board	37.26g	22.68g[5]	N/A	N/A	N/A
Tube[5]	LLDPE/Polyester	1.19g	N/A	N/A	N/A	N/A
Tape[5]	LLDPE/PET	0.18g	N/A	N/A	N/A	N/A
Total		6.03g	8.92g	12.03g	13.33g	37.81g
Functional Unit Total		48.22 kg	35.69 kg	32.08 kg	26.66 kg	18.90 kg

Sources:

1. Cup weights were assumed to be the part weights listed on Polytainers' spec sheets. The material was also from Polytainers spec sheets.
2. Lid weights were assumed to be the part weights listed on Polytainers' spec sheets. The material was also from Polytainers spec sheets.
3. Seal weights measured by Stonyfield Farm. Seal material from verbal correspondence with supplier.
4. Wrap and carton weights from correspondence with Stonyfield Farm. Material composition from supplier's spec sheet.
5. Tube and tape weights were calculated from packaging dimensions and specified ream weights.

Note: One wrap is used to package six cups and one carton for eight 2 oz. tubes.

Table 4-17: Primary Packaging Weights: HDPE Injection Molded Cups

Component	**4 oz.**		**6 oz.**		**8 oz.**		**32 oz.**	
	Weight	Material	Weight	Material	Weight	Material	Weight	Material
Cup[1]	5.44g	HDPE	8.66g	HDPE	10.11g	HDPE	32.21g	HDPE
Lid[2]	N/A	N/A	3.90g	LLDPE	3.90g	LLDPE	8.10g	LLDPE
Seal[3]	0.24g	PE/PET	0.33g	PE/PET	0.33g	PE/PET	0.71g	PE/PET
Wrap[4]	22.68g[5]	D/T Board	N/A	N/A	N/A	N/A	N/A	N/A
Total	9.46g		12.89g		14.34g		41.02g	
Functional Unit Total	37.84 kg		34.37 kg		28.68 kg		20.51 kg	

Sources:

1. Cup weights calculated based on 105% of the volume of PP cups and density of HDPE.
2. Lid weights were assumed to be the part weights listed on Polytainers' spec sheets. The material was also from Polytainers spec sheets.
3. Seal weights measured by Stonyfield Farm. Seal material from verbal correspondence with supplier.
4. Wrap weight from correspondence with Stonyfield Farm. Wrap material from supplier's spec sheet.

Notes:

1. One wrap is used to package 6 cups.
2. 2 oz. tube specifications were not affected by change of cup material and were therefore omitted.

Table 4-18: Primary Packaging Weights: PP Thermoformed Cups

Component	4 oz.		6 oz.		8 oz.		32 oz.	
	Weight	Material	Weight	Material	Weight	Material	Weight	Material
Cup[1]	4.26g	PP	6.00g	PP	7.90g	PP	20.00g	PP
Lid[2]	N/A	N/A	3.90g	LLDPE	3.90g	LLDPE	8.10g	LLDPE
Seal[3]	0.24g	PE/PET	0.33g	PE/PET	0.33g	PE/PET	0.71g	PE/PET
Wrap[4]	22.68g[5]	D/T Board	N/A	N/A	N/A	N/A	N/A	N/A
Total	8.28g		10.23g		12.13g		28.81g	
Functional Unit Total	33.12 kg		27.28 kg		24.26 kg		14.41 kg	

Sources:
1. Cup weights from Polytainers spec sheets with the exception of the 4oz. cup, which was calculated assuming the same reduction in mass as with the 8 oz. cup.
2. Lid weights were assumed to be the part weights listed on Polytainers' spec sheets. The material was also from Polytainers spec sheets.
3. Seal weights measured by Stonyfield Farm. Seal material from verbal correspondence with supplier.
4. Wrap weight from correspondence with Stonyfield Farm. Wrap material from supplier's spec sheet.

Notes:
1. One wrap is used to package 6 cups.
2. 2 oz. tube specifications were not affected by change of cup material and were therefore omitted

Table 4-19: Primary Packaging Weights: Coated Paperboard with Plastic Lid

Component	4 oz.		6 oz.		8 oz.	
	Weight	Material	Weight	Material	Weight	Material
Cup[1]	6.01g	LDPE Coated Paperboard	7.53g	LDPE Coated Paperboard	9.26g	LDPE Coated Paperboard
Lid[2]	N/A	N/A	3.90g	LLDPE	3.90g	LLDPE
Seal[3]	0.24g	PE/PET	0.33g	PE/PET	0.33g	PE/PET
Wrap[4]	22.68g	D/T Board	N/A	N/A	N/A	N/A
Total	10.03g		11.76kg		13.49g	
Functional Unit Total	40.12kg		31.36kg		26.98kg	

Sources:
1. Japanese paperboard cup manufacturer. Cup weights adjusted to 4 oz., 6 oz., and 8 oz. sizes from 124ml, 150ml, 220ml
2. Lid weights were assumed to be the part weights listed on Polytainers' spec sheets. The material was also from Polytainers spec sheets.
3. Seal weights measured by Stonyfield Farm. Seal material from verbal correspondence with supplier.
4. Wrap weight from correspondence with Stonyfield Farm. Wrap material from supplier's spec sheet.

Notes:
1. One wrap is used to package 6 cups.

Table 4-20: Primary Packaging Weights: PLA Thermoformed Cups

Component	4 oz.		6 oz.		8 oz.		32 oz.	
	Weight	Material	Weight	Material	Weight	Material	Weight	Material
Cup[1]	4.45g	PLA	6.68g	PLA	8.91g	PLA	N/A	N/A
Lid[2]	N/A	N/A	4.72g	PLA	4.72g	PLA	N/A	N/A
Seal[3]	0.24g	PE/PET	0.33g	PE/PET	0.33g	PE/PET	N/A	N/A
Wrap[4]	22.68g	D/T Board	N/A	N/A	N/A	N/A	N/A	N/A
Total	8.47g		11.73g		13.96g		N/A	
Functional Unit Total	33.88 kg		31.28 kg		27.92 kg		N/A	

Sources:

1. Cup weights were estimated based on weights of PS thermoformed cups currently used in the marketplace. Savoie (France) uses a 6.35 oz. PS yogurt cup with a mass of 6.60g. This cup had a ratio of yogurt capacity to cup mass of 3.67%. The ratio was adjusted for to account for the difference in specific gravity between PS (1.05) and PLA (1.25). It was also adjusted to account for a downgauging of 10%, which CDP stated was possible due to the increased stiffness of PLA over PS. The resulting yogurt capacity to cup mass ratio was 3.93%. This ratio was used for the 4, 6 and 8 oz. cup sizes. The 32 oz. cup was excluded due to lack of data and concern about the performance of PLA for that size container due to its reduced impact resistance compared to PP.
2. Lid weights were estimated based on weights of LLDPE injection molded lids. The weights of the lids were adjusted to account for the difference in specific gravity between LLDPE (0.93) and PLA (1.25). The weights of the lids were also adjusted to account for a downgauging of 10%, which CDP stated was possible due to the increased stiffness of PLA over LLDPE.
3. Seal weights measured by Stonyfield Farm. Seal material from verbal correspondence with supplier.
4. Wrap weight from correspondence with Stonyfield Farm. Wrap material from supplier's spec sheet.

Notes:

1. One wrap is used to package 6 cups.
2. 2 oz. tube specifications were not affected by change of cup material and were therefore omitted

Table 4-21: Material Production Phase Inputs

Material	**Composition**
Color Concentrate – Cotton Fluff	53% Pigment, 47% LLDPE[1]
Color Concentrate – White	59% Pigment, 41% LLDPE[1]
Coated Paperboard	82% Post-consumer, 18% Pre-consumer[2]
HDPE	HDPE, Additives[3]
LDPE	100% LDPE
LLDPE	LLDPE, Additives[3]
PE	PE, EVA, Additives[4]
PET	PET, Additives[4]
PLA	PLA[5]
PP	Propylene Ethylene Copolymer[6]
SUS (Solid Unbleached Sulfate) Paperboard	100% Pre-consumer[1]
Other	Unknown

Sources:

1. Supplier's Product Information Sheet.
2. Written correspondence from supplier.

3. Supplier's Product Data Sheet.
4. Verbal correspondence with supplier.
5. Verbal correspondence with Cargill Dow Polymers
6. Supplier's Material Safety Data Sheet.

Table 4-22: Distribution 1 Phase Inputs

Transport			
Primary Material	**Distance**	**By Rail**	**By Truck**
Color Concentrate – Cotton Fluff	90 mi.[1]	0%[1]	100%[1]
Color Concentrate – White	90 mi.[1]	0%[1]	100%[1]
D/T Board	406 mi.[2]	0%[3]	100%[3]
HDPE	190 mi.[1]	0%[1]	100%[1]
LDPE	1695 mi.[2]	100%[7]	0%[7]
LLDPE (Lids)	190 mi.[1]	92%[1]	8%[1]
LLDPE (Tubes, Tape)	1100 mi.[5]	100%[5]	0%[5]
PE	492 mi.[4]	0%[3]	100%[3]
PET (Seals)	492 mi.[4]	0%[3]	100%[3]
PET (Tubes, Tape)	1100 mi.[5]	0%[3]	100%[3]
PLA	969 mi.[6]	0%[3]	100%[3]
PP	425 mi.[1]	99%[1]	1%[1]
SUS Paperboard	1390 mi.[2]	75%[7]	25%[7]
White Poly	1100 mi.[5]	100%[5]	0%[5]
Other	492 mi.[4]	0%[3]	100%[3]

Sources:
1. Data Collection Sheet completed by Polytainers.
2. Calculated using MapQuest.
3. Assumption.
4. Assumption based on average of primary packaging transport distances.
5. Information supplied by tube and tape supplier.
6. Calculated using Microsoft Expedia Trip Planner 98.
7. Correspondence with paperboard cup manufacturer.

Table 4-23: Distribution 1 Phase Inputs Continued

Secondary Packaging				
Primary Material	**Type**	**Composition**	**Mass of Material per Package**	**Weight**
Color Concentrate Cotton Fluff	Bag[1]	PE[1]	24.95 kg.[1]	0.08 kg.[2]
	Pallet[1]	Wood[1]	449.06 kg.[3]	18.14 kg.[4]
Color Concentrate White	N/A	N/A	N/A	N/A
SUS Paperboard	Core[5]	Paperboard[5]	1406kg	5.4kg
	Core Plug[5]	Pressed Wood[5]	1406kg	2.7kg
LDPE	N/A	N/A	N/A	N/A
Coated Paperboard	N/A	N/A	N/A	N/A
HDPE	N/A	N/A	N/A	N/A
LLDPE	N/A	N/A	N/A	N/A
PE	N/A	N/A	N/A	N/A
PET	N/A	N/A	N/A	N/A

PLA	N/A	N/A	N/A	N/A
PP	N/A	N/A	N/A	N/A
White Poly	N/A	N/A	N/A	N/A
Other	N/A	N/A	N/A	N/A

Sources:
1. Verbal correspondence with supplier.
2. Estimated based on information provided by supplier.
3. Assumption.
4. Estimate based on pallet weight data provided by Stonyfield Farm.
5. Verbal correspondence with paperboard cup manufacturer.

Table 4-24: Manufacturing Phase Inputs

Component	Process	Electricity	Natural Gas	Scrap Rate	Recycle Rate
Cup	Injection Molding	7.59 MJ/kg[1]	0.0118 m^3/kg[2]	3.76%[3]	100%[4]
Cup	Thermoforming (PP)	N/A[5]	0.0118 m^3/kg[2]	3.76%[3]	100%[4]
Cup	Thermoforming (PLA)	N/A[5]	0.0118 m^3/kg[2]	3.76%[3]	0%[6]
Cup	Conversion, Printing	N/A[5]	N/A[1]	11.2%[5]	100%[5]
Lid	Injection Molding (LLDPE)	7.59 MJ/kg[1]	0.0118 m^3/kg[2]	3.76%[3]	100%[4]
Lid	Injection Molding (PP)	7.59 MJ/kg[1]	0.0118 m^3/kg[2]	3.76%[3]	0%[6]
Seal	Co-extrusion	N/A[5]	N/A[5]	2.00%[7]	0%[8]
Wrap / Carton	Printing, coating, cutting	N/A[9]	N/A[9]	19.80%[9]	100%[10]
Tube / Tape	Film Extrusions	N/A[5]	N/A[5]	16%[11]	90%12

Sources:
1. Data Collection Sheet completed by Polytainers. Rate was calculated by dividing total 1999 electricity consumption by total plastic resin purchased in 1999.
2. Data Collection Sheet completed by Polytainers. Rate was calculated by dividing total 1999 natural gas consumption by total plastic resin purchased in 1999.
3. Data Collection Sheet completed by Polytainers. Rate was calculated by dividing total plastic scrap sold by total plastic resin purchased in 1999.
4. Correspondence from Polytainers.
5. Data obtained from DEAM
6. Assumption based on lack of established market for recycled PLA.
7. Data obtained from SAEFL pg. 325.
8. Assumption based on recyclability of mixed plastics.
9. SAEFL pg. 344.
10. Correspondence from supplier.
11. Scrap rate averaged from range given by tube and tape supplier (7% to 25%)
12. Recycle rate assumed from information supplied by tube and tape supplier stating the “vast majority” of scrap is recycled.

Table 4-25: Distribution 2 Phase Inputs

Transport			
Component	**Distance**	**By Rail**	**By Truck**
Plastic Cup	587 mi.[1]	0%[1]	100%[1]
Coated paperboard cup	363 mi.[5]	0%[6]	100%[6]
Lid	587 mi.[1]	0%[1]	100%[1]
Seal	1050 mi.[2]	0%[2]	100%[2]
Wrap/Carton	694 mi.[3]	0%[4]	100%[4]
Tube/Tape	1194 mi.[3]	0%[4]	100%[4]

Sources:
1. Data Collection Sheet completed by Polytainers.
2. Correspondence from supplier.
3. Calculated using Microsoft Expedia.
4. Correspondence from supplier.
5. Calculated using MapQuest.
6. Verbal correspondence with paperboard cup manufacturer.

Table 4-26: Distribution 2 Phase Inputs Continued

Secondary Packaging							
Component	**Type**	**Composition**	**Units per Package**	**Weight**	**Reuse Rate**	**Recycle Rate**	**Distance to Mfg.**
Plastic Cup – 4 oz.	Box	Corrugated[1]	3150[1]	1043g[2]	0%[3]	100%[3]	5 mi.[4]
	Liner	LDPE[5]	3150[1]	111g[6]	0%[3]	0%[3]	9.4 mi.[7]
	Pallet	Wood[5]	75600[1]	18,144g[5]	94%[8]	71%[9]	23 mi.[7]
	Stretch Wrap	LLDPE[1]	75600[3]	635g[4]	0%[3]	0%[3]	18 mi.[1]
Paperboard Cup – 4 oz.	Box	Corrugated[20]	2100[20]	1497g	0%[3]	100%[3]	21mi[7]
	Liner	LDPE	2100[20]	111g	0%[3]	0%[3]	77 mi.[13]
	Pallet	Wood[20]	50400	18,144g	94%[8]	71%[9]	77 mi.[13]
	Stretch Wrap	LLDPE	50400	635g	0%[3]	0%[3]	77 mi.[13]
Plastic Cup – 6 oz.	Box	Corrugated[1]	2130[1]	1497g[2]	0%[3]	100%[3]	5 mi.[4]
	Liner	LDPE[5]	2130[1]	111g[6]	0%[3]	0%[3]	9.4 mi.[7]
	Pallet	Wood[5]	51120[1]	18,144g[5]	94%[8]	71%[9]	23 mi.[7]
	Stretch Wrap	LLDPE[1]	51120[3]	635[4]g	0%[3]	0%[3]	18 mi.[1]
Paperboard Cup – 6 oz.	Box	Corrugated[20]	1420[20]	1497g	0%[3]	100%[3]	21mi[7]
	Liner	LDPE	1420[20]	111g	0%[3]	0%[3]	77 mi.[13]
	Pallet	Wood[20]	34080	18,144g	94%[8]	71%[9]	77 mi.[13]
	Stretch Wrap	LLDPE	34080	635g	0%[3]	0%[3]	77 mi.[13]
Plastic Cup – 8 oz.	Box	Corrugated[1]	1500[1]	1451g[2]	0%[3]	100%[3]	5 mi.[4]
	Liner	LDPE[5]	1500[1]	111g[6]	0%[3]	0%[3]	9.4 mi.[7]
	Pallet	Wood[5]	45000[1]	18,144g[5]	94%[8]	71%[9]	23 mi.[7]
	Stretch Wrap	LLDPE[1]	45000[3]	635g[4]	0%[3]	0%[3]	18 mi.[1]

Paperboard Cup – 8 oz.	Box	Corrugated[20]	1000[20]	1451g	0%[3]	100%[3]	21mi[7]
	Liner	LDPE	1000[20]	111g	0%[3]	0%[3]	77 mi.[13]
	Pallet	Wood[20]	30000	18,144g	94%[8]	71%[9]	77 mi.[13]
	Stretch Wrap	LLDPE	30000	635g	0%[3]	0%[3]	77 mi.[13]
Cup – 32 oz.	Box	Corrugated[1]	400[1]	1270g[2]	0%[3]	100%[3]	5 mi.[4]
	Sleeve	LDPE[5]	400[1]	9g[6]	0%[3]	0%[3]	9.4 mi.[7]
	Pallet	Wood[5]	8000[1]	18,143g[5]	94%[8]	71%[9]	23 mi.[7]
	Stretch Wrap	LLDPE[1]	8000[3]	635g[4]	0%[3]	0%[3]	18 mi.[1]
Lid – 6/8 oz.	Box	Corrugated[1]	1500[1]	862g[2]	0%[3]	100%[3]	5 mi.[4]
	Sleeve	LDPE[5]	1500[1]	3g[6]	0%[3]	0%[3]	9.4 mi.[7]
	Pallet	Wood[5]	72000[1]	18,144g[5]	94%[8]	71%[9]	23 mi.[8]
	Stretch Wrap	LLDPE[1]	72000[3]	635g[4]	0%[3]	0%[3]	18 mi.[1]
Lid – 32 oz.	Box	Corrugated[1]	1000[1]	998g[2]	0%[3]	100%[3]	5 mi.[4]
	Liner	LDPE[5]	1000[1]	58g[6]	0%[3]	0%[3]	9.4 mi.[7]
	Pallet	Wood[5]	20000[1]	18,144g[5]	94%[8]	71%[9]	23 mi.[7]
	U-Board	Corrugated[1]	250[3]	178g[2]	0%[3]	100%[3]	
	Stretch Wrap	LLDPE[1]	20000[3]	635g[4]	0%[1]	0%[1]	18 mi.[1]
Seal – 4 oz.	Core Tube	Paperboard[11]	31200[11]	688g[12]	0%[3]	0%[3]	77 mi.[13]
	Pallet	Wood[12]	998400[11]	13608g[12]	94%[8]	71%[9]	77 mi.[13]
	Stretch Wrap	LLDPE[11]	998400[11]	186g[12]	0%[3]	0%[3]	77 mi.[13]
	Slip Sheet	Paperboard[11]	998400[11]	1361g[12]	0%[3]	0%[3]	77 mi.[13]
	Roll Wrap	LDPE[11]	31200[11]	23g[14]	0%[3]	0%[3]	77 mi.[13]
Seal – 6/8 oz.	Core Tube	Paperboard[11]	20800[11]	635g[12]	0%[3]	0%[3]	77 mi.[13]
	Pallet	Wood[12]	665600[11]	13608g[12]	94%[8]	71%[9]	77 mi.[13]
	Stretch Wrap	LLDPE[11]	665600[11]	181 g[12]	0%[3]	0%[3]	77 mi.[13]
	Slip Sheet	Paperboard[11]	665600[11]	1361g[12]	0%[3]	0%[3]	77 mi.[13]
	Roll Wrap	LDPE[11]	20800[11]	18g[14]	0%[3]	0%[3]	77 mi.[13]
Seal – 32 oz.	Core Tube	Paperboard[11]	20800[11]	1043 g[12]	0%[3]	0%[3]	77 mi.[13]
	Pallet	Wood[12]	332800[11]	13608g[12]	94%[8]	71%[9]	77 mi.[13]
	Stretch Wrap	LLDPE[11]	332800[11]	181 g[12]	0%[3]	0%[3]	77 mi.[13]
	Slip Sheet	Paperboard[11]	332800[11]	1361g[12]	0%[3]	0%[3]	77 mi.[13]
	Roll Wrap	LDPE[11]	20800[11]	27g[14]	0%[3]	0%[3]	77 mi.[13]

Wrap – 4 oz.	Box	Corrugated[15]	950[15]	703 g[16]	0%[3]	100%[3]	380 mi.[17]
	Pallet	Wood[15]	42750[15]	18144g[15]	94%[8]	71%[9]	20 mi.[17]
	Stretch Wrap	LLDPE[15]	42750[15]	227 g[15]	0%[3]	0%[3]	20 mi.[17]
	Divider	Paperboard[1]	950[15]	77 g[15]	0%[3]	0%[3]	180 mi.[17]
Carton – 2 oz.	Box	Corrugated[15]	200[15]	703 g[16]	0%[3]	100%[3]	380 mi.[17]
	Pallet	Wood[15]	12600[15]	18144g[15]	94%[8]	71%[9]	20 mi.[17]
	Stretch Wrap	LLDPE[15]	12600[15]	227 g[15]	0%[3]	0%[3]	20 mi.[17]
Tube – 2 oz.	Core Tube	Paperboard[17]	38,500[18]	136g[19]	0%[3]	0%[3]	77 mi.[13]
	Roll Wrap	PE[17]	38,500[18]	41g[19]	0%[3]	0%[3]	77 mi.[13]
	End Cap	PE[17]	19,250[18]	13g[19]	0%[3]	0%[3]	77 mi.[13]
	Pallet	Wood[15]	385,000[18]	18144g[15]	94%[8]	71%[9]	77 mi.[13]
	Stretch Wrap	LLDPE[15]	385,000[18]	227 g[15]	0%[3]	0%[3]	77 mi.[13]
Tape – 2 oz.	Spool	Paperboard[17]	13,000[18]	316g[19]	0%[3]	0%[3]	77 mi.[13]
	Case	Corrugated[17]	52,000[18]	1134g[19]	0%[3]	0%[3]	77 mi.[13]
	Liner	LDPE[17]	52,000[18]	227 g[19]	0%[3]	0%[3]	77 mi.[13]
	Pallet	Wood[15]	416,000[18]	18144g[15]	94%[8]	71%[9]	77 mi.[13]
	Stretch Wrap	LLDPE[15]	416,000[18]	227 g[15]	0%[3]	0%[3]	77 mi.[13]

Sources:
1. Polytainers component technical bulletin.
2. Correspondence with supplier.
3. Correspondence with Stonyfield.
4. Data Collection Sheet completed by Polytainers.
5. Correspondence with Stonyfield.
6. Correspondence with supplier.
7. Calculation using MapQuest.
8. Correspondence from Polytainers stating that pallets make 16 roundtrips on average before they are remanufactured or discarded.
9. Transdigest July 1999, Vol. IV Issue No. 24, <www.transportlaw.com/td.htm>.
10. Calculation using Microsoft Expedia TripPlanner 98.
11. Supplier's spec sheets.
12. Correspondence from supplier dated 4/5/00.
13. Assumption based on average of transport distances for secondary packaging.
14. Calculated based on roll size.
15. Supplier's Packaging Specifications.
16. Estimated based on size and weights of boxes supplied to Polytainers for cups and lids.
17. Correspondence from supplier.
18. Units per packaging were estimated using roll weights and tube and tape supplier specification sheets.
19. Secondary packaging weights supplied by Stonyfield Farm memo dated Jan. 18, 2001.
20. Correspondence with paperboard cup manufacturer.

Table 4-27: Filling Phase Inputs

Component	Engineered Scrap Rate	Process Scrap Rate	Recycle Rate
Cup	0%[1]	0%[1]	0%[1]
Lid	0%[1]	0%[1]	0%[1]
Wrap/Carton	0%[1]	0%[1]	0%[1]
Seal – 4 oz.	149%[2]	0%[1]	0%[1]
Seal – 6/8 oz.	150%[2]	0%[1]	0%[1]
Seal – 32 oz.	93%[2]	0%[1]	0%[1]
Tube	3.0%[1]	0%[1]	0%[1]
Tape	0%[1]	0%[1]	0%[1]

Sources:
1. Correspondence from Stonyfield.
2. Calculated based on data from supplier's spec sheets and correspondence from Stonyfield.

Table 4-28: Distribution 3 Phase Inputs

Transport		
Distance	**By Rail**	**By Truck**
552 mi.[1]	0%[2]	100%[2]

Sources:
1. Correspondence from Stonyfield. Calculated using the weighted average of product shipments from Stonyfield.
2. Correspondence from Stonyfield.

Table 4-28: Distribution 3 Phase Inputs Continued

Secondary Packaging							
Component	**Type**	**Compositio n**	**Units per Package**	**Weight**	**Reuse Rate**	**Recycle Rate**	**Distance to Mfg.**
2 oz.	Box	Corrugated	96[1]	243[8]	0%[1]	95%[3]	48 mi.[4]
	Pallet	Wood[1]	4800[1]	18144g[1]	94%[5]	71%[6]	10 mi.[4]
	Stretch Wrap	LLDPE[1]	4800[1]	331g[1]	0%[1]	7%[7]	138 mi.[4]
4 oz.	Box	Corrugated[1]	24[1]	158g[2]	0%[1]	95%[3]	48 mi.[4]
	Pallet	Wood[1]	4800[1]	18144g[1]	94%[5]	71%[6]	10 mi.[4]
	Stretch Wrap	LLDPE[1]	4800[1]	331g[1]	0%[1]	7%[7]	138 mi.[4]
6 oz.	Box	Corrugated[1]	12[1]	132g[2]	0%[1]	95%[3]	48 mi.[4]
	Pallet	Wood[1]	4800[1]	18144g[1]	94%[3]	71%[6]	10 mi.[4]
	Stretch Wrap	LLDPE[1]	4800[1]	331g[1]	0%[1]	7%[7]	138 mi.[1]
8 oz.	Box	Corrugated[1]	12[1]	137g[2]	0%[1]	95%[3]	48 mi.[4]
	Pallet	Wood[1]	4800[1]	18144g[1]	94%[3]	71%[6]	10 mi.[4]
	Stretch Wrap	LLDPE[1]	4800[1]	331g[1]	0%[1]	7%[7]	138 mi.[4]
32 oz.	Box	Corrugated[1]	6[1]	188g[2]	0%[1]	95%[3]	48 mi.[4]
	Pallet	Wood[1]	4800[1]	18144g[1]	94%[3]	71%[6]	10 mi.[4]
	Stretch Wrap	LLDPE[1]	4800[1]	331g[1]	0%[1]	7%[7]	138 mi.[4]

Sources:

1. Correspondence from Stonyfield.
2. Correspondence from supplier.
3. Transport Packaging, Prepared by Headly Pratt Consulting in association with J. Leslie Bell for The Minnesota Office of Environmental Assistance and the American Plastics Council, August 1999.
4. Calculated using Microsoft Expedia TripPlanner 98.
5. Correspondence from Polytainers stating that pallets make 16 roundtrips on average before they are remanufactured or discarded.
6. Transdigest July 1999, Vol. IV Issue No. 24, <www.transportlaw.com/td.htm>.
7. "Understanding Plastic Film: Its Uses, Benefits and Waste Management Options", Prepared for the American Plastics Council by Headley Pratt Consulting, December 1996.
8. Correspondence from Stonyfield Farm dated November 20, 2000.

Table 4-29: End-of-Life Phase Inputs

Recycle Rates				
Component	**Recycle Rate**	**Fraction Plastic**	**Fraction Paper**	**Fraction Other**
Plastic Cup	0%[1]	100%[2]	0%[2]	0%[2]
Paperboard Cup	0%[1]	7%[4]	93%[4]	0%[4]
Lid	0%[1]	100%[2]	0%[2]	0%[2]
Seal	0%[1]	100%[2]	0%[2]	0%[2]
Wrap/Carton	16%[3]	0%[4]	100%[4]	0%[4]
Tube/Tape	0%[1]	100%[2]	0%[2]	0%[2]

Sources:
1. Assumption based on data in "Characterization of Municipal Solid Waste in the United States: 1998 Update", EPA Report No. EPA530-.
2. Polytainers spec sheets.
3. "Characterization of Municipal Solid Waste in the United States: 1998 Update", EPA Report No. EPA530-.
4. Supplier's spec sheet.

Table 4-29: End-of-Life Phase Inputs Continued

Incineration Rate	
Component	**Incineration Rate**
Cup	23.5%[1]
Lid	23.5%[1]
Seal	23.5%[1]
Wrap/Carton	23.5%[1]
Tube/Tape	23.5%[1]

Sources:
1. "Characterization of Municipal Solid Waste in the United States: 1998 Update", EPA Report No. EPA530-.

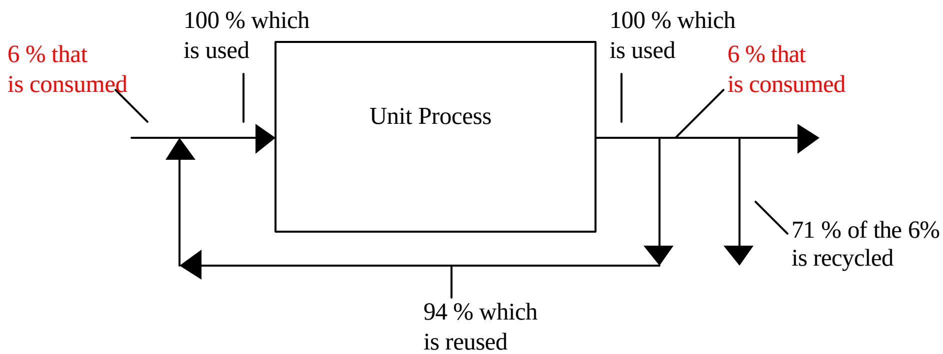
4.8 Assumptions

4.8.1 General

- There was no scrap rate assumed within the system model for several unit processes due to insufficient data. Scrap generation for the following key processes, however, were modeled: the engineered scrap rate associated with the application of the seal and trimming of the tubes (See Filling phase below); the scrap rate of cup and base manufacturing at Polytainers (See Manufacturing below); the scrap rate of the tube and tape manufacturing (see Manufacturing below) and the scrap rate of wrap and carton manufacturing (See Manufacturing below).

- All distances that were not provided directly by one of the concerned endpoint entities or assumed based on estimates (as noted in Distribution 1 below) were calculated using the travel planning component of MapQuest.[44]
- Burdens associated with distribution phases were based on the assumptions and calculations of the DEAM Road Transport module (Truck, 40 ton capacity, Diesel, kg/km, 100% efficiency).
- Wooden pallets were reused until worn or damaged, at which time they were typically remanufactured. The re-manufacturing process entailed replacing only the worn or damaged components of the pallets. Therefore, burdens associated with the production of pallets were calculated using only the quantity of wood consumed per functional unit as indicated by the 6% in Figure 4-14 below.

Figure 4-14: Pallet Material Flow Schematic



4.8.2 Material Production

- The environmental burdens associated with material production of PP, LLDPE, HDPE, PET, PE, and color concentrate were based on European production data. Material production burdens for Europe were assumed to be similar to those in North America.
- A propylene ethylene copolymer was used in the PDS, but it was modeled as polypropylene.
- The environmental burdens associated with PLA production were based on estimates by Cargill Dow that the Blair, Nebraska plant would expend 56 MJ for every kg of PLA produced.[45] It was assumed that the 56 MJ includes the primary energy requirements for all material production processes including Corn Farming, Corn Wet Milling and Polymer Production. The allocation of the 56 MJ of energy between these three processes was estimated based on published estimates of energy consumption for corn farming in Iowa and Nebraska[46] as well as estimates of energy consumption for corn wet milling[47].

4.8.3 Distribution 1

- All materials were shipped in bulk trucks or railcars and therefore did not use secondary packaging except Cotton Fluff color concentrate, which was shipped using bags and pallets, and SUS paperboard.

- The burdens per kg-km for transport using a bulk truck with a capacity of 70,000-75,000 lbs. were assumed to be similar to the burdens per kg-km using a truck with a capacity of 40 tons.
- Trucks were assumed to be, on average, full on the delivery leg of the trip and empty on the return leg of the trip.

4.8.4 Manufacturing

- The PP and PLA thermoforming processes were assumed to be located in the same facility as the injection molding process (Polytainers, Toronto).
- The natural gas used for space heating and water heating in the thermoforming processes was assumed to be consumed at the same rate per kg as in the injection molding process.
- Manufacturing burdens for the co-extruded seal were assumed to be the same as the manufacturing burdens for PE extrusion.
- Manufacturing burdens for all extrusion processes performed by the tube and tape supplier were assumed to be the same as the manufacturing burdens for PE extrusion.
- The scrap rate for cup and lid manufacturing at Polytainers was calculated based on the amount of container material scrap sold by the company in 1999 as a percentage of amount of container material purchased the same year.
- The scrap rate for wrap and carton manufacturing at the paperboard product supplier was based on the "Offset Printing" data module from SAEFL.[48]
- The scrap rates for seal manufacturing were based on the "Polyethylene Extrusion" data module from SAEFL.[49]
- The scrap rate for thermoforming PP and PLA cups was assumed to be the same as the scrap rate for the injection molding process. This scrap includes defective or contaminated containers, drool and purgings. The web scrap produced during the thermoforming process was not included. It was assumed that the web scrap would be reclaimed in a closed loop recycling system.
- The scrap rates for tube and tape manufacturing were provided by the supplier.
- A 0% recycle rate was assumed for seal manufacturing because the seal is a mix of two materials, which inhibits recycling.
- The weight of injection molded cups and lids were assumed to be equal to the Polytainers' spec sheet weights. (The actual average weight is less.)
- The wall thickness of the PLA thermoformed containers was assumed to be 10% less than the wall thickness of thermoformed PS containers currently on the market. This assumption was based on a discussion with an Application Development Manager at CDP.
- It is assumed that the quantity of plastic resins purchased by Polytainers in 1999 was equal to the quantity of plastic resins used in 1999.
- The thermoforming of PP and PLA cups was modeled using PS thermoforming data. It was assumed that thermoforming of PS results in similar burdens to thermoforming of PP and PLA.
- It is assumed that PLA cups and coated unbleached paperboard cups would use the lids (LLDPE) and seals (PE/PET) currently used for the PP cups.
- At this time, the manufacturer of coated unbleached paperboard containers for Stonyfield's frozen yogurt product line does not make 4 oz., 6 oz., or 8 oz.

containers from the same material for refrigerated yogurt. It was assumed that paperboard containers could be provided.

- The cup weights from a Japanese paperboard container manufacturer were used for the model because they were the lightest weight found. It was assumed that cups of equal weight could be made in the U.S. by a current Stonyfield Farm supplier in New York.
- It was assumed that there is no adhesive used to coat paperboard with LDPE. The LDPE is extruded to coat the paperboard before printing.

4.8.5 Distribution 2

- All secondary packaging was assumed to be shipped by truck from the supplier to the manufacturer.
- Trucks were assumed to be, on average, full on the delivery leg of the trip and empty on the return leg of the trip.
- Pallets were assumed to have a life of 16 round trips after which they were remanufactured. (Based on verbal communication with Polytainers.)
- It was assumed that 94% of the original material for pallets was reused when a pallet was remanufactured.
- Secondary packaging for PLA containers was assumed to be identical to the secondary packaging currently being used for PP containers.
- Secondary packaging in Distribution 2 was assumed to be the same for paperboard cups, except for transport distances. In addition, according to correspondence with the paperboard cup manufacturer, boxes hold 2/3 as many 8 oz. paperboard cups. It was assumed that this ratio held for the other sizes.
- Scrap rate was calculated based on an engineered scrap rate of 5% for sidewalls and 25% for round tops and bottoms and a process scrap rate of 3.5%. Overall scrap rate was found to be 11.2% based on the relative surface areas of sidewalls, tops, and bottoms.

4.8.6 Filling

- The application of the seals in the filling phase had an engineered scrap rate associated with it based on the number of impressions per roll.
- The PLA, HDPE, and coated unbleached paperboard containers would be similar in design to the PP containers and therefore existing filling, sealing and palletizing equipment would be used.
- Containers made with alternative materials or thermoforming will not incur more losses than PP containers during Filling or Distribution 3.

4.8.7 Distribution 3

- Trucks were assumed to be, on average, full on the delivery leg of the trip and empty on the return leg of the trip.
- Refrigerated trucks were assumed to have the same burdens as standard trucks.
- The same secondary packaging for Distribution 3 was used for coated paperboard as for PP containers.

4.8.8 End-of-Life

- At End-of-Life, the system model assumes that for the percentage of solid waste that was incinerated, the container components were separated to produce burdens associated with paper incineration (wrap and carton), plastic incineration (cup and lid), and general municipal solid waste incineration in accordance with the container materials and weights.
- All wastes produced during the Material Production, Manufacturing, Filling and Distribution phases (all except End-of-Life) was assumed to be sent to landfill.
- One hundred percent (100%) of the containers shipped to the distributor/retailer/consumer unit process in Distribution 3 are assumed to reach the End-of-Life phase. For example, none were assumed to be disposed of improperly or maintained by the consumer to be reused for other purposes.

4.9 Missing Data

4.9.1 Material Production

- The type of polyester used in the seals was considered to be proprietary; its Material Production was modeled using PET, which is a type of polyester commonly used for film.
- The type of PE used in the seals was considered to be proprietary. The Material Production of this PE was modeled using a DEAM module that consisted of data from producers of LDPE (62.78%), HDPE (29.15%) and LLDPE (8.07%).[50]
- Data were not available for 4.9% of the materials of the seal, and therefore the Material Production burdens associated with these materials were excluded.
- Data for the adhesives inputs to the tubes and tape were not available. Therefore, the burdens associated with these components were not included in the LCA calculations.
- Material inputs and emissions, other than those related to energy production and combustion, were omitted for the material production of PLA. Material inputs for fertilizers used in corn farming were included.

4.9.2 Distribution 1

- Data were not available on the transport distances between the material suppliers and the seal material manufacturer. This distance was estimated by taking the average of the distances between the material suppliers and the primary packaging manufacturers.
- Data were not available on the transport distances between the secondary packaging supplier and the seal manufacturer. This distance was estimated by taking the average of the distances between the secondary packaging suppliers and the primary packaging manufacturers.
- Data were not available on the transport distances and transport mode between the corn farms and the corn wet milling facility. The average distance was assumed to be equal to the distance from Des Moines, IA to Blair, NE. The transport mode was assumed to be 50% truck and 50% rail.

4.9.3 Manufacturing

- Ancillary material inputs to the injection molded cups and lids were excluded from the system model. Ancillary materials included materials such as hydraulic oil, grease, mold release and water treatment chemicals.
- Air and water emissions and solid waste data were not available from Polytainers for the actual injection molding process and were excluded. The air and water emissions were expected to be small because these emissions were less than the levels monitored by regulatory agencies. The solid waste was also expected to be small since all plastic, corrugated and wood pallet scrap was sold to recycling organizations. The emissions related to energy consumption were accounted for.
- Air and water emissions and solid waste data were not available for the thermoforming manufacturing process and were excluded.
- Polytainers does not currently manufacture 4 oz. cups using the thermoforming process and therefore the weight of a 4 oz. cup was not available. The reduction in the weight of the thermoformed 4 oz. cup was estimated to be proportional to the weight reduction of the 8oz. cup. This weight reduction was the smallest reduction of the three cup sizes.
- Electric energy consumption associated with the printing of the thermoformed cups and lids was not available and was excluded from the system model.

4.10 Yogurt Consumption Considerations

Yogurt consumption was determined to be outside the scope of this LCA study and the environmental burdens have not been included in the overall LCA results. However, there are environmental impacts that result from yogurt consumption that deserve to be mentioned. Refrigeration at the grocery store, transport from the store to the shopper's home, household refrigeration, dishwashing, and reuse or transport to a waste facility are some of the activities that produce environmental impacts associated with consumption.

4.10.1 Refrigeration

Because refrigeration is required for proper yogurt storage, it should be included in the consumption phase impacts. The amount of energy used to keep yogurt chilled will vary depending on the size of the yogurt container, the length of time it is refrigerated, and the energy efficiency of the refrigerator. A newer appliance must meet regulatory standards for energy efficiency that an older appliance does not. More detailed calculations of the energy consumption associated with household refrigeration are provided in Appendix B.

4.10.2 Container Function

In the case of 4 oz., 6 oz., and 8 oz. containers, the disposable PP container serves to transport and store yogurt, and it also functions as the cup or bowl from which the yogurt is eaten. In contrast, the 32 oz. container does not usually perform the same function. It is used to transport and store the yogurt, but not to eat it. In most cases, an additional bowl is used to hold the yogurt for consumption. The use of bowl contributes to life cycle burdens. Additional water and energy is required to wash the bowl after each use. The additional water and energy should be considered in the life cycle of 32 oz. containers.

Spoons are also used for yogurt consumption for all container sizes, with the exception of 2 oz YoSqueeze. Again, washing a reusable spoon or using a disposable plastic spoon to eat the yogurt requires water and/or energy in the Consumption phase. More detailed calculations of the water and energy consumption associated with household dishwashing are also provided in Section 5.4.

5. RESULTS AND INTERPRETATION

The results are presented in four sections. First, the results of a life cycle assessment of the Current PDS are presented. This includes a comparison of the PDS by container size as well as a discussion of the human health impacts. The second section compares the environmental burdens of the current PDS with four alternative composite PDSs: HDPE, Thermoformed PP, PLA and Coated Unbleached Paperboard. The third section compares the Current PDS with the four Alternative PDSs on a container size basis. Finally, the results of the Yogurt Consumption Phase analysis are presented.

Result forms from the computer calculation model can be found in Appendix F.

5.1 Current PDS Results

5.1.1 Container Size Comparison

The Current PDS is composed of PP injection molded cups (4, 6, 8 and 32 oz. sizes), LLDPE lids (6, 8 and 32 oz. sizes), PE/PET seals (4, 6, 8 and 32 oz. sizes), paperboard wraps (4 oz. size) and LLDPE tubes with paperboard carton for the 2 oz. size. The following Container Size Comparison shows the results of the life cycle assessment by container size. This comparison will highlight differences in environmental burdens due to the different capacities and composition of the containers. Table 5-1 shows the material inputs and outputs, emissions and energy consumption for the PDS life cycle by container size. The discussion of the results is presented according to the Data Categories detailed in Section 3.5 and the Impact Categories listed in Section 3.6.

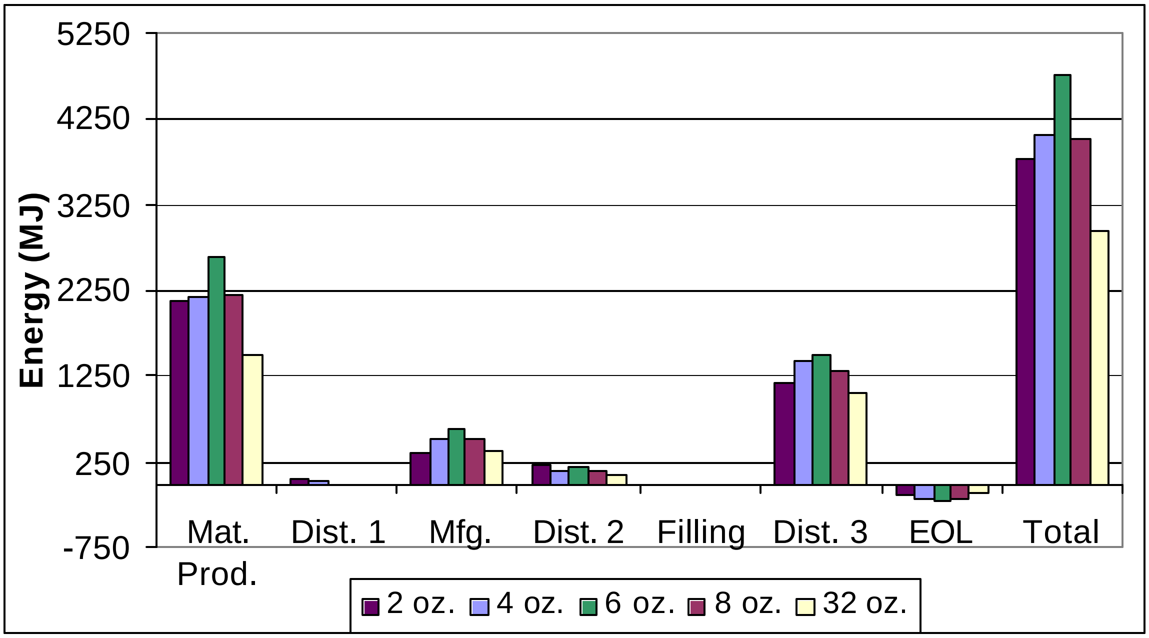
Table 5-1: Environmental Burdens for Current PDS (1000 lbs. Yogurt Delivered)

Environmental Flows	Units	2 oz.	4 oz.	6 oz.	8 oz.	32 oz.
Inputs						
(r) Clay (in ground)	kg	15.871	10.814	8.070	6.699	4.566
(r) Coal (in ground)	kg	5.22	5.01	4.61	3.88	2.76
(r) Lignite (in ground)	kg	0.9978	0.7169	0.5557	0.4422	0.3082
(r) Limestone (CaCO3, in ground)	kg	2.692	1.284	0.258	0.214	0.154
(r) Natural Gas (in ground)	kg	26.62	20.34	29.79	24.22	16.08
(r) Oil (in ground)	kg	26.8	43.4	49.0	43.3	34.2
Diesel	kg	13.7	12.9	12.3	12.0	11.3
Wastepaper	kg	61.97	41.86	29.86	23.83	16.69
Wood	kg	11.20	11.75	11.12	9.50	6.37
Raw Materials (other)	kg	9.01	8.39	8.62	6.97	4.83
Water Used (total)	liter	1147	981	916	784	608
Outputs						
(a) Carbon Dioxide (CO2, fossil)	g	119444	133985	136968	120893	95976
(a) Carbon Monoxide (CO)	g	279.1	227.9	223.5	201.8	162.7
(a) Heavy Metals (total)	g	0.0335	0.0291	0.0260	0.0230	0.0168
(a) Hydrocarbons (except methane)	g	132.9	93.3	82.7	74.2	61.6
(a) Hydrocarbons (unspecified)	g	211	337	482	403	278
(a) Hydrogen Chloride (HCl)	g	4.77	4.61	4.68	3.91	2.76
(a) Hydrogen Fluoride (HF)	g	0.256	0.257	0.213	0.182	0.133
(a) Metals (unspecified)	g	1.109	0.609	0.494	0.400	0.252
(a) Methane (CH4)	g	467	376	342	287	203
(a) Nitrogen Oxides (NOx)	g	877	925	982	891	746
(a) Particulates (total)	g	109.1	114.2	121.8	105.9	80.3
(a) Sulfur Oxides (Sox as SO2)	g	418	453	451	388	288
(w) Acids (H+)	g	0.48	1.96	2.49	2.13	1.56
(w) BOD5 (Bio Oxygen Demand)	g	73.1	74.8	77.8	62.2	43.8
(w) Chlorides (Cl-)	g	320.4	294.4	271.7	250.8	220.2
(w) COD (Chem. Oxygen Demand)	g	320.8	267.3	238.0	196.6	144.8
(w) Dissolved Matter (unspecified)	g	1.36	5.14	5.51	4.88	3.71
(w) Heavy Metals (total)	g	0.0446	0.0310	0.0252	0.0200	0.0136
(w) Hydrocarbons (unspecified)	g	1.61	6.33	8.03	6.89	5.09
(w) Metals (unspecified)	g	5.77	7.27	14.91	12.11	8.08
(w) Nitrate (NO3-)	g	48.7	57.7	67.5	53.8	37.6
(w) Nitrogenous Matter (as N)	g	1.243	1.044	1.511	1.193	0.783
(w) Oils (unspecified)	g	8.37	7.58	6.70	5.97	4.90
(w) Salts (unspecified)	g	88.63	67.05	54.92	43.61	30.22
(w) Sulfate (SO4--)	g	50.89	48.78	50.04	39.84	27.75
(w) Suspended Matter (uspec.)	g	78.4	68.3	65.0	56.4	44.9
Waste (total)	kg	47.00	38.02	34.30	28.79	20.35
Energy						
E Feedstock Energy	MJ	1911	1881	2507	2053	1390
E Fuel Energy	MJ	1878	2186	2234	1954	1531
E Non Renewable Energy	MJ	2594	3060	3865	3294	2423
E Renewable Energy	MJ	1191	1003	873	710	495
E Total Primary Energy	MJ	3800	4067	4756	4019	2920
Electricity	MJ elec	221	185	186	146	99

5.1.1.1 Life Cycle Energy

When the overall energy requirements for the product delivery systems were compared, the 32 oz. containers performed the best. The total energy consumption for 2 oz., 4 oz., 6 oz., 8 oz. and 32 oz. were 3800, 4080, 4760, 4020, and 2930 MJ respectively. Significant amounts of energy are consumed at the Material Production and Manufacturing phases as well as in Distribution 3, the delivery of yogurt from Stonyfield Farm to distributors and retailers. Figure 5-1 below shows the Current PDS life cycle energy by phase.

Figure 5-1: Life Cycle Energy - Current PDS

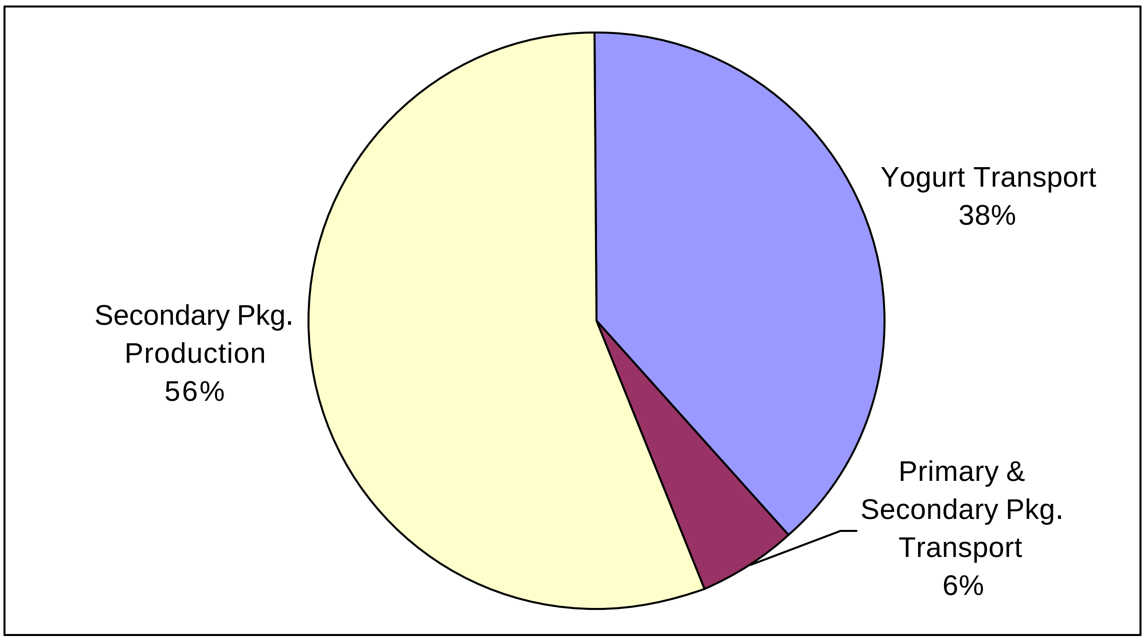


In the Material Production phase, the 6oz. PDS showed the highest energy value due to the quantity of material needed to deliver one functional unit of yogurt and the material production energy of the LLDPE lids. The lids for the 6 oz. PDS are significant because they were originally designed for the 8 oz. container size and as a result have a higher mass to yogurt ratio than lids of any other container size. Energy results for the 6 oz., 8 oz. and 32 oz. containers demonstrate the relationship between material intensity and energy burdens. As the size of the container decreased more primary packaging was required to deliver the same amount of yogurt. Therefore, energy demand per functional unit is expected to increase as the size decreases. This container size - energy intensity correlation held true for the three largest sizes because they have consistent configurations (cup, lid and seal). The 2 oz. and 4 oz. PDSs did not adhere to the container size - energy intensity pattern because they employ different configurations, both of which use less plastic per functional unit. The 4 oz. PDS replaces six LLDPE lids with one coated paperboard wrap and the 2oz. uses lightweight tubes with a coated paperboard carton. The primary packaging weights of the 2 oz. and 4 oz. PDS exceed that of the 6 oz. per functional unit but have an energy advantage due to the material production energy of coated paperboard (25.7 MJ/kg) falling below that of LLDPE (72.3 MJ/kg) lids and PP (74.9 MJ/kg) cups.

The quantity and composition of materials required for each size container PDS were also responsible for the pattern observed at the Manufacturing stage. The Injection Molding of Plastics module used in the calculation model assumed specific burdens per mass of plastic formed. So, the plastic intensive 6 oz. PDS again had the highest energy burden. The 2oz. and 4 oz. PDSs again departed from the pattern because the conversion process for paperboard required only 6.9 MJ/kg compared to 19.6 MJ/kg for injection molding.

Another notable feature of the energy profile shown in Figure 5-1 was the significance of the Distribution 3 phase. The two segments of this phase with the highest energy burdens were secondary packaging production and product transport. Figure 5-2 shows that the energy attributed to these two segments accounted for 94% of the energy burdens of this phase for the 8 oz. PDS and one third of the life cycle total.

Figure 5-2: Distribution 3 Energy - Current 8 oz. PDS



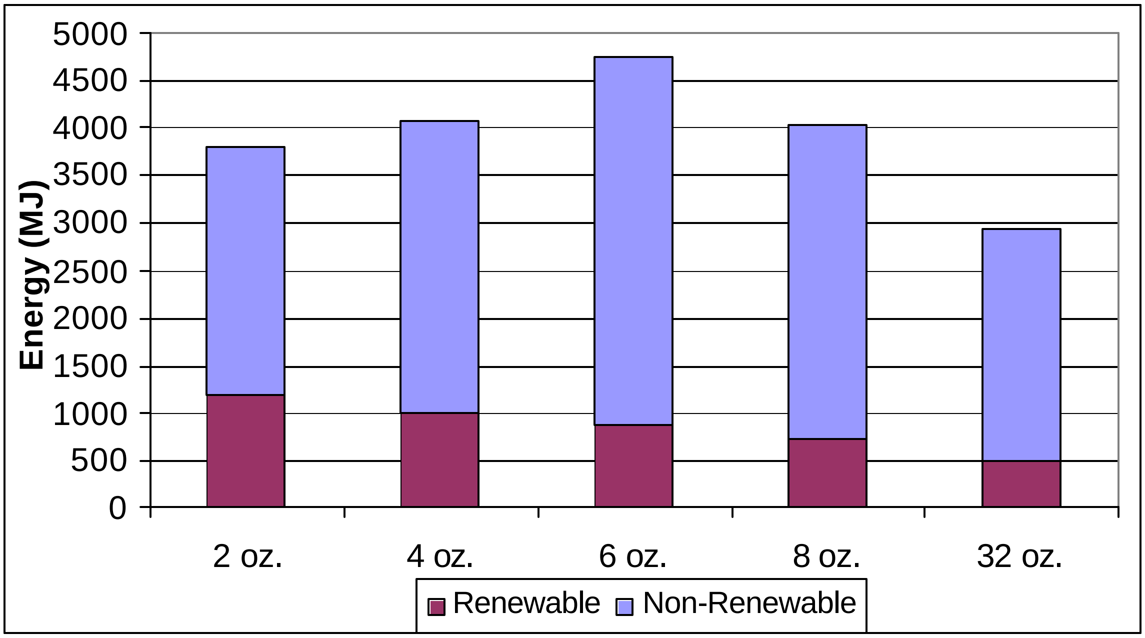
The End-of-Life phase shows an energy credit rather than a burden due to the electricity produced from the incineration of plastics and paperboard. This credit extended to other life cycle metrics to account for the avoided burdens from generating electricity by burning fossil fuels.

Renewable Energy

The use of renewable and non-renewable energy was also tracked throughout the life cycle of each size container. Figure 5-3 shows the quantities of each division of energy for the different size containers. From the graph it can be seen that the 2 oz.

and 4 oz. PDSs had the highest fraction renewable energy, with 31% and 25% respectively, compared to 6 oz. (18%), 8 oz. (18%) and 32 oz. (17%). This is due in part to the fact that the quantity of biomass energy used to produce coated paperboard (for the wraps and cartons) was significantly more than that of any of the plastic packaging materials used. Another factor that contributes to the higher renewable energy fraction of the 2 oz. and 4 oz. PDSs is that the feedstock energy of the paperboard components is from renewable resources.

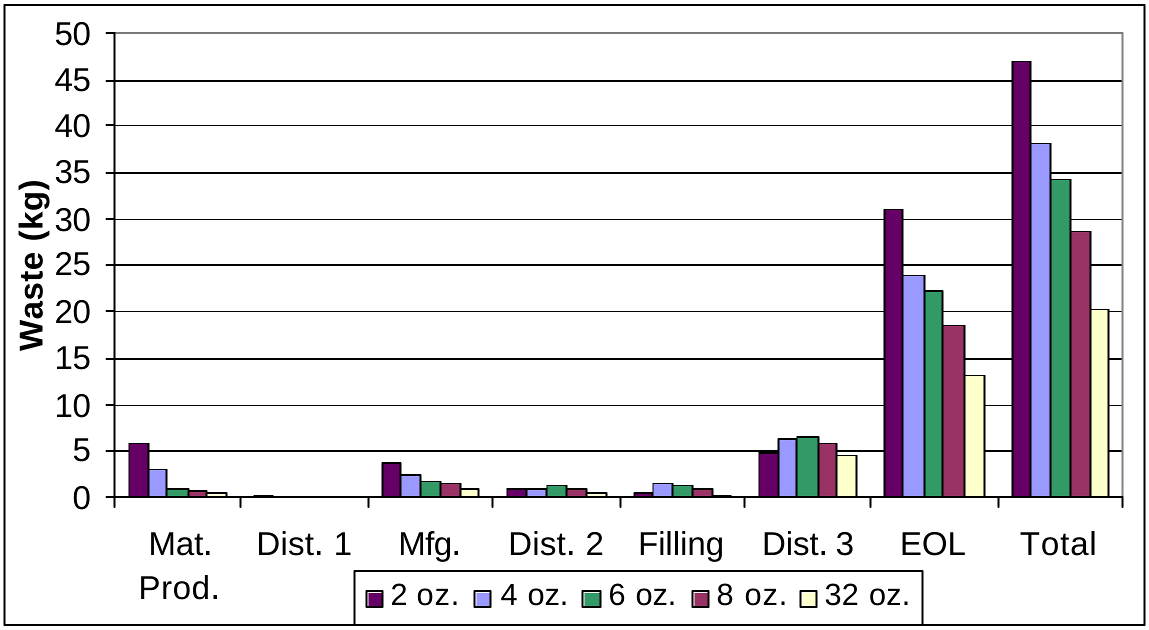
Figure 5-3: Life Cycle Renewable Energy - Current PDS



5.1.1.2 Life Cycle Solid Waste

The life cycle solid waste profile follows the pattern that smaller containers require a greater amount of material to deliver the same quantity of product. This relationship, seen as the size decreased from 32 oz. (20.4 kg) to 8 oz. (28.8 kg) to 6 oz. (34.3 kg), was slightly exaggerated for the 4 oz. PDS (38.0 kg) and 2 oz. PDS (47.0 kg). The phases responsible for the large solid waste burdens for the 2 oz. and 4 oz. PDSs were Material Production, Manufacturing and End-of-Life. Figure 5-4 shows the life cycle solid waste generation of the PP injection molded PDS by phase.

Figure 5-4: Life Cycle Solid Waste - Current PDS



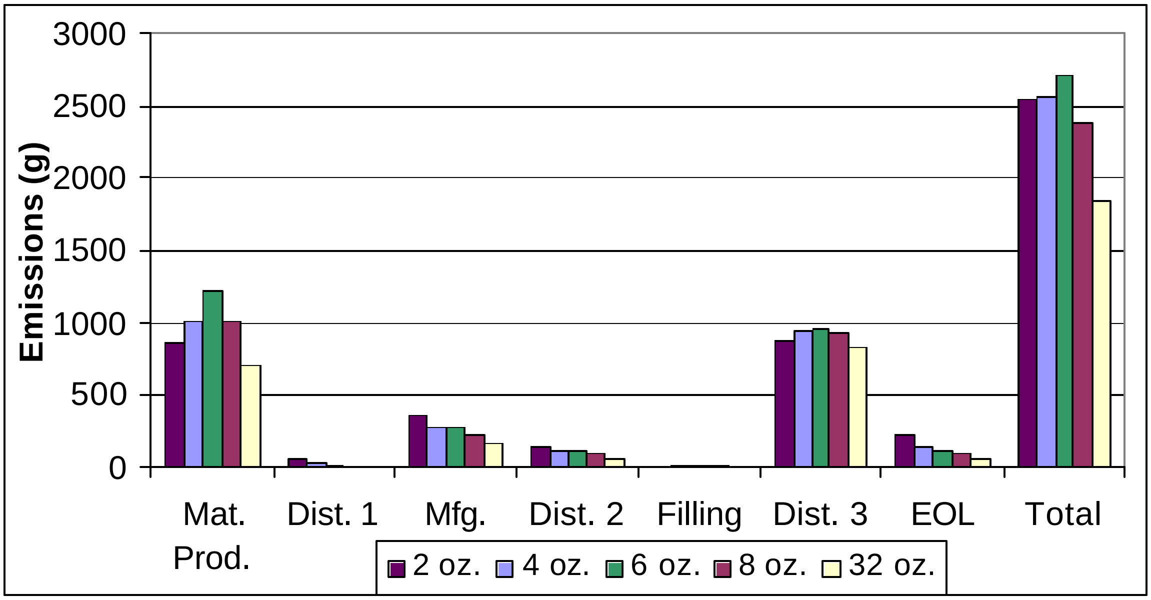
Solid waste produced at the Manufacturing phase was calculated from the mass of material and the conversion process employed. The 2 oz. and 4oz. PDSs were penalized for both these aspects. The quantity of primary packaging material needed for a functional unit delivered in 2 oz. tubes and 4 oz. containers were 48.2 kg and 35.7 kg compared to 34.5 kg for 6 oz. containers. The conversion process for wraps produced 0.09 kg of solid waste for each kilogram of output, while injection molding generated only 0.05 kg per kilogram of output.

The End-of-Life solid waste burdens were calculated by subtracting recycled cups, lids and wraps from the total mass of primary packaging. The remaining waste stream was then landfilled or incinerated at the average U.S. rate (23.5% incineration). Recycled rates were determined from an EPA municipal solid waste report to be zero percent for plastic and 15.8% for cardboard.[51] These rates seem to give an advantage to 2 oz. and 4 oz. PDSs, but the material intensity of these systems is much greater due to the weight of primary packaging needed to hold a functional unit.

5.1.1.3 Life Cycle Air Emissions

The profile of total air emissions demonstrated a similar trend to that of life cycle energy. The 32 oz. PDS had the lowest life cycle air emission at 1840g, and the 6 oz. PDS was highest with 2710g, and 2 oz., 4 oz. and 8 oz. fell in between with 2540g, 2550g and 2370g respectively. The two phases with the heaviest contribution to air emissions were Material Production and Distribution 3, from Stonyfield Farm to retailers. Figure 5-5 shows the air emissions per life cycle phase. Note that CO_2 emissions were not included to avoid obscuring other releases, but they were considered in the Global Warming Potential, which is discussed below.

Figure 5-5: Life Cycle Air Emissions (excl. CO_2) - Current PDS



The Material Production phase was energy intensive and therefore resulted in substantial air emissions. Material production of plastic releases more air emissions than material production of paperboard so the relative amounts of air emissions from the Material Production phase closely match the quantity of plastic utilized in the respective PDS.

The air emission burdens in the Distribution 3 phase were due to the burning of diesel fuel in delivery trucks and the production of secondary packaging. The transportation burdens were relatively constant throughout all container sizes since approximately 88% of shipping weight was attributed to the yogurt itself. Therefore, the majority of the differences were caused by varying amount of secondary packaging required by each size container.

Somewhat surprising was the minimal contribution of the Manufacturing phase to life cycle air emissions. Although container manufacturing requires large amounts of electricity, it showed relatively low air emissions. This was due to the Canadian electricity grid that utilized 63% renewable sources, primarily hydropower. The 2 oz. PDS showed significantly more manufacturing air emissions because all it's components were manufactured in the United States.

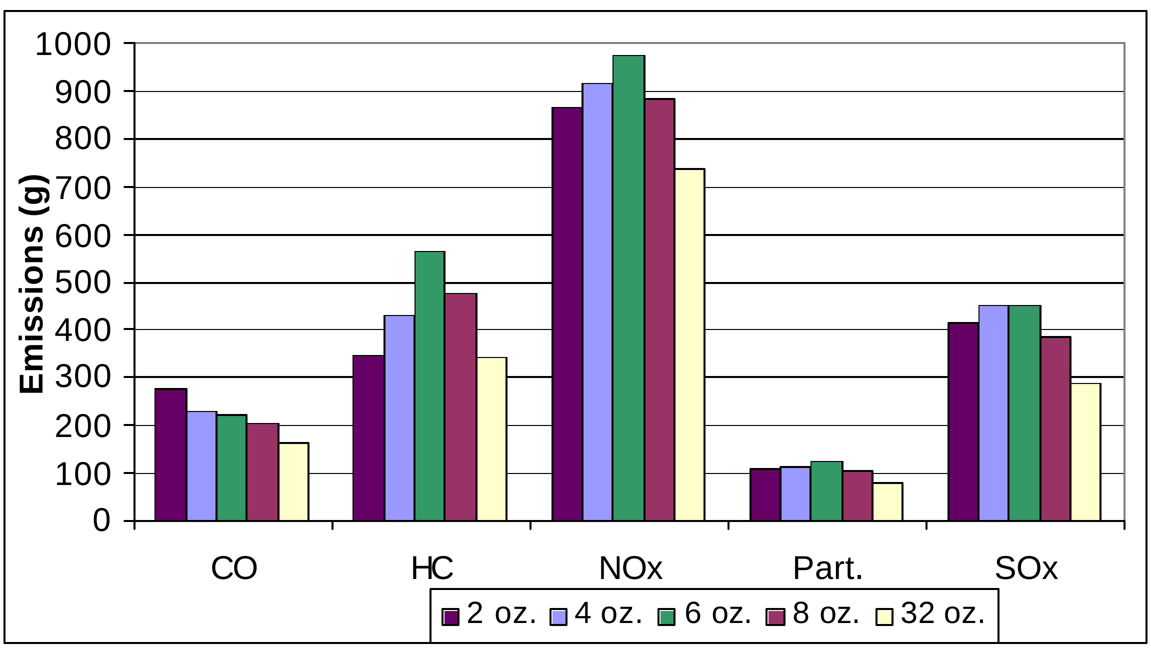
Total mass of air pollutant emissions should be used with caution. It is misleading to consider only total mass without considering the breakdown of specific pollutants as shown in Figure 5-6. For 6, 8 and 32 oz container systems the specific air pollutant emissions in each phase roughly correlate with container size. The composition of the 2 and 4 oz container systems is significantly different, and therefore the total air pollutant emission in each phase is more difficult to interpret.

The U.S. EPA has designated five air emissions as the criteria air pollutants. The criteria pollutants are carbon monoxide (CO), volatile organic compounds (VOC, hydrocarbon releases were used a proxy for VOC in this study), nitrogen oxides (NO_X), particulate matter and sulfur oxides (SO_X). See Table 5-2 for a description of the ill effects of each of these pollutants. A graph showing the relative life cycle quantities of these emissions for each PDS appears in Figure 5-6.

Table 5-2: Criteria Air Pollutants[52]

Pollutant	Symbol	Environmental Impact
Sulfur Oxides	SO_X	In the atmosphere, SO_X combines with moisture to form sulfuric acid, also know as acid rain. Acid rain damages buildings and crops as well as disrupts ecosystems.
Nitrogen Oxides	NO_X	NO_X is produced during high temperature combustion. Its release into the atmosphere increases ground level ozone, which is also called smog.
Volatile Organic Compounds	VOC	VOCs are commonly released from incomplete combustion and painting operations. Along with NO_X, VOCs contribute to the formation of ground level ozone.
Carbon Monoxide	CO	CO is a byproduct of incomplete combustion. It is a colorless and odorless gas that can be very poisonous at elevated concentrations when inhaled.
Particulate Matter	PM	Mixture of solids and liquid droplets in the air, which can accumulate in the respiratory system and are associated with the aggravation of respiratory conditions. PM is also a cause of reduced visibility and damage to paints and building materials.

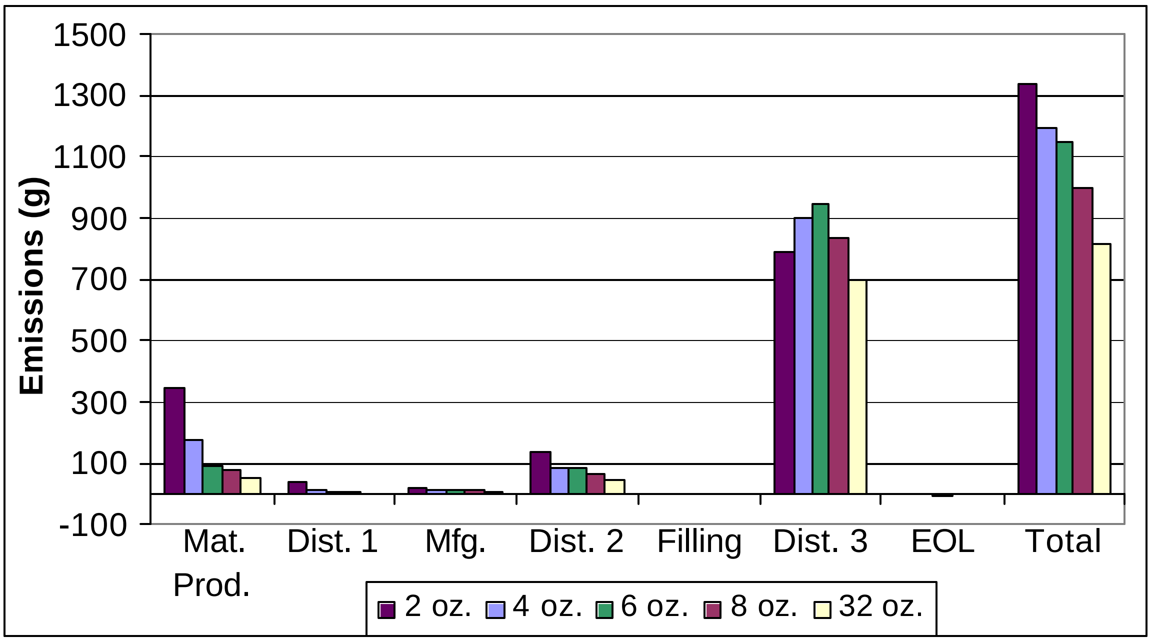
Figure 5-6: Life Cycle Criteria Air Pollutant Emissions - Current PDS



5.1.1.4 Life Cycle Emissions to Water

The life cycle emissions to water again show the benefits of delivering yogurt in larger containers. The 2 oz. PDS had the most water emission with 1340g, followed by 4 oz. (1190g), 6 oz. (1140g), 8 oz. (1000g) and 32 oz. (812g). The vast majority of emissions occurred in Distribution 3 with smaller but still significant quantities in Material Production and Distribution 2. Similar to Emissions to Air, the total volume of emissions to water is only part of the story. This category does not contain information about the types of emissions, nor their impacts on the environment. The graph showing the water emission profiles of each size PDS appears in Figure 5-7.

Figure 5-7: Life Cycle Emissions to Water - Current PDS

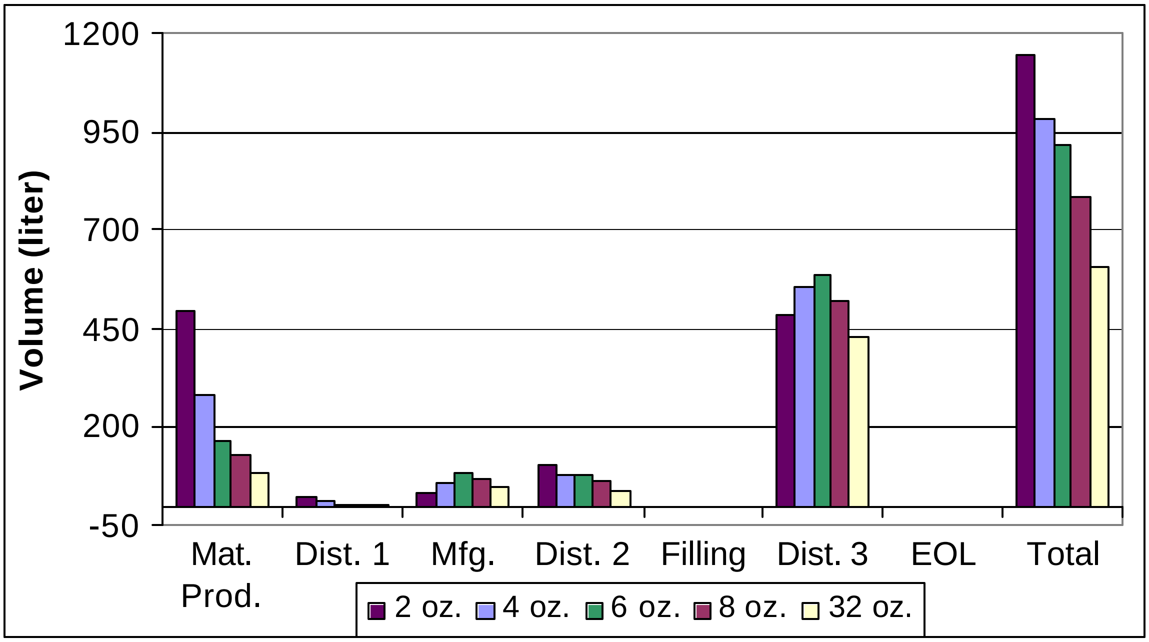


Water emission per phase corresponded closely with the quantity of cardboard and other timber products consumed. This was evident in the Material Production phase where the 2 oz. and 4oz. PDSs had significantly more emissions to water than the all plastic PDSs, due to the production of coated paperboard for the wrap and carton. The two Distribution phases that had significant emissions to water required large amounts of corrugated board used for boxes.

5.1.1.5 Life Cycle Water Use

Water use was another burden category that favored the 32 oz. PDS, with 606 liters followed in order by 8 oz. (784 liters), 6 oz. (916 liters), 4oz. (981 liters) and 2 oz. (1150 liters). The differences between the various container sizes occurred in the Material Production phase. The results for water use were predicted with the 2 oz. and 4 oz. PDSs' use of coated paperboard for cartons and wraps, which require more water than plastic materials. The water required to produce duplex/triplex board is 9.6 liters/kg compared to 4.1 liters/kg for LLDPE and 3.1 liters/kg for PP. Figure 5-8 shows the water use by phase for each size PDS.

Figure 5-8 Life Cycle Water Use - Current PDS

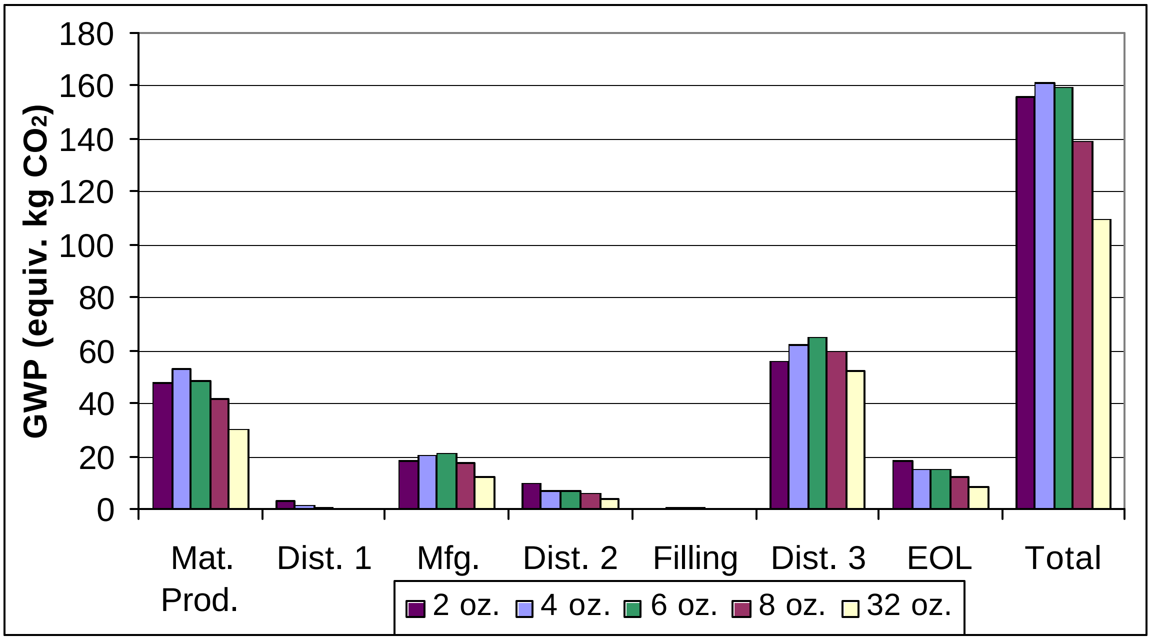


5.1.1.6 Characterized Impact Categories

Air emissions for all sizes of PDSs were evaluated for their Global Warming Potential (GWP), Ozone Depleting Potential (ODP) and Maximum Allowable Concentration (MAC). Yogurt refrigeration and dishwashing were outside the scope of the study and has not been included in any of the characterized impact categories.

Global Warming Potential (GWP), which was measured in equivalent kg of carbon dioxide, demonstrated a similar profile to that seen in life cycle energy and life cycle air emissions. The 32 oz. PDS had the lowest GWP at 109 kg CO_2 equivalent, followed by 8 oz. (139 kg CO_2) 2 oz. (156 kg CO_2), 6 oz. (159 kg CO_2) and 4 oz. (161 kg CO_2).

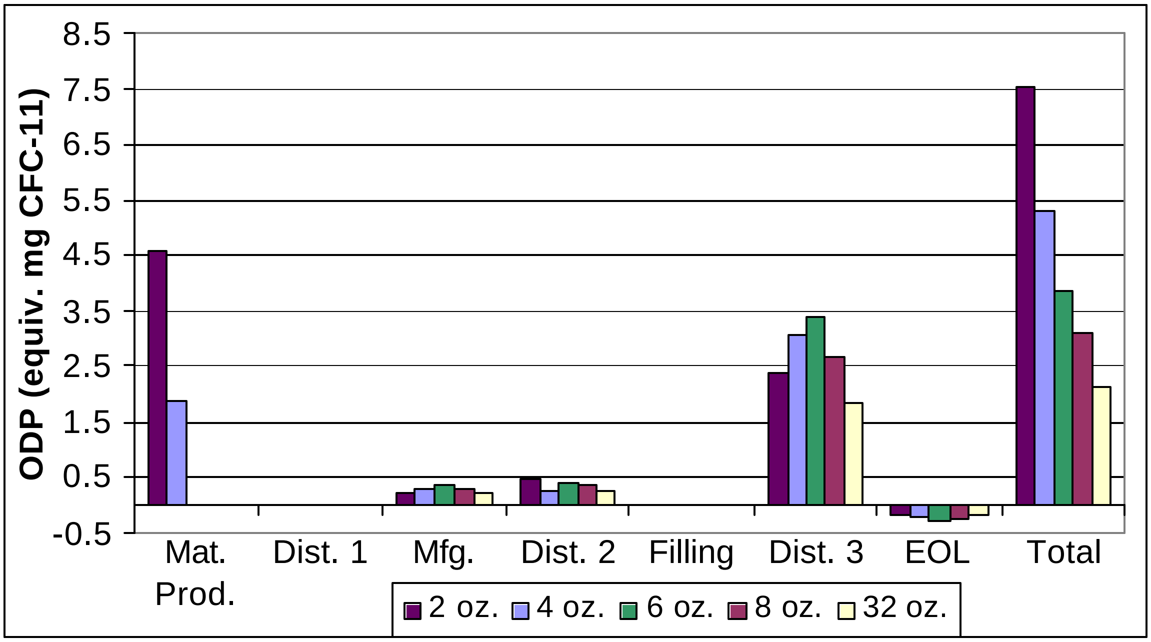
Figure 5-9 Life Cycle Global Warming Potential - Current PDS



The next characterized impact indicator is ozone depletion potential (ODP), which was measured in equivalent milligrams CFC-11 (chlorofluorocarbon number 11). The life cycle profile for each size PDS appears in Figure 5-10. Nearly all releases of ozone depleting substances occurred in the production of forest products, such as corrugated cardboard and paperboard. This was evident in the relatively significant release shown in the Material Production phase for the 2 oz. and 4 oz. PDSs, since they utilized coated paperboard for the wrap. Overall, the 2 oz. PDS had the highest ODP with 7.53 equivalent milligrams of CFC-11 followed by the 4 oz. PDS with 5.31 mg CFC-11. The other PDSs had decreasing ODP totals as size increased from 6 oz. (3.89 mg CFC-11) to 8 oz. (3.09 mg CFC-11) to 32 oz. (2.14 mg CFC-11).

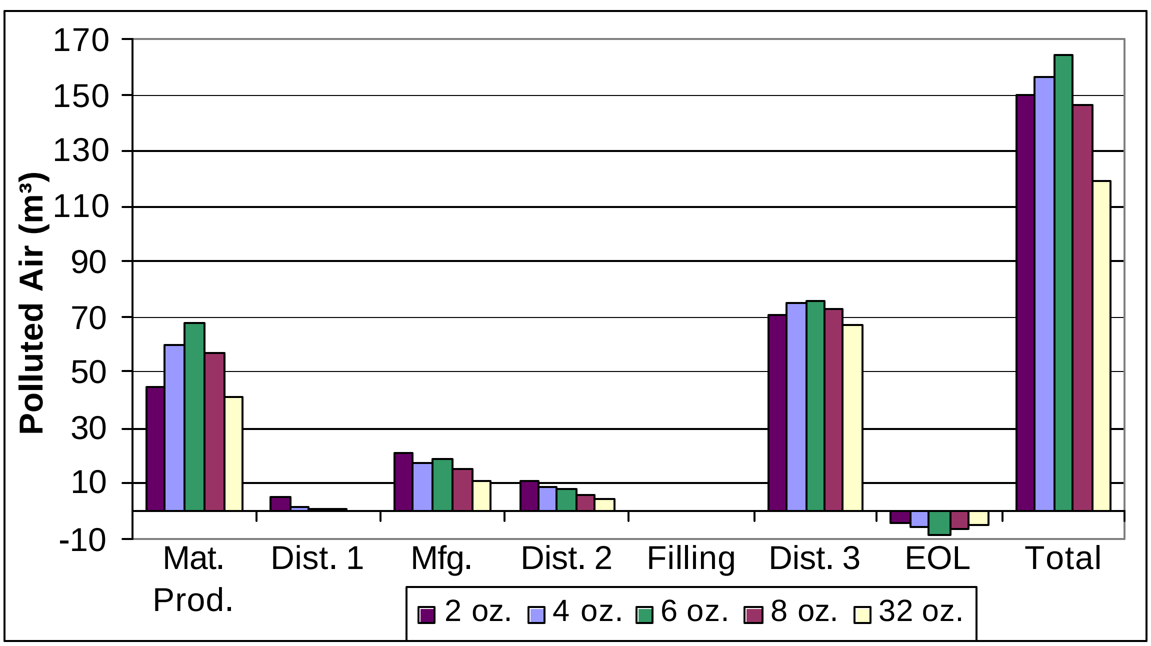
It should be noted that halon 1301 and methyl bromide, the two compounds that accounted for nearly all of the ODP, are no longer produced in this country and their use is heavily restricted.[53] It would be expected that updates in data would reflect significant reductions in emissions of ozone depleting substances.

Figure 5-10 Life Cycle Ozone Depletion Potential - Current PDS



Through the use of weighting factors, criteria air pollutants were compiled into a single indicator. The method used for this study determined the amount of polluted air by using maximum allowable concentrations (MAC). The graph of polluted air volumes appears in Figure 5-11. The profile of each container size PDS was nearly identical to the global warming potential described above. Although, MAC tracks CO, hydrocarbons, SO_X, NO_X and particulate matter rather than greenhouse gases, the reasoning for the results is similar to that of GWP.

Figure 5-11 Life Cycle Maximum Allowable Concentration - Current PDS



5.1.2 Human Health Impacts

5.1.2.1 Evaluating Chemical Risks

Just as it was difficult to accurately quantify environmental impacts of a product system, it was equally difficult to assess the human health risks posed by chemicals released during the product life cycle. Several factors including the intensity or concentration, route (i.e., skin contact, inhalation, ingestion), and duration of exposure determine the risk of a substance. Individuals respond differently to similar exposures depending on their gender, age, overall health, nutritional status, and inherited characteristics. While there have been attempts to develop methodologies for chemical hazard evaluation, a uniform ranking of potential human health and environmental impacts does not exist. Even though rankings are subject to criticism, there is a substantial amount of scientific information about the substances that are known or are likely to cause cancer and other health problems.

Both the Environmental Protection Agency (EPA) and Agency for Toxic Substances and Disease Registry (ATSDR), under the authority of the U.S. Department of Health and Human Services (DHHS), have responsibilities evaluating and providing information regarding the toxicity or potential hazards associated with exposure to chemicals in the environment. The Integrated Risk Information System (IRIS), prepared and maintained by the U.S. Environmental Protection Agency (U.S. EPA), is an electronic database containing information on human health effects that may result from exposure to various chemicals in the environment. IRIS was initially developed for EPA staff in response to a growing demand for consistent information on chemical substances for use in risk assessments, decision-making and regulatory activities.[54] The EPA also publishes The Report on Carcinogens (RoC), which identifies and discusses substances or exposure circumstances that may pose a carcinogenic hazard to humans. The most recent RoC lists 218 entries as either known to be human carcinogens or reasonably anticipated to be human carcinogens.

Unlike the EPA, ATSDR is a public health agency created under CERCLA “to prevent exposure and adverse human health effects and diminished quality of life associated with exposure to hazardous substances.”[55] It is not a regulatory agency, but rather one that advises EPA on the health aspects of hazardous waste sites or spills and makes recommendations to EPA when specific actions are needed to protect the public's health. ATSDR ranks the top 20 hazardous substances on the ASTDR/EPA Priority List. ASTDR is required to produce a list of substances that “are most commonly found at facilities on the National Priorities List (NPL) and which are determined to pose the most significant potential threat to human health due to their known or suspected toxicity and potential for human exposure at these NPL sites. It should be noted that this priority list is not a list of "most toxic" substances, but rather a prioritization of substances based on a combination of their frequency, toxicity, and potential for human exposure at NPL sites.”[56] The complete list consists of 275 substances.

Another method to assess potential health risk is by calculating the Minimum Risk Level (MRL). The MRL is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over a specified duration of exposure. These substance-specific estimates are intended to serve as screening levels only.

5.1.2.2 Evaluation of Health Impacts of Current PDS

The Stonyfield Farm PDSs used or produced 25 of the 275 ATSDR priority hazardous substances, of which 12 are included on the Top 20 list. The majority of these substances were the result of electricity generation during the Material Production and Manufacturing life cycle phases.

To evaluate the hazardous chemicals found in the Stonyfield Farm PDSs, chemicals were identified that fit into one or more of three groupings commonly used to categorize hazardous substances: Known and Reasonably Anticipated Carcinogens, Water Quality Concerns, and Hazardous Air Pollutants (Appendix D). There were 46 items in the group of known and anticipated carcinogens, 38 in the water quality group, and 46 in the air pollutant group. Of all chemicals listed, 32 were on both the air pollutant and carcinogen lists and 13 were on both the water quality and carcinogen lists.

The amounts of each chemical inventoried in the PP injection molded, PP thermoforming, and HDPE injection molded PDSs were compared. In general, substance quantities were slightly higher for HDPE injection molded containers and lower for PP thermoformed containers. Organic matter (unspecified) and hydrogen chloride (HCl) were the largest single contributors to hazardous air pollutants. Prolonged inhalation exposure to HCl is linked to respiratory (nasal and larynx) problems. Chlorides, sodium, and chemical oxygen demand (COD) had the highest quantities of the water quality list. Benzene (C_6H_6), a known carcinogen associated with leukemia, was the largest quantity on the list of known and anticipated to be carcinogens.

Table 5-3: CERCLA list of Priority Hazardous Substances Emitted from PDS[57]

ATSDR	Chemical	mg.	Health Information
1	(a)(w) Arsenic (As)	3.29	Inorganic arsenic is a powerful poison which has both acute and chronic health effects
2	(a)(w) Lead (Pb)	19.1	Lead can damage the nervous system, the kidneys, and the immune system.
3	(a)(w) Mercury (Hg)	1.74	Mercury can damage the brain, kidneys, and developing fetus
5	(a)(w) Benzene (C6H6)	1037	Long-term exposure to high levels of benzene can cause leukemia
7	(a)(w) Cadmium (Cd)	1.69	Cadmium damages lungs, can cause kidney disease, and may irritate the digestive tract
8	(a) Benzo(a)pyrene ($C_{20}H_{12}$)	0.0608	Multiple animal studies demonstrate Benzo(a)pyrene to be carcinogenic
9	(a)(w) Polycyclic Aromatic Hydrocarbons (PAH)	2.63	PAHS are a group of over 100 different chemicals, some are known to cause cancer
10	(a) Benzo(b)fluoranthene	3.24×10^5	Multiple animal studies demonstrate Benzo(b)fluroanthene to be carcinogenic
11	(a)(w) Chloroform ($CHCl_3$, HC-20)	0.211	Chronic exposure to chloroform may damage liver and kidneys
15	(a)(w) Trichloroethylene (CCl_2CHCl)	8.77×10^5	Trichloroethylene may cause nervous system effects and/or liver and lung damage
16	(a)(w) Chromium (Cr III, Cr VI)	12.8	Long term exposure to chromium(VI) can increase risk of non-cancer lung diseases
17	(a) Dibenzo(a,h)anthracene	2.23×10^5	Multiple animal studies demonstrate Dibenzo(a,h)anthracene to be carcinogenic
26	(a)(w) Cyanide (CN-)	1.96	Poisonous with effects including death, breathing difficulties, and thyroid enlargement
31	(a)(w) Tetrachloroethylene (C_2Cl_4)	16.4	Studies suggest that women exposed to TCE are more likely to have reproductive problems
39	(a) Beryllium (Be)	0.136	Lung damage has been observed in people who have breathed Beryllium-contaminated air
46	(a) Carbon Tetrachloride (CCl_4)	0.0185	Exposure to carbon tetrachloride can damage the liver, kidneys, and nervous system
52	(a)(w) Nickel (Ni)	31.6	Workers exposed to nickel compounds have developed lung and nasal sinus cancers
57	(a) Benzo(k)fluoranthene	3.24×10^5	Multiple animal studies demonstrate Benzo(k)fluoranthene to be carcinogenic
62	(a)(w) Toluene ($C_6H_5CH_3$)	88.5	Breathing harms the brain and can cause headaches, confusion, and memory loss
70	(a)(w) Zinc (Zn)	22.9	Zinc is essential but at levels 10-15 times the RDA, it can cause anemia and pancreas damage
75	(a) Naphthalene ($C_{10}H_8$)	0.0419	Exposure to naphthalene may damage or destroy red blood cells
84	(a)(w) Chlorine (Cl_2)	1.30	Chlorine is an irritant and can react in water to form cancer-causing organo-chlorine compounds
141	(a) Manganese (Mn)	2.47	Chronic exposure to high levels of manganes can cause impairment of neuro-behavioral function
167	(a) Dichlorobenzene (1,4-$C_6H_4C_{12}$)	0.0206	Exposure to dichlorobenzene can cause headaches, dizziness, and liver problems
256	(a) Formaldehyde (CH_2O)	43.5	Multiple animal studies demonstrate formaldehyde to be carcinogenic

5.1.2.3 Chemical Migration into Foods

A literature search was conducted to discover which chemicals migrate from PP or LDPE into foods. Several antioxidants have been shown to migrate into food from non-film plastics made from LDPE or PP. One study showed that phenolic antioxidant migrated in decreasing order: LDPE, HDPE, PP, SB (high-impact polystyrene), and ABS (acrylonitrile-butadiene-styrene).[58] Another study showed that the antioxidant n-octadecyl 3-(3,5-di-tert-butyl-4-hydroxyphenyl)-propionate migrated in a similar decreasing order with LDPE greater than HDPE greater than PP greater than SB. Moreover, the migration was significantly smaller from injection-molded cups, deep-drawn tubs, and blown bottles compared to migration from compressed or extruded sheets.[59] Another study showed that the antioxidants, Irganox-1010 (I-1010) and Irganox-1076 (I-1076), had different migration rates for different food simulating liquids at temperatures up to 135 degrees C. For aqueous simulants, antioxidant migrations were largest for PP while for non-aqueous simulants, the highest losses were from LDPE. In both cases, lowest losses were from HDPE, which is a different result from the two studies mentioned above.[60]

Several studies dealt with the migration of chemicals from plastic films into food in a microwave, but because they used plastic film, they are not relevant to this report.[61][62] Stonyfield yogurt containers are comprised of PP, LLDPE, and certain additives including antioxidants. It is unknown if Stonyfield yogurt containers are comprised of specific antioxidants that migrate into foods. Furthermore, the rate of migration appeared to vary due to the fat content and the aqueous content of the food, which made it extremely difficult to know if the above studies are directly relevant to Stonyfield yogurt containers. The results of the literature search are not conclusive and do not directly address the plastics analyzed in this study. Without more information about the specific additives and antioxidants, it is not possible to determine health risks with certainty.

Plasticizers in plastic dairy food containers have been a human health issue in the past due to chemical migration. It was confirmed that Color Concentrate (i.e., white and cotton fluff pigment) does not contains plasticizers. In addition, plasticizers are not found in the PP cups, HDPE cups, PE/PET seals, or the LLDPE lids.

5.1.2.4 UV Ink

Printing inks used by Polytainers were an issue of particular concern for this study. The inks used for Stonyfield Farm cups and lids belong to a group called UV inks that polymerize to a solid by exposure to ultraviolet (UV) radiation, improving their drying characteristics.[63] They are currently used in nearly every printing process and market and have been growing in popularity due largely to their environmental advantages. Initially, the chemical composition of UV inks was reported to irritate skin, but this problem has since been resolved.[64]

Since clearing the early technical hurdles, the environmental and health benefit of the UV inks have been touted. They eliminated the emission of volatile organic compounds (VOCs) into the atmosphere during printing, something that had been a cause of concern in the past.[65] The problem with VOCs is that in the presence of sunlight they undergo a chemical reaction that produces ozone (O_3). Elevated levels of ozone can cause respiratory problems such as asthma in a sizable percentage of the population. Additionally, the removal of harmful VOCs puts these inks in compliance with environmental regulation and allows printers to avoid investing in costly environmental control equipment.[66]

With the proper safety precautions, handling these solid inks do not adversely affect health. However, UV inks contain monomers, oligomers and photoinitiators – chemicals that may cause adverse health reactions if they are accidentally touched, inhaled, or ingested.[67] Acrylates in the inks may cause irritation, redness, and blistering if they come in contact with skin due to improper handling. These risks do not apply to ink that has set as with the printed containers that have been packaged for use.

5.2 Alternative PDS Comparison

This section compares the LCA results of the Current PDS with four alternatives. Section 5.2.1 includes two PDSs that were identified as alternatives at the beginning of the study. One utilizes HDPE in place of PP and the other changes the cup manufacturing process from injection molding to thermoforming. Sections 5.2.2 and 5.2.3 each include a PDS that was identified as an alternative during a survey of packaging materials. The survey was conducted to identify the most promising primary packaging materials with respect to environmental burdens. The two materials selected as the most promising were PLA and coated unbleached paperboard. Both materials were seen as favorable alternatives due to their use of renewable materials and physical properties that would allow for a relatively low cup weight. Also considered in the material selection were economic consequences and customer perception. The complete material survey can be found in Appendix A.

5.2.1 HDPE and Thermoformed PP PDS Comparison

This comparison focuses on the difference in life cycle burdens associated with changes to the primary packaging. Therefore, it is assumed that other than changes to the cup material or manufacturing process, other aspects of the PDS remain the same. To simplify the comparison, a composite product delivery system was created. The composite PDS was compiled by apportioning the five container sizes (2 oz. 4 oz., 6 oz., 8 oz. and 32 oz.) by weight of yogurt sold in fiscal year 2000 as shown in Table 5-4. The life cycle material inputs, outputs and energy usage for the composite PDSs appear in Table 5-5.

Table 5-4: Sales By Container Size - Fiscal Year 2000

Product	% of Sale by Case	Units/Case	Pounds of Yogurt per Case	Weight Fraction
2 oz.	5.49%	96	12	8.99%
4 oz. CF	11.4%	24	6.0	9.34%
4 oz. WH	7.79%	24	6.0	6.38%
6 oz	19.8%	12	4.5	12.2%
8 oz	33.8%	12	6.0	27.7%
32 oz. CF	10.8%	6	12	17.7%
32 oz. WH	10.8%	6	12	17.7%
Total	100%	N/A	N/A	100%

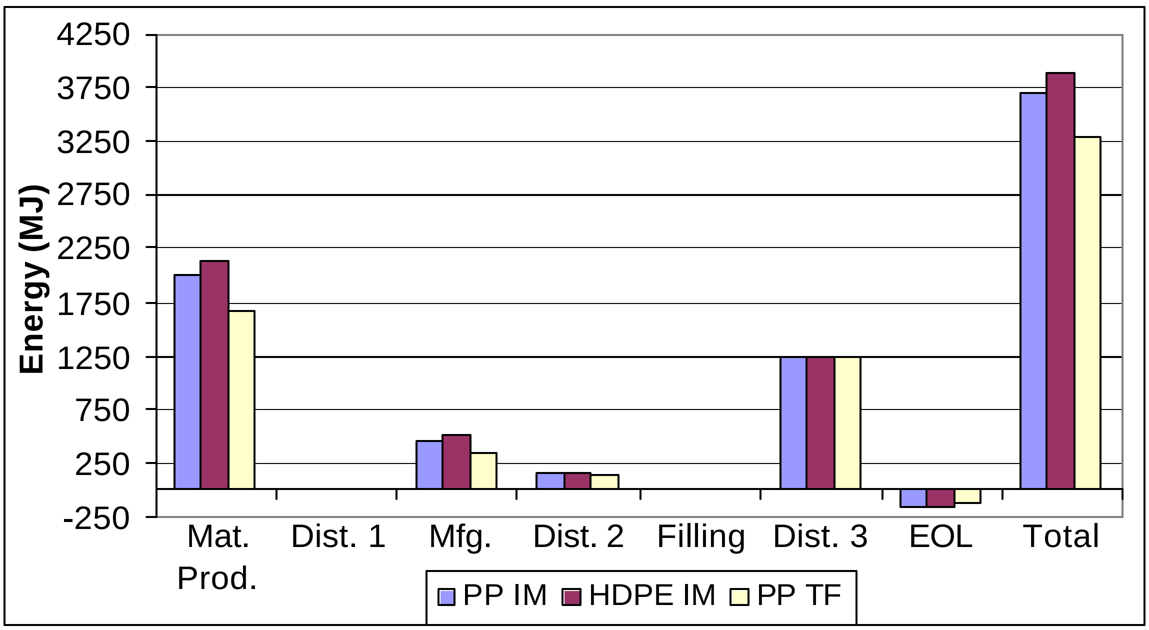
Table 5-5: Environmental Burdens for Alternative PDSs (1000 lbs. Yogurt Delivered)

Item	Units	Current PDS	PE IM PDS	PP TF PDS
Inputs				
(r) Clay (in ground)	kg	7.582	7.951	6.743
(r) Coal (in ground)	kg	3.9	4.4	2.9
(r) Lignite (in ground)	kg	0.50	0.50	0.50
(r) Limestone ($CaCO_3$, in ground)	kg	0.59	0.60	0.53
(r) Natural Gas (in ground)	kg	21.6	28.8	19.1
(r) Oil (in ground)	kg	39.3	34.3	34.6
Diesel	kg	12.1	12.3	11.9
Wastepaper	kg	28.30	28.30	28.30
Wood	kg	9.10	9.10	9.10
Raw Materials (other)	kg	6.82	6.93	6.51
Water Used (total)	liter	801	929	741
Outputs				
(a) Carbon Dioxide (CO_2, fossil)	g	115957	123212	104031
(a) Carbon Monoxide (CO)	g	201.6	204.9	190.5
(a) Heavy Metals (Total)	g	0.0231	0.0234	0.0217
(a) Hydrocarbons (except methane)	g	79.1	79.7	78.0
(a) Hydrocarbons (unspecified)	g	341	506	286
(a) Hydrogen Chloride (HCl)	g	3.79	4.17	2.98
(a) Hydrogen Fluoride (HF)	g	0.187	0.194	0.127
(a) Metals (unspecified)	g	0.456	0.394	0.438
(a) Methane (CH_4)	g	294	308	261
(a) Nitrogen Oxides (NO_X)	g	855	882	794
(a) Particulates (total)	g	100.4	105.0	87.0
(a) Sulfur Oxides (SO_X as SO_2)	g	373	306	326
(w) Acids (H+)	g	1.80	2.13	1.47
(w) BOD5 (Biochemical Oxygen)	g	60.5	61.5	60.2
(w) Chlorides (Cl-)	g	255.6	259.5	248.9
(w) COD (Chemical O_2 Demand)	g	205.6	203.4	202.9
(w) Dissolved Matter (unspecified)	g	4.27	9.82	3.48
(w) Heavy Metals (Total)	g	0.0223	0.0223	0.0223
(w) Hydrocarbons (unspecified)	g	5.83	3.70	4.75
(w) Metals (unspecified)	g	9.69	10.24	8.15
(w) Nitrate (NO3-)	g	49.86	49.72	49.79
(w) Oils (unspecified)	g	6.15	6.08	5.95
(w) Salts (unspecified)	g	47.98	47.98	47.97
(w) Sulfate (SO_4--)	g	39.20	39.20	39.20
(w) Suspended Matter (unspecified)	g	57.23	57.92	55.98
Waste (total)	kg	29.56	30.98	26.27
Energy				
E Feedstock Energy	MJ	1834	1907	1622
E Fuel Energy	MJ	1868	1959	1658
E Non Renewable Energy	MJ	2955	3116	2575
E Renewable Energy	MJ	743	747	703
E Total Primary Energy	MJ	3712	3878	3290
Electricity	MJ	147	147	147

5.2.1.1 Life Cycle Energy

When the overall energy requirements for the product delivery systems are compared, the thermoformed PP PDS was preferred. The total energy consumption for PP injection molded (IM); HDPE IM; and PP thermoformed (TF) PDSs were 3710 MJ, 3880 MJ and 3290 MJ respectively. See Figure 5-12 for the energy burdens per life cycle phase. The variation between the different systems studied can be primarily accounted for by the weight difference of the primary packaging. Thermoforming allowed the weight of the PP containers to be further reduced. Lower weight translated to lower material production energy, which accounted for the majority of the difference between the PDSs.

Figure 5-12: Life Cycle Energy – HDPE and PP TF PDSs



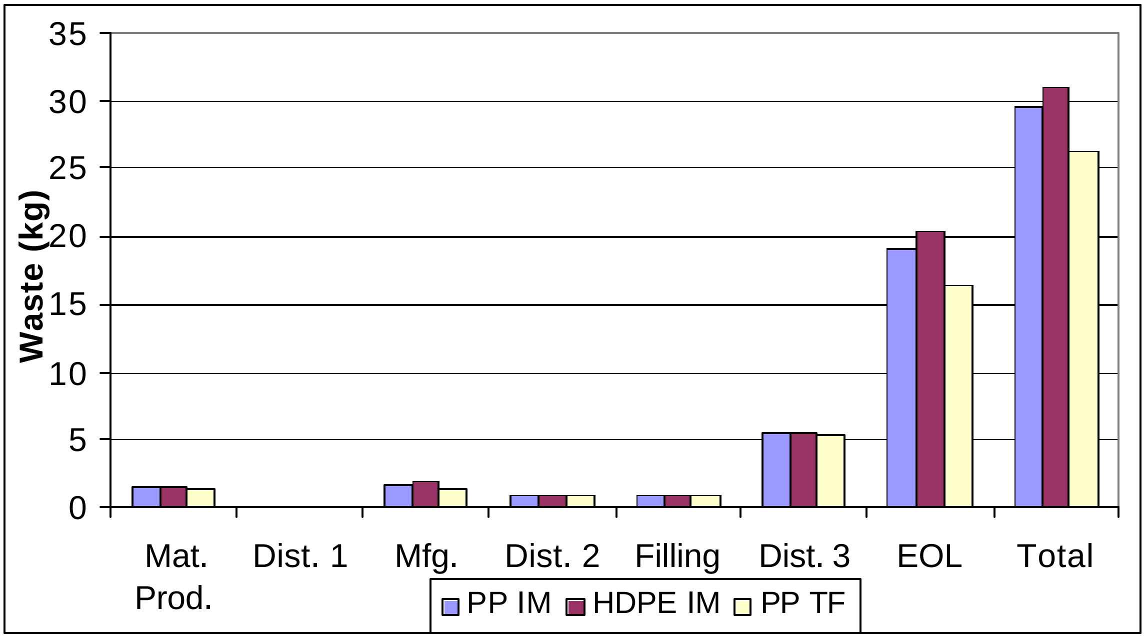
The energy requirement in manufacturing also favored thermoforming. The energy needed to injection mold one kilogram of plastic is 19.6 MJ compared to 15.7 MJ for thermoforming. The material production energy for HDPE (74.9 MJ) was 3% higher than that for PP (72.6 MJ), however, this difference is probably not statistically significant given the uncertainty of the inventory data.

Another factor contributing to the higher energy burden for the HDPE PDS was the material production energy for polyethylene compared to PP. By requiring of primary energy, HDPE is approximately 3% more energy intensive than PP ().

5.2.1.2 Life Cycle Solid Waste

The life cycle solid waste profile, like the energy profile described above, was heavily dependent on the weight of the primary packaging. The highest solid waste burdens belonged to the HDPE PDS with 31.0 kg followed by PP IM with 29.6 kg and PP TF with 26.3 kg. The effect of the container weight variation between the PDSs was evident in the End-of-Life and Manufacturing phases where the lighter thermoformed container was the clear winner.

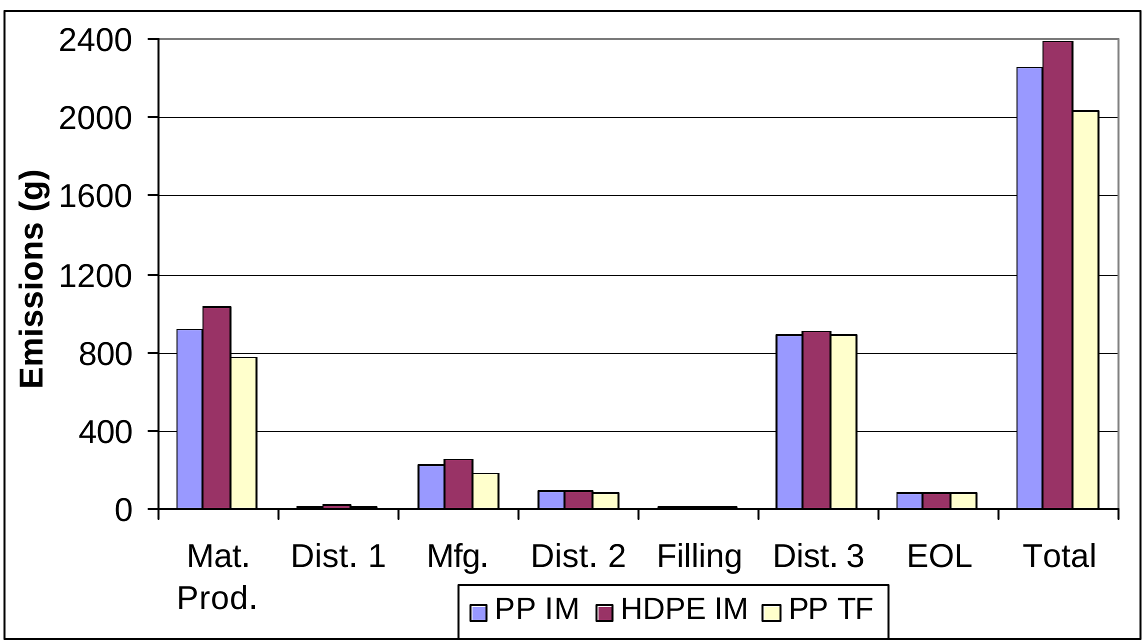
Figure 5-13: Life Cycle Solid Waste – HDPE and PP TF PDSs



5.2.1.3 Life Cycle Air Emissions

Again, the PP TF PDS had an advantage over PP IM and HDPE IM in terms of total air emissions. The total air emissions, excluding carbon dioxide, for each PDS were PP IM (2250g), HDPE IM (2390g) and PP TF (2040g). As discussed above, in the cup size comparison section, the air emissions profile mimicked the energy profile. Figure 5-14 shows a graph comparing the air emissions per life cycle phase.

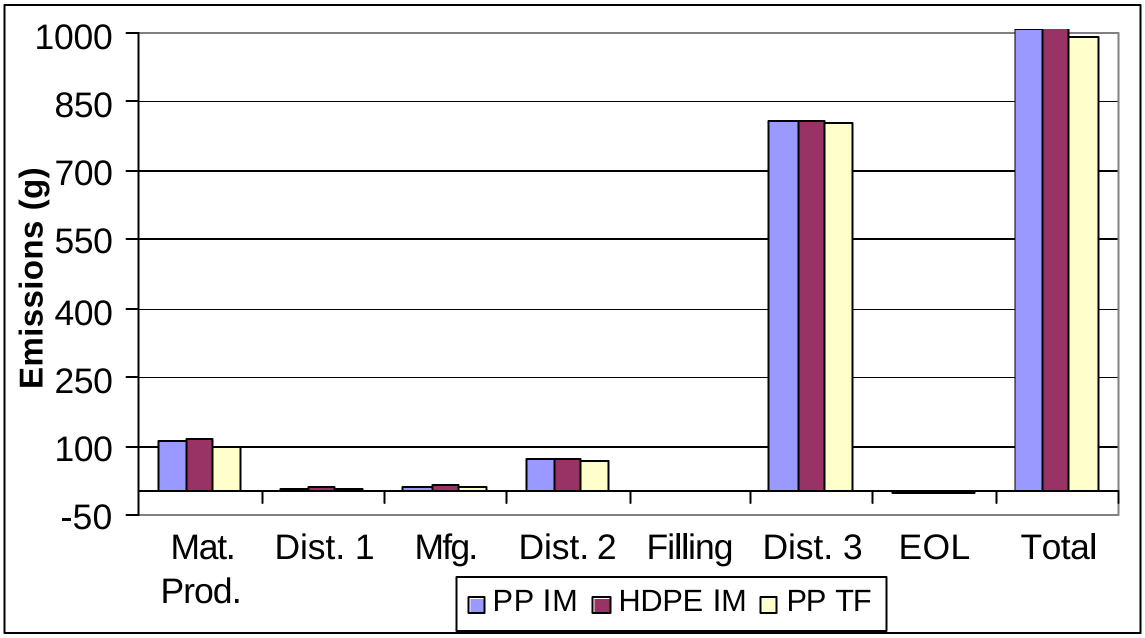
Figure 5-14: Life Cycle Air Emissions (excl. CO_2) – HDPE and PP TF PDSs



5.2.1.4 Life Cycle Emissions to Water

As seen in Figure 5-15, the life cycle quantity of water pollution was essentially a three-way tie. The small variation between the different PDSs, 29g between the highest and lowest life cycle burdens, is beyond the sensitivity of the mathematical model. The emissions to water totals for each PDS in order are PP TF (1010g), PP IM (1020g) and HDPE IM (990g). The small variations seen in the Material Production and Distribution 3 phases were related to weight differences in the primary packaging.

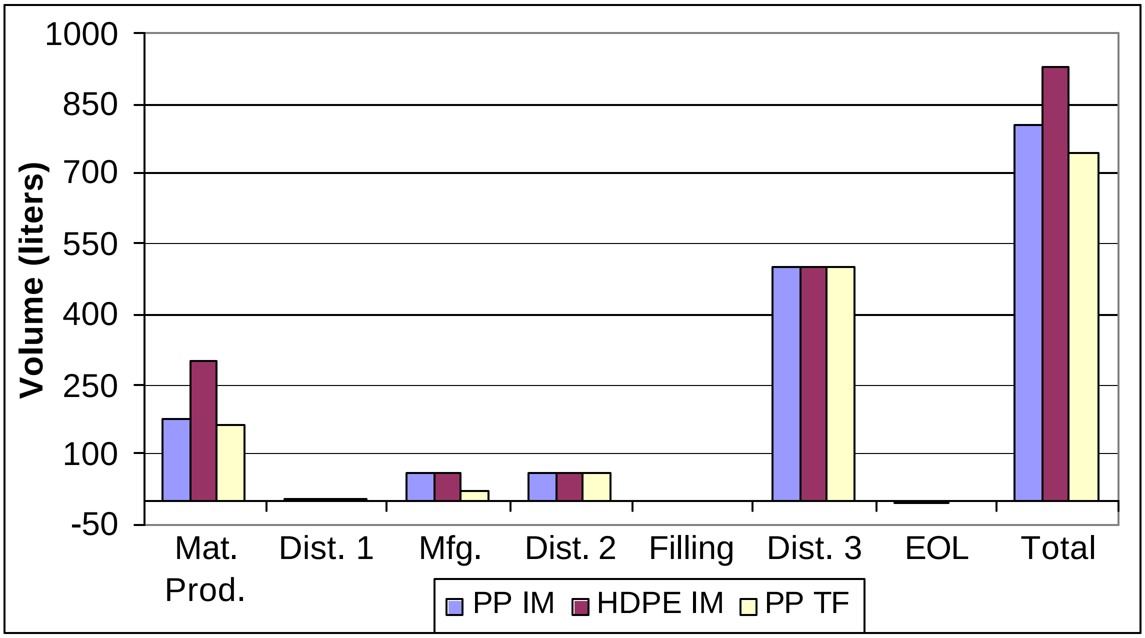
Figure 5-15: Life Cycle Emissions to Water – HDPE and PP TF PDSs



5.2.1.5 Life Cycle Water Use

Water use again favored the lighter thermoformed PDS (741 liters) over the two injection molded options, PP IM (801 liters) and HDPE IM (929 liters). Figure 5-16 showed a profile similar to that observed with energy, solid waste and air emissions. The pattern was slightly exaggerated due to the HDPE requiring 9.5 liters of water per kilogram during Material Production compared to PP, which only used 3.1 liters per kilogram. The differences in water use for the three different cups are obscured by the high water intensity (124 liters per kilogram) of LLDPE, the material used for 6 oz, 8 oz, and 32 oz lids.

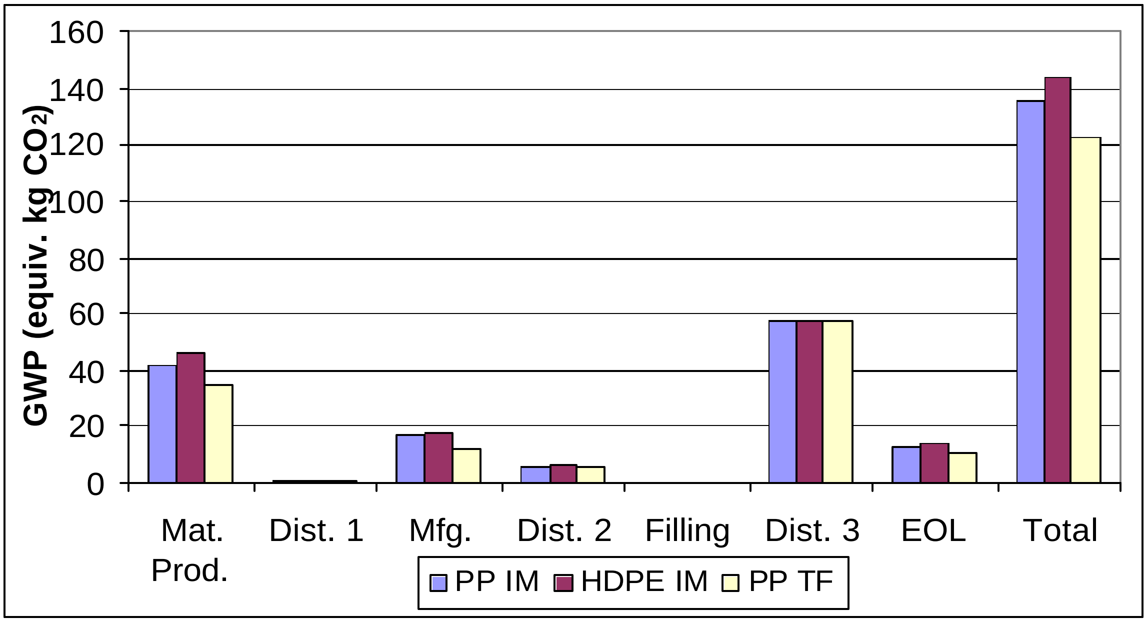
Figure 5-16: Life Cycle Water Use – HDPE and PP TF PDSs



5.2.1.6 Characterized Impact Categories

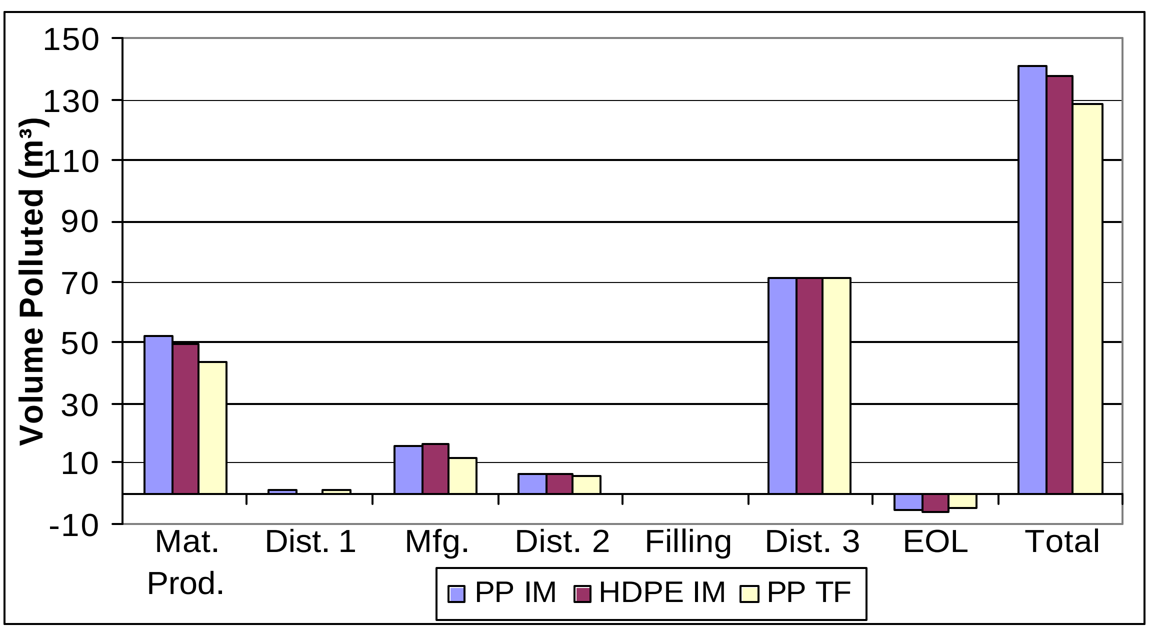
Global Warming Potential (GWP) demonstrates the now familiar pattern with HDPE IM showing the greatest burden (144 equiv. kg CO_2), PP TF the lowest (122 kg CO_2) and PP IM in between (136 kg CO_2). Between the three PDSs modeled, all life cycle phases were essentially equal except Material Production and Manufacturing. The variation in both these phases was attributed to the quantity of material required and the process employed. The TF PDS required the least material and, therefore, had the lowest Material Production GWP. Also, thermoforming used less energy than injection molding, so the burdens during Manufacturing were less than the injection molded options. A graph comparing GWP for the three PDSs appears in Figure 5-17. To put the GWP results in perspective, they can be expressed in the equivalent number of passenger vehicles on the road. When viewed on a yearly basis the current product delivery system has the GWP of 1950 automobiles. Making the switch to thermoformed cups would be equivalent to removing 259 vehicles. While using HDPE would have the same effect as adding 63 passenger cars.

Figure 5-17: Life Cycle GWP – HDPE and PP TF PDSs



The volume of polluted air determined using MAC values was the only metric that favored HDPE (138 m^3) over the current PP PDS (140 m^3). However, the thermoformed PP PDS received the best rating with a MAC value of 129 m^3 of polluted air. The reversal between PP and HDPE was caused by the quantity of sulfur oxides (SO_X) released during their respective material production processes. PP emitted 11.0g SO_X, nearly twice as much HDPE at 6.0g. The MAC calculations gave a heavy weighting to SO_X, assuming that 13 m^3 of clean air were required to dilute 1g of SO_X to a safe concentration. Figure 5-18 shows a comparison of MAC polluted air volumes by phase.

Figure 5-18: Life Cycle MAC – HDPE and PP TF PDSs



5.2.2 Polylactide Results

For the PDS modeled for this study, it was assumed that the PLA is corn-based and produced at Cargill-Dow's facility in Nebraska. The manufacturing process selected was thermoforming, and at the end-of-life the incineration of PLA was treated as incineration of paper. Other than these items all other attributes were assumed to be identical to the existing PDS.

It should be noted that PLA is not yet commercially produced in this country and therefore LCA data were not available for PLA production. Environmental burdens were calculated based on Cargill Dow Polymers' estimate of energy consumption for PLA production at its commercial scale production facility, which is currently under construction. The energy consumption for corn farming and wet milling was obtained from published data. In addition, the weights of the PLA cups were estimates based on information provided by Cargill Dow Polymers rather than weights of actual PLA cups. While the data used in calculating the environmental burdens of the PLA PDS were considered to be the best available, these results should be considered preliminary. It is expected that Cargill Dow Polymers will release LCA data to the public for the Blair, Nebraska facility, which will commence production in 2002.

The results shown below are for a composite PDS consisting of 4 oz., 6 oz. and 8 oz. containers. Thirty-two ounce (32 oz.) containers were not included because it was deemed unfeasible to produce such a large PLA container due to its brittleness. Two-ounce (2 oz.) packaging was also not included because the use of PLA film to replace LLDPE film was not considered for this report. Table 5-6 shows the weight of yogurt sold for the 4, 6 and 8 oz. container sizes, which was used as the basis for creating the composite PDS.

Table 5-6: Sales By Container Size - Fiscal Year 2000 (4, 6, and 8 oz.)

Product	% of Sale by Case	Units/Case	Pounds of Yogurt per Case	Weight Fraction
4 oz. CF	15.7%	24	6.0	16.9%
4 oz. WH	10.7%	24	6.0	11.5%
6 oz	27.2%	12	4.5	21.9%
8 oz	46.4%	12	6.0	49.7%
Total	100%	N/A	N/A	100%

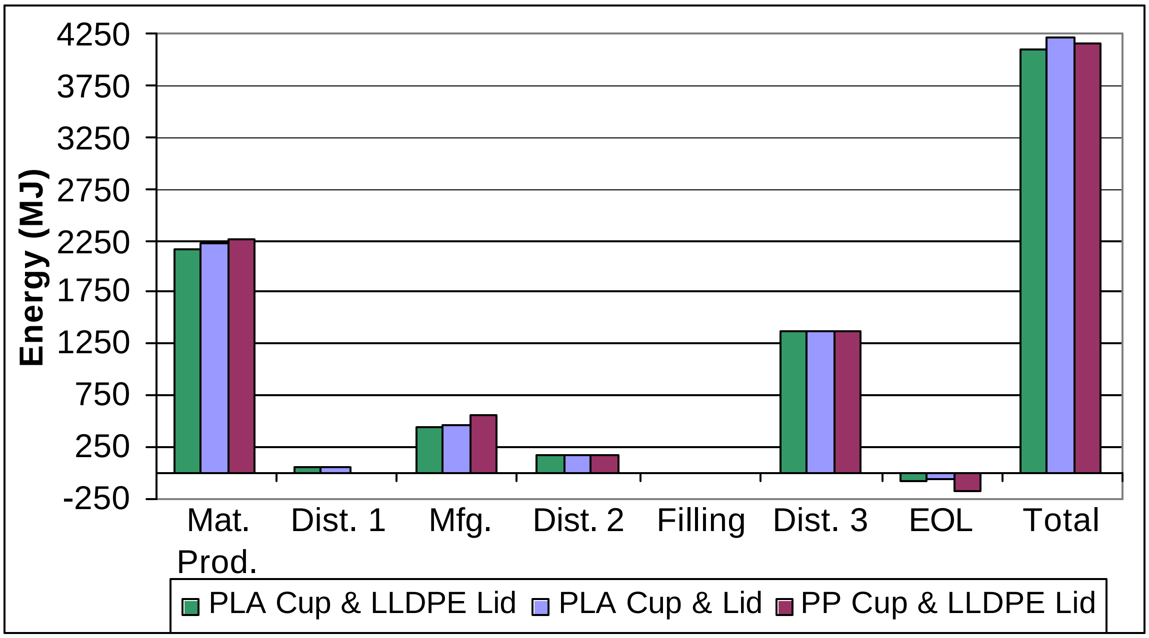
Two scenarios were run through the model: 1) PLA thermoformed cups with the existing LLDPE lids (PLA/LLDPE PDS) and 2) PLA thermoformed cups with PLA injection molded lids (PLA/PLA PDS). Also included on the graphs for comparison were the results for the current PDS using PP injection molded cups with LLDPE injection molded lids.

5.2.2.1 PLA Life Cycle Energy

The results of the life cycle energy analysis appears favorable for the PLA/LLDPE PDS (4100 MJ), which is slightly lower than the current PDS (4170 MJ) and the

PLA/PLA PDS configuration (4200 MJ). The variations are primarily due to the different component weights for the PDSs. The PLA/LLDPE PDS is the lightest configuration with an 8.9g cup and 3.9g lid for the 8oz. containers. Injection molding the PP creates a slightly heavier cup (9.1 g) for the current PDS and producing the lid out of denser PLA results in a 4.2g component. If all component weights were the same, the energy would be very close since PP and PLA have nearly identical material production energies, 74.9 MJ/kg and 75.5 MJ/kg respectively. Further examination of the material production energy of PLA reveals that corn farming accounts for 5.9 MJ/kg, wet milling accounts for 11.2 MJ/kg and the polymerization process accounts for 58.4 MJ/kg.

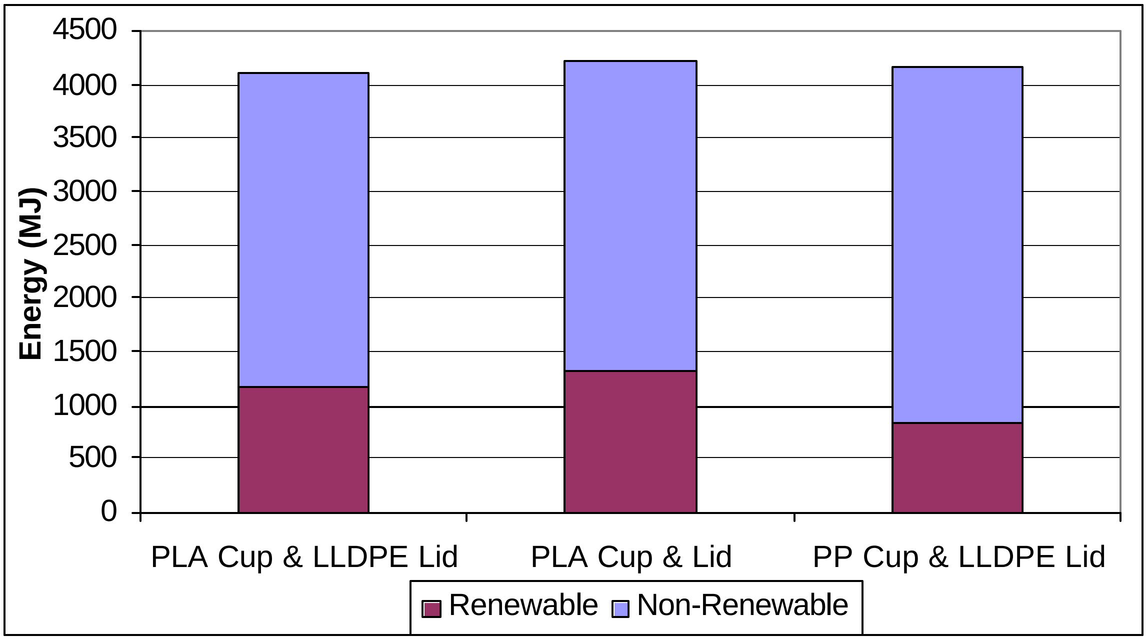
Figure 5-19: Life Cycle Energy - PLA PDS



Also notable in Figure 5-19 is the energy required at Distribution 1 and Manufacturing, and the energy credit from End-of-Life. The use of trucks rather than trains, and the longer distance from the PLA producer to the container manufacturer (969 miles compared to 425 miles for PP) both contribute to the higher Distribution 1 energy burden seen for PDSs using PLA. The higher energy requirement for the current PDS in the Manufacturing phase is attributed to the lower energy requirement of thermoforming (15.7 MJ/kg) compared to that of injection molding (19.6 MJ/kg). In the End-of-Life phase the current PDS shows a much larger energy credit (179 MJ) than the PDSs using PLA components (93 MJ for PLA/LLDPE and 69 MJ for PLA/PLA). The difference at the end-of-life is due to the incineration of PLA being modeled as paper incineration, which has a energy credit of 9.9 MJ/kg, instead of plastic incineration which has an energy credit of 28.5 MJ/kg. The decision to model PLA as paper for end-of-life was made based on Cargill Dow Polymers' claim that the incineration of PLA is similar to incineration of paper, cellulose and carbohydrates.[68] In addition, the feedstock energy of PLA (19.5 MJ/kg) is closer to that of paper (15.1 MJ/kg) than PP (45.3 MJ/kg).

For PLA, a greater advantage can be seen in Figure 5-20, which shows the life cycle energy split into renewable and non-renewable. In this comparison, the PLA/PLA PDS has the advantage by requiring the least non-renewable energy, 2880 MJ. Just behind is the PLA/LLDPE PDS with 2940 MJ. All of the PDSs compared in this section have significant renewable energy inputs due the high percentage of renewable energy used in paper-based packaging such as the wraps for the 4oz. containers and the corrugated boxes used during the distribution phases.

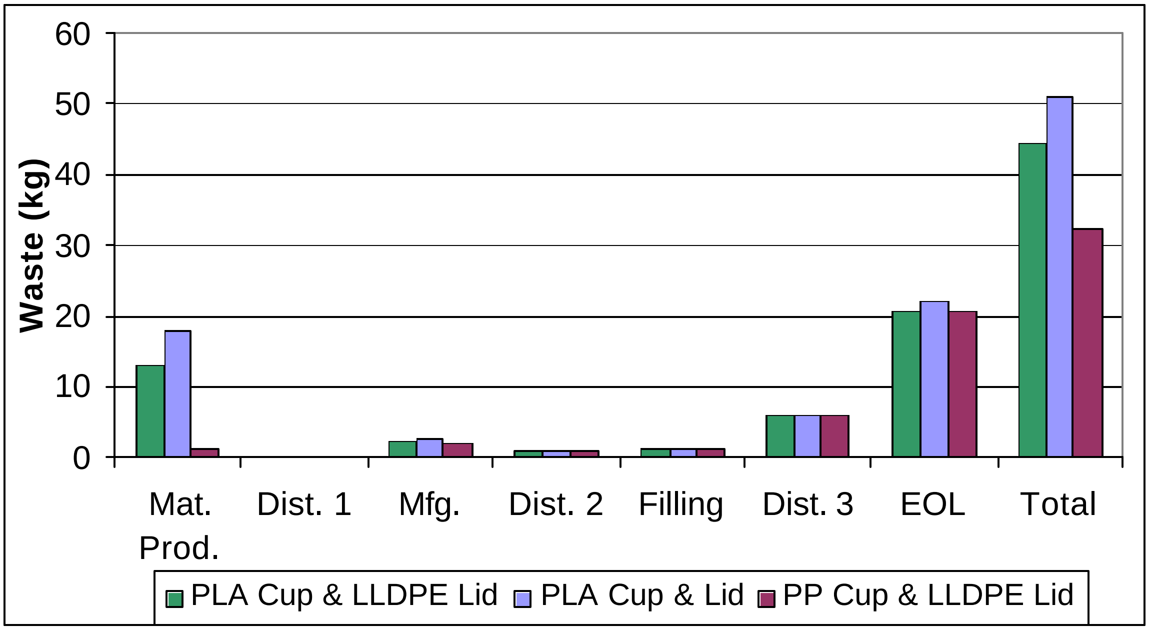
Figure 5-20: Life Cycle Renewable Energy - PLA PDS



5.2.2.2 PLA Life Cycle Solid Waste

The PDS configurations using PLA do not fare as well with respect to solid waste. As seen in Figure 5-21, the solid waste generation during the material production phase for PLA (13.0 kg for PLA/LLDPE and 17.9 kg for PLA/PLA) is far greater than that of the current PDS (1.44 kg). This was due to the large quantities of slag and ash produced during the generation of electricity used during the polymerization process. It should be pointed out that there is some uncertainty regarding the quantity and sources of energy used during the polymerization process. PLA is not yet produced commercially and therefore detailed data were not available. The quantity of energy used for the production of PLA was based on a published estimate provided by scientists at Cargill Dow.[69] It was assumed that the source of energy consumed during the polymerization process was electricity from the U.S. grid.

Figure 5-21: Life Cycle Solid Waste - PLA PDS

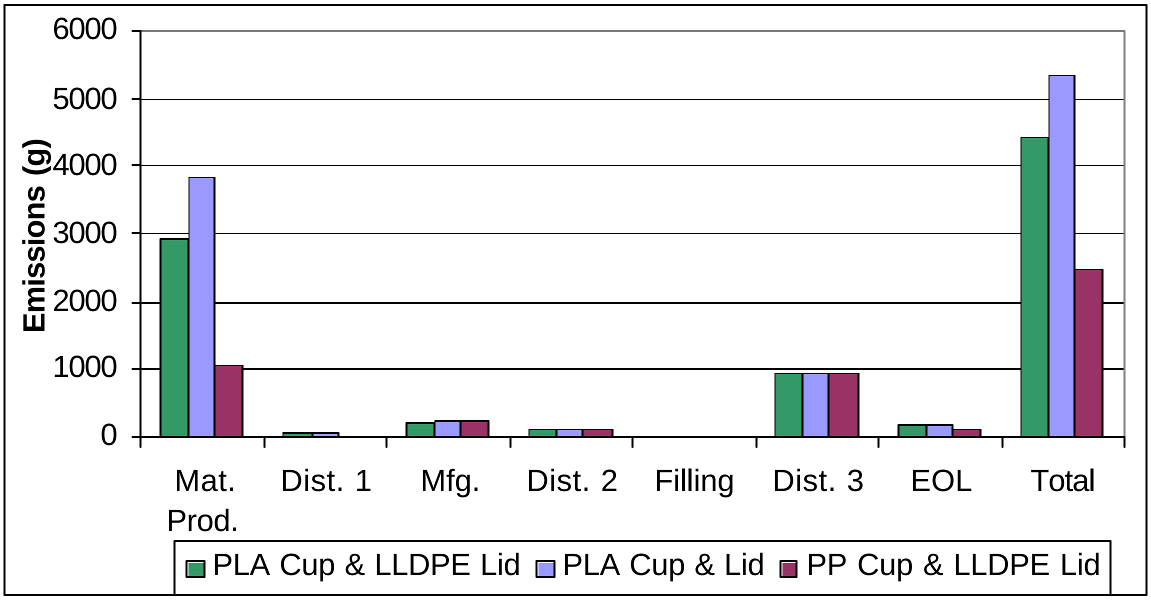


Overall results for the life cycle solid waste for the PLA/LLDPE PDS, PLA/PLA PDS and PP/LLDPE PDS are 44.5 kg, 50.9 kg and 32.5 kg respectively.

5.2.2.3 PLA Life Cycle Air Emissions

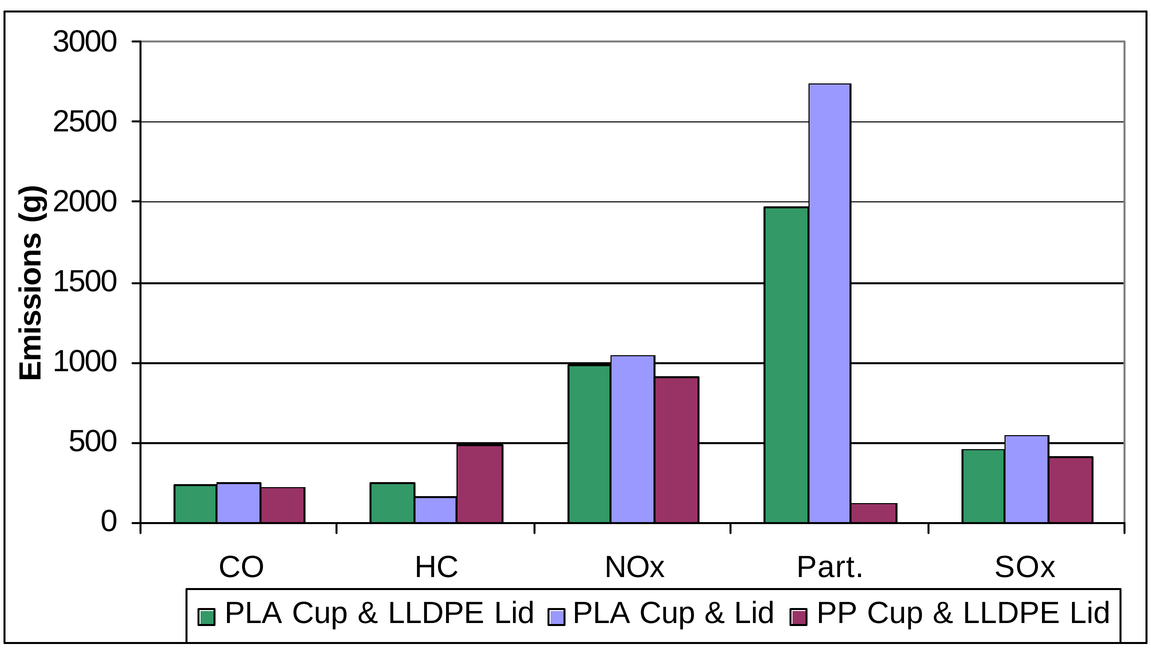
The next set of environmental burdens generated by the model is for the emissions to air. The graph showing the total air emission for each life cycle phase is shown in Figure 5-22. Similar to the solid waste profile, the current PDS has the lowest burden (2490g), followed by the PLA/LLDPE PDS (4420g) and the all PLA configuration (5350g). The explanation for this profile is rooted in the higher fraction of energy consumed during the material production phase. The majority (60%) of PP material production energy remains embodied in the material compared with only 30% for PLA. The rest of the energy, 30.2 MJ for PP and 52.5 MJ for PLA, is consumed. The combustion of coal and other energy resources results in significant generation of air emissions.

Figure 5-22: Life Cycle Air Emissions - PLA PDS



Quantities of the criteria air pollutants were compiled for the entire life cycle of each PDS and the results appear in Figure 5-23. Most pollutants are produced in similar levels with two notable exceptions, hydrocarbons (HC, which can be used as a proxy for volatile organic compounds (VOC)) and particulate matter. The amount of hydrocarbons released to the atmosphere is much higher for the current PDS due to its use of oil and natural gas as the feedstock for PP. During the production and processing of propylene, VOCs are released in much greater quantities than from the farm equipment used to harvest the corn used in the PLA.

Figure 5-23: Life Cycle Criteria Pollutants - PLA PDS



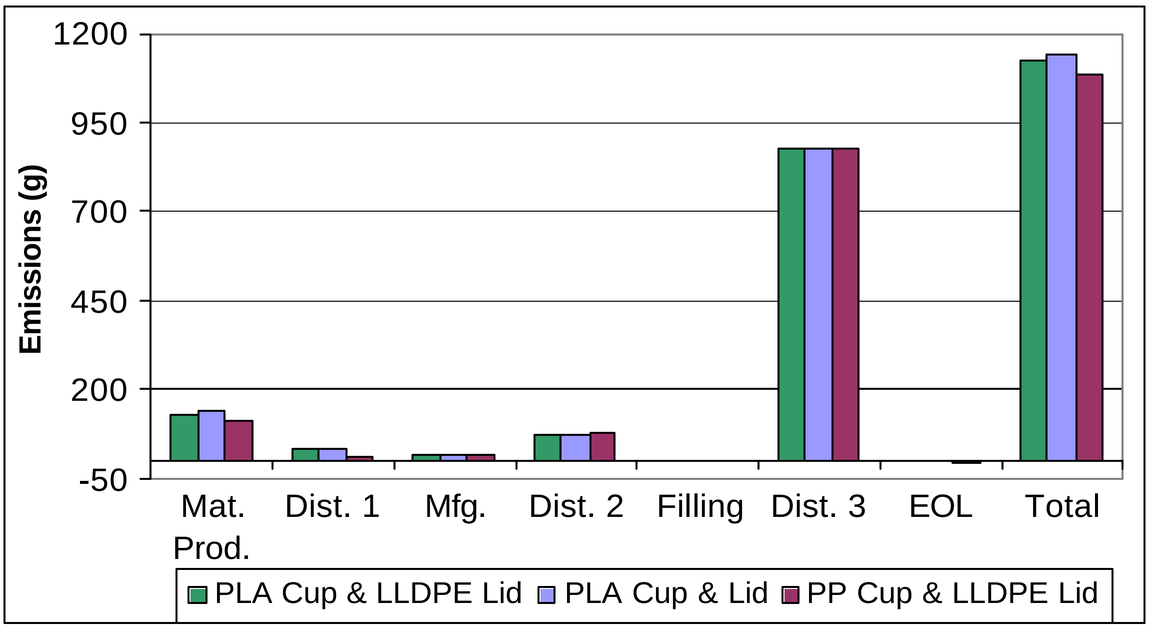
An even more significant difference is the amount of particulate matter released during the production of PLA compared to that of PP and LLDPE. The higher particulate burden from PLA is chiefly due to the dust generated from the production of fertilizer inputs for corn farming. Of the four basic fertilizer ingredients, lime and phosphates create the most PM with 72.0 g/kg and 13.6 g/kg respectively.

5.2.2.4 PLA Life Cycle Emissions to Water

The profiles for waterborne emissions are nearly identical for the three PDSs included in Figure 5-24. These results are likely to be incorrect due to the limitations in modeling PLA production. While the energy and material inputs to corn farming, milling and polymer production were considered, an attempt to estimate the emissions to water for these processes was not made.

In light of the data shortcoming above, only 60g of waterborne emissions separated the PLA/PLA PDS (1140g) from the current PDS (1080g) with the PLA/LLDPE PDS falling in-between (1120g).

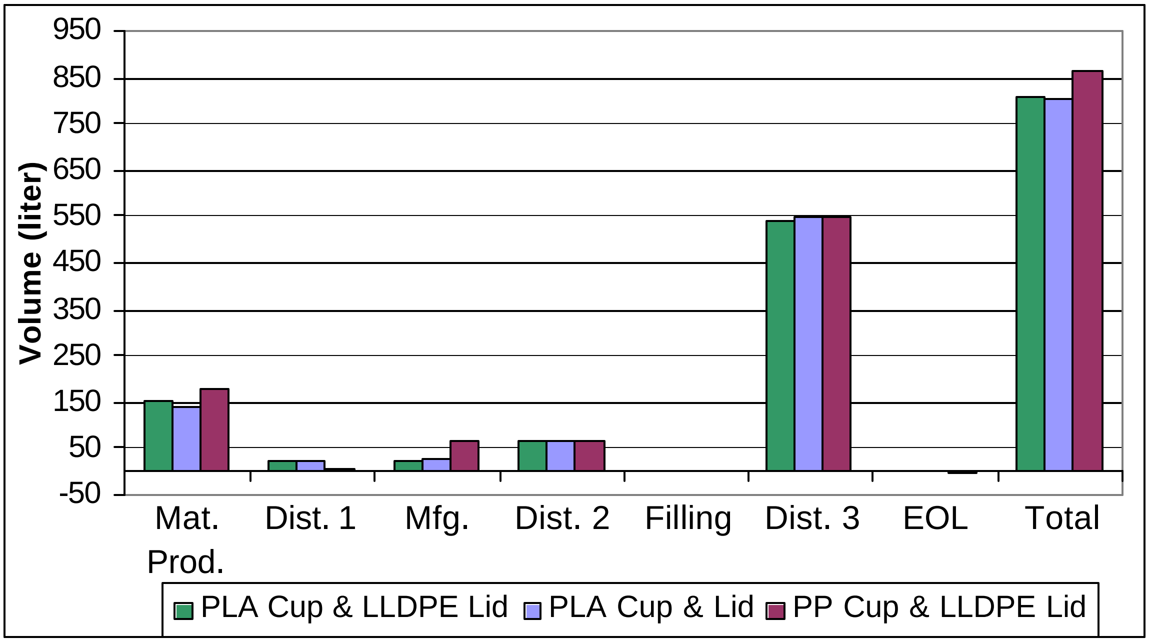
Figure 5-24: Life Cycle Emissions to Water - PLA PDS



5.2.2.5 PLA Life Cycle Water Use

Again, water use gives another unexpected result that can be attributed to the boundaries used to build the PLA material production module. The PDSs using PLA are shown in Figure 5-25 to have a lower life cycle water requirement (800 liters for the PLA/PLA PDS and 806 liters for the PLA/LLDPE PDS) than the current PDS (866 liters). However, water use for corn farming, wet-milling and polymer production was not included in the PLA module. If added, the water used for these processes would likely reveal that PLA production consumes far more water than PP production.

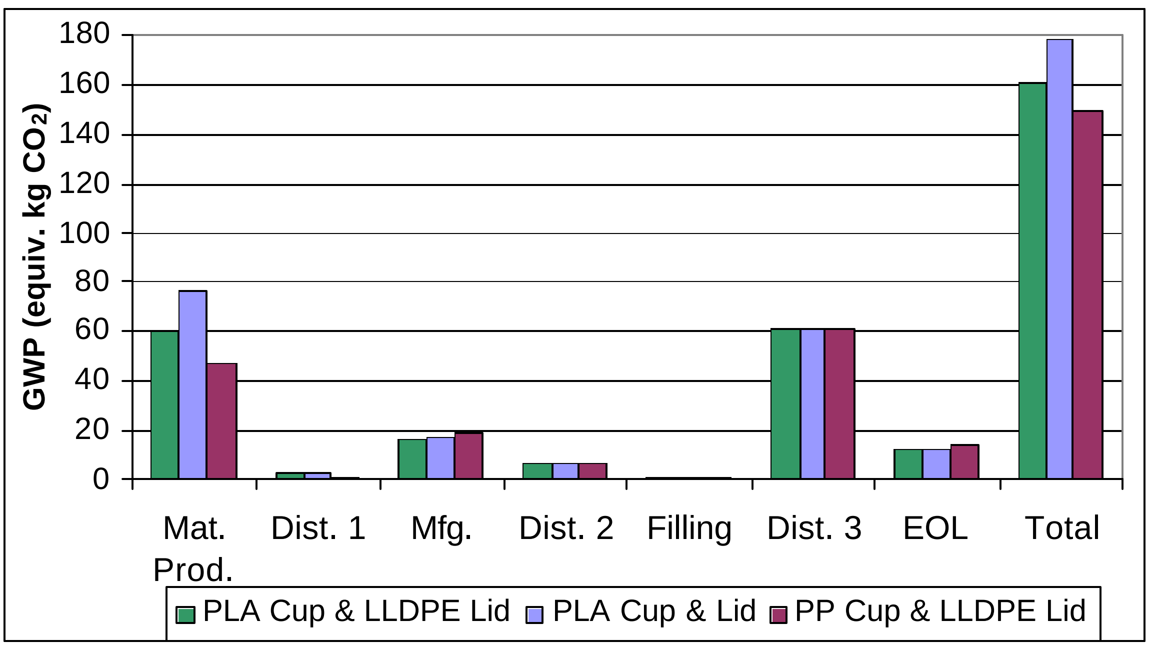
Figure 5-25: Life Cycle Water Use - PLA PDS



5.2.2.6 PLA Characterized Impact Categories

To evaluate the air pollution generated throughout the life cycle of each PDS, global warming potential (GWP), maximum allowable concentration (MAC) and ozone depletion potential (ODP) were calculated for each phase of the life cycle. The results for these characterized impact categories can be seen graphically in Figure 5-26, Figure 5-27 and Figure 5-28.

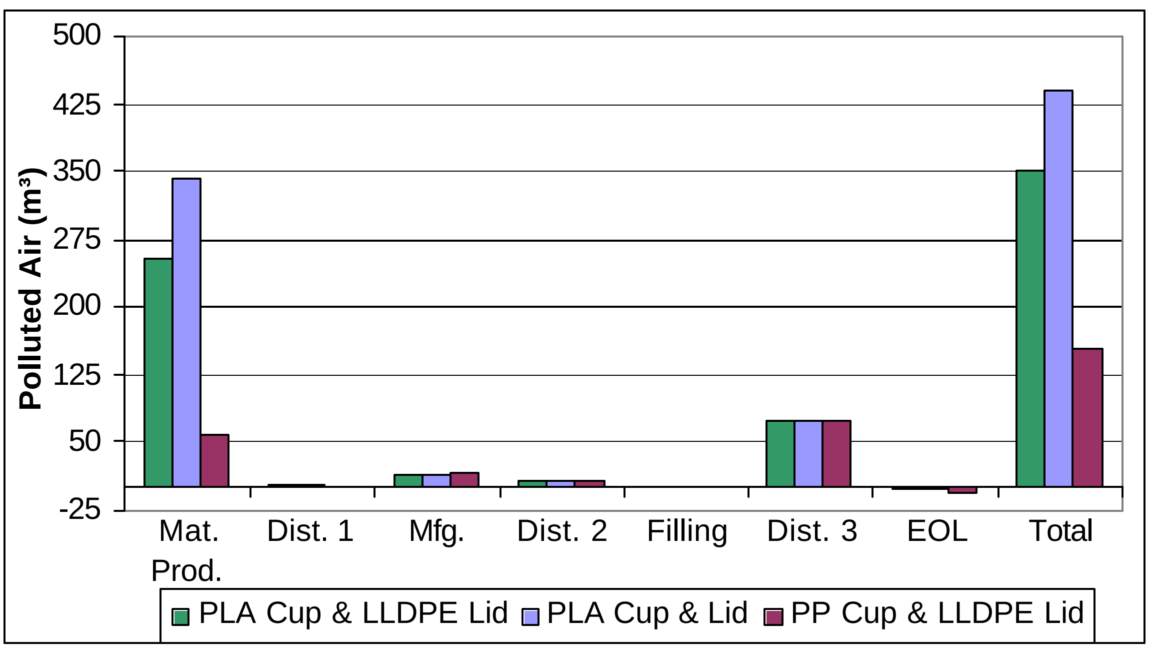
Figure 5-26: Life Cycle GWP - PLA PDS



The GWP profiles indicate that using PLA releases more greenhouse gases into the atmosphere. The graph in Figure 5-26 shows 161 equivalent kg of CO_2 for the PLA/LLDPE PDS and 178 equivalent kg of CO_2 for the PLA/PLA PDS. These results do not agree with the claim made by Cargill-Dow that the production of PLA releases less carbon dioxide than production of most hydrocarbon-based polymers.[70]. As described in the assumptions section, the CO_2 emission burden from PLA was calculated by subtracting the CO_2 equivalent of the carbon fixed in the corn from the CO_2 generated from the burning of fossil fuels. Despite this accounting the PLA still shows a higher GWP due its CO_2 emissions (2410 g/kg) from material production being greater than that of PP (1780 g/kg). A higher level of CO_2 emissions would be expected for PLA since the PLA PDSs consumed more life cycle energy as fuel (3,066 MJ/kg for the PLA/LLDPE PDS and 3,138 MJ/kg for the PLA/PLA PDS) than the PP PDS (2,345 MJ/kg).

The MAC graph in Figure 5-27 shows a much higher air pollution burden for the PDSs using PLA components. The difference between PLA and PP is due to two items discussed above, the higher process energy required for PLA and the dust generated during fertilizer production. The exagerated shape of the profiles in comparison to the air emission is due to the relatively high weighting given to particulate matter in the maximum allowable concentration formula. The totals for each PDS are: PLA/LLDPE (350 m^3 of polluted air), PLA/PLA (441 m^3) and PP/LLDPE (153 m^3).

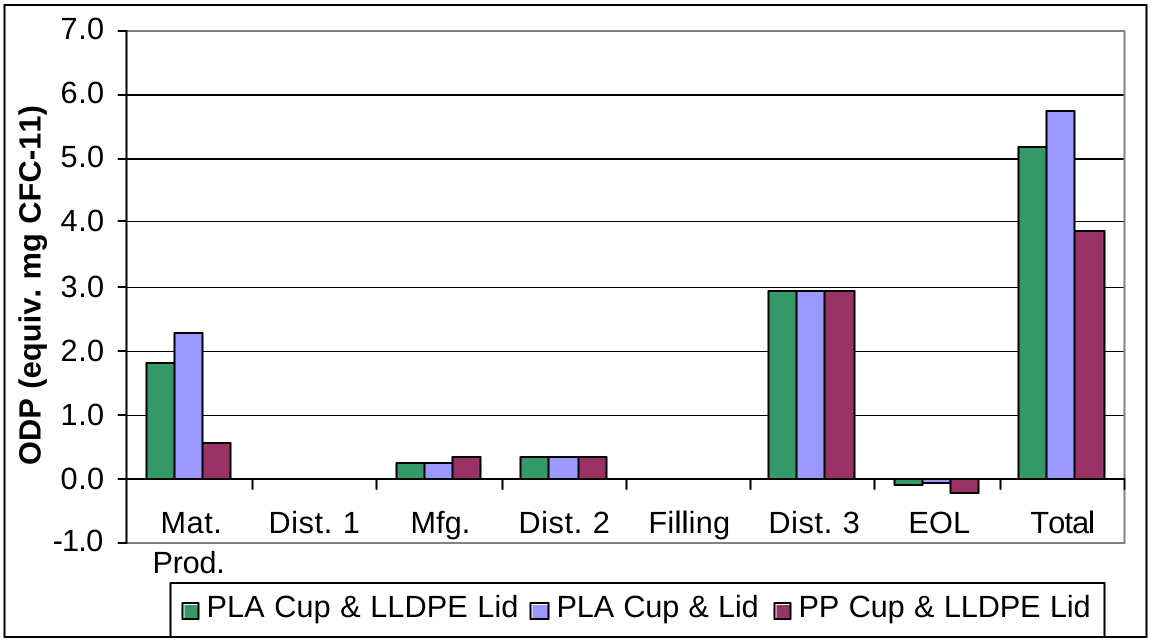
Figure 5-27: Life Cycle MAC - PLA PDS



The final characterized impact category is ozone depletion potential (ODP). As with most of other environmental metrics the difference between the PDSs lie in the material production phase. The input attributing for the bulk of ODP substances (halon 1301 and carbon tetrachloride) in this phase is the phosphate used for fertilizing the corn crops. Overall life cycle ODP for the PLA/LLDPE, PLA/PLA and

PP/LLDPE PDSs are 5.19, 5.74 and 3.88 equiv. g of CFC-11 respectively. Also, it should be noted that refrigeration was outside the systems boundaries, but many refrigerants could greatly increase the life cycle ODP.

Figure 5-28: Life Cycle ODP - PLA PDS



5.2.3 Coated Unbleached Paperboard PDS Comparison

This section compares the Current PDS to an alternative PDS that utilizes coated Solid Unbleached Sulfate (SUS) paperboard cups in place of PP cups. In one analysis, the paperboard cups were coated with LDPE, and in a second analysis, the paperboard cups were coated with PLA. The results shown below are for a composite PDS consisting of 4oz., 6 oz. and 8 oz. containers. Table 5-6 in the previous section shows the breakdown of the composite PDS by container size. All containers with lids were analyzed using the current LLDPE lid from Polytainers and the current seals.

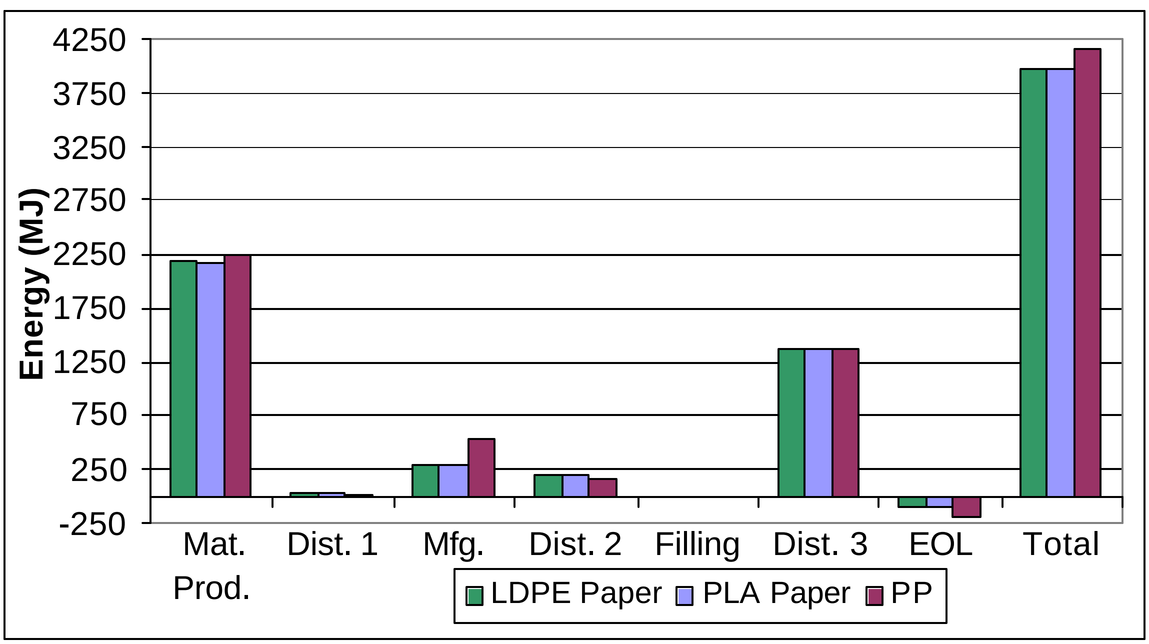
The 6 oz. coated paperboard cups considered in this study were lighter than the 6 oz. PP containers, while the 4oz. and 8 oz. paperboard containers were heavier than the corresponding PP cups. The composite comparisons yielded mixed results for coated paperboard as it performed better than PP in some categories and worse in others. Generally, there were only slight differences between the performance of LDPE and PLA coated unbleached paperboard containers. Although the final cups are lightweight, more paper material is needed to make up for higher scrap rates. During conversion, sidewalls, tops, and bottoms are cut out of sheets of paperboard leaving behind a significant amount of pre-consumer material that is baled and recycled in an open-loop system. Recycled pre-consumer paper may be put to higher quality uses than “down-cycled” plastic resins, but cannot be used for food containers.

5.2.3.1 Coated Paperboard Life Cycle Energy

The total energy consumption for the LDPE coated unbleached paperboard PDS was 3970 MJ and 3960 MJ for PLA coated unbleached paperboard PDS. These amounts are 4.8% lower and 5.0% lower respectively than PP containers at 4170 MJ. The profile of energy use across the life cycle phases was similar for each of the PDSs with the Material Production phase having the highest energy consumption for all three. The coated paperboard PDSs had lower energy consumption in the Material Production and Manufacturing phases. The primary reason that the coated paperboard PDSs had lower energy consumption in the Material Production phase was that the feedstock energy for paperboard is much lower than for PP.

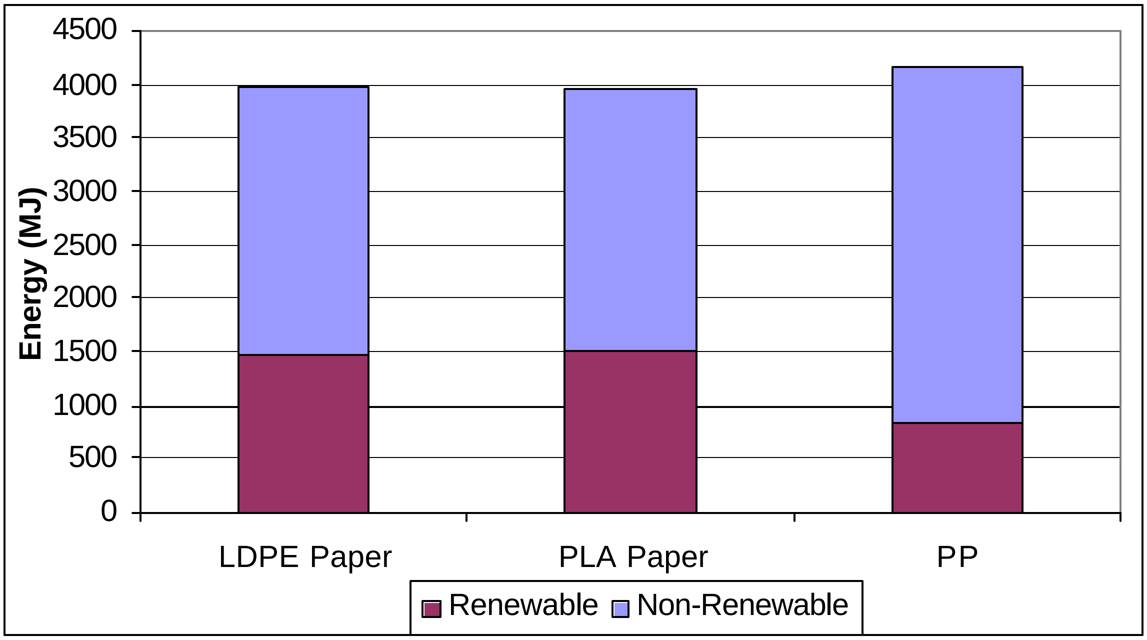
The Current PDS used significantly more energy in the Manufacturing phase. However, it is difficult to draw conclusions about the energy intensity of the paperboard cup manufacturing process as compared to the PP cup manufacturing process. The two manufacturing processes are very different, as are the material inputs. The Material Production phase for both materials includes the burdens associated with materials manufacture. For PP, materials manufacture includes polymerization and pelletizing operations while PP manufacturing consists of the injection molding of the pelletized PP. For paperboard, materials manufacture includes pulp production as well as the production of the paperboard itself. Coated paperboard manufacturing consists of the coating and conversion operations. With these differences, it was impossible to define the boundary between Material Production and Manufacturing in a way that was consistent for both paperboard and PP.

Figure 5-29: Life Cycle Energy - Coated Paperboard PDS



Another way to analyze energy consumption is the mixture from renewable and non-renewable sources. As seen in Figure 5-30, the composition of renewable and non-renewable energy is more favorable for the paperboard PDS than for PP. There are two reasons for this. The feedstock energy for paperboard is almost entirely derived from renewable resources. In addition, a significant amount of the fuel energy used in material production of paperboard is derived from renewable resources. The paper industry self-generates much of the energy from wood waste byproducts.

Figure 5-30: Life Cycle Renewable Energy - Coated Paperboard PDS

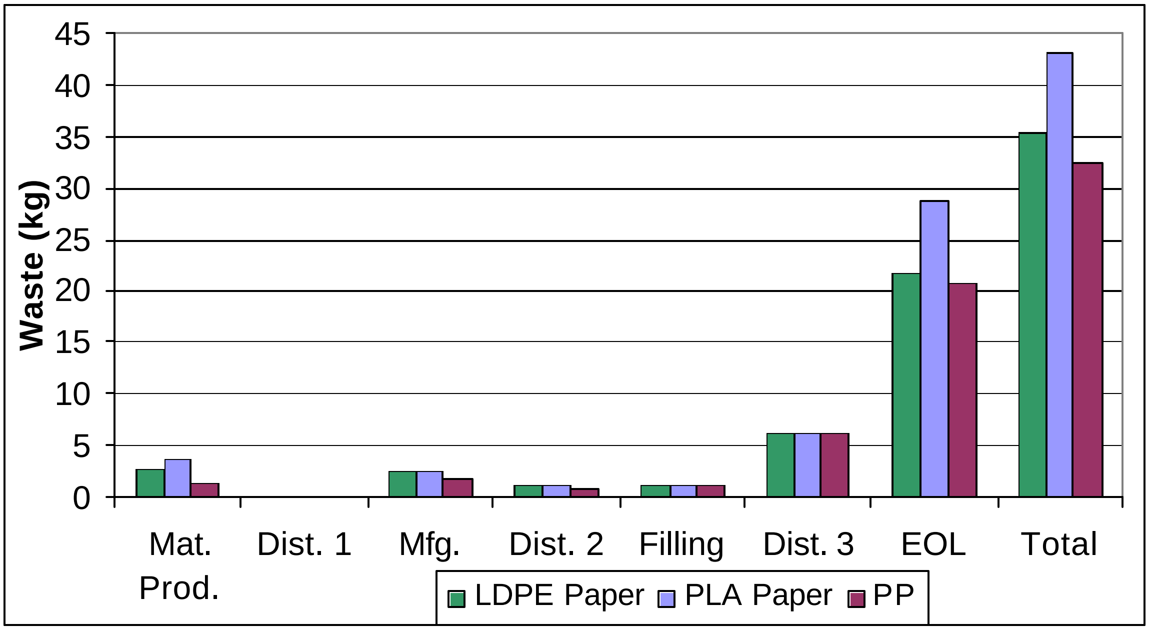


5.2.3.2 Coated Paperboard Life Cycle Solid Waste

Coated unbleached paperboard had significantly higher life cycle solid waste than PP. The Material Production and Manufacturing phases accounted for some of this additional solid waste. There was also more solid waste at the End-of-Life phase for the paperboard, particularly the paperboard coated with PLA. One reason for this is that a credit is given at End-of-Life for solid waste avoided due to the energy produced during incineration. The incineration of solid waste in waste-to-energy plants decreases the need to burn coal and other fossil fuels, and therefore the life cycle environmental burdens associated with the fossil fuels are partially offset. Incineration of PP results in a higher credit than incineration of paperboard because the feedstock energy of PP is higher than that of paperboard.

The highest solid waste burdens belonged to the PLA coated paperboard PDS with 43.3 kg followed by LDPE coated paperboard with 35.4 kg and PP with 32.5 kg. Since fewer paperboard cups are packaged in a box in Distribution 2, there is slightly more solid waste generated by coated paperboard than PP in this phase, as well.

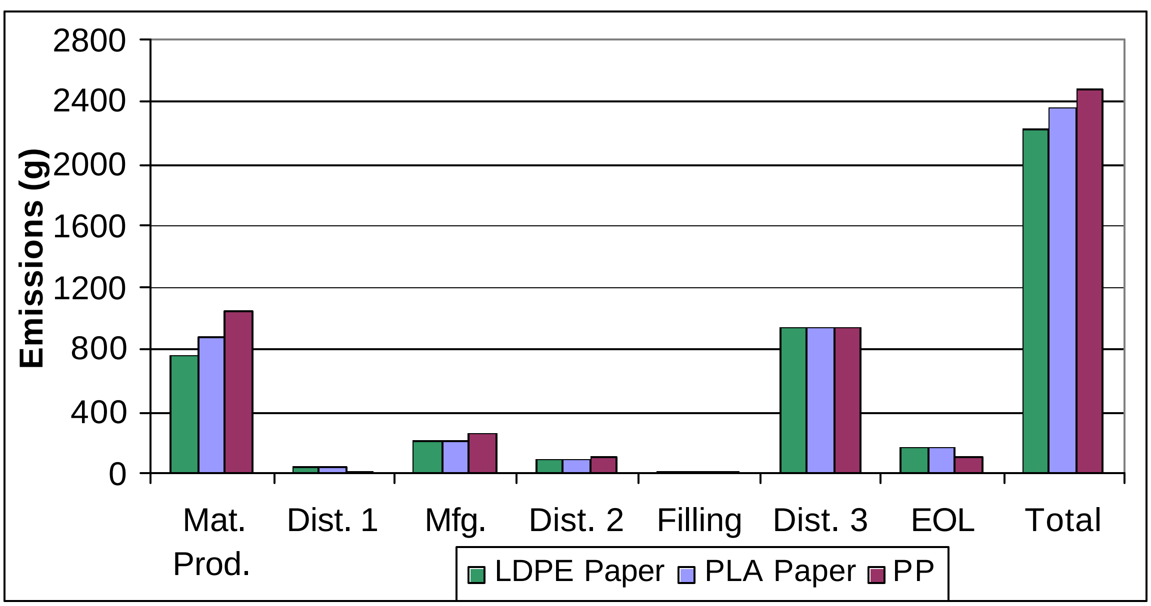
Figure 5-31: Life Cycle Solid Waste – Coated Paperboard PDS



<u>*5.2.3.3 Coated Paperboard Life Cycle Air Emissions*</u>

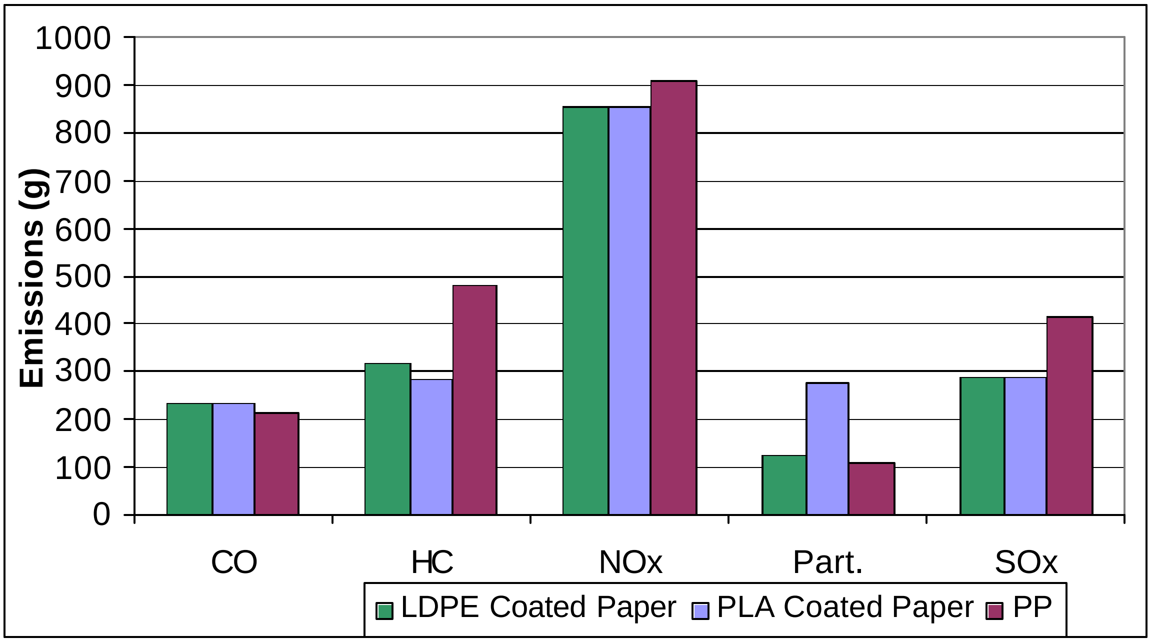
When comparing air emissions, the LDPE coated unbleached paperboard PDS and the PLA coated unbleached paperboard PDS measured 2220g and 2350g, respectively. PP (2486g) was shown to be the worst performer despite receiving a larger credit for air emissions offset by waste-to-energy incineration at End-of-Life. PP had higher air emissions in the Material Production and Manufacturing phases. The difference between the two paperboard PDSs was that PLA had greater emissions in the Material Production phase.

Figure 5-32: Life Cycle Air Emissions - Coated Paperboard PDS



A graph showing the relative life cycle quantities of criteria air pollutants for each PDS appears in Figure 5-33. There were trade-offs among the different configurations and quantities of criteria air pollutants. For example, PP had the lowest CO and Particulate Matter (PM) emissions of the three but the highest HC, NOx and SOx emissions. The PLA coated paperboard had the highest PM emissions, which could be traced back to corn farming and the production of fertilizer.

Figure 5-33: Life Cycle Criteria Air Pollutants - Coated Paperboard PDS

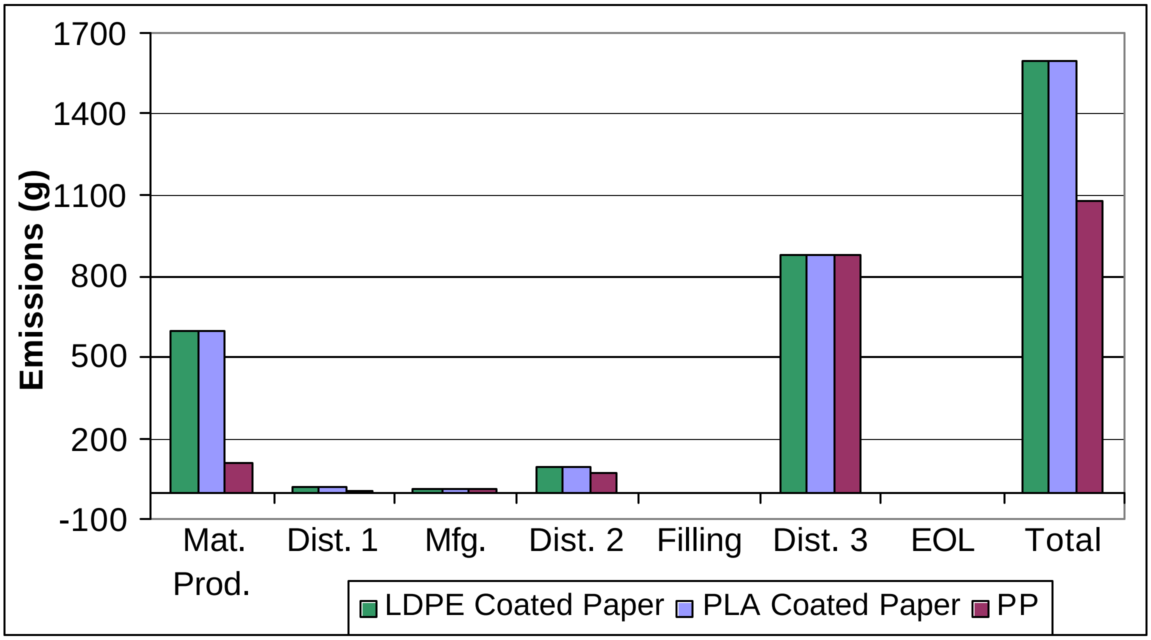


5.2.3.4 Coated Paperboard Life Cycle Emissions to Water

With respect to emissions to water, PP (1080g) out-performed the coated unbleached paperboard PDSs, which both resulted in 1560g of total emissions to water. Much of the difference was due to the high emissions from the Material Production of paper. In general, the production of paper products is water intensive and has high emissions to water compared to plastics. For this reason,

In the Material Production phase, the paperboard PDS had approximately four times the emissions to water compared to that of the PP PDS. In all other life cycle phases, the quantities of emissions to water were relatively close together.

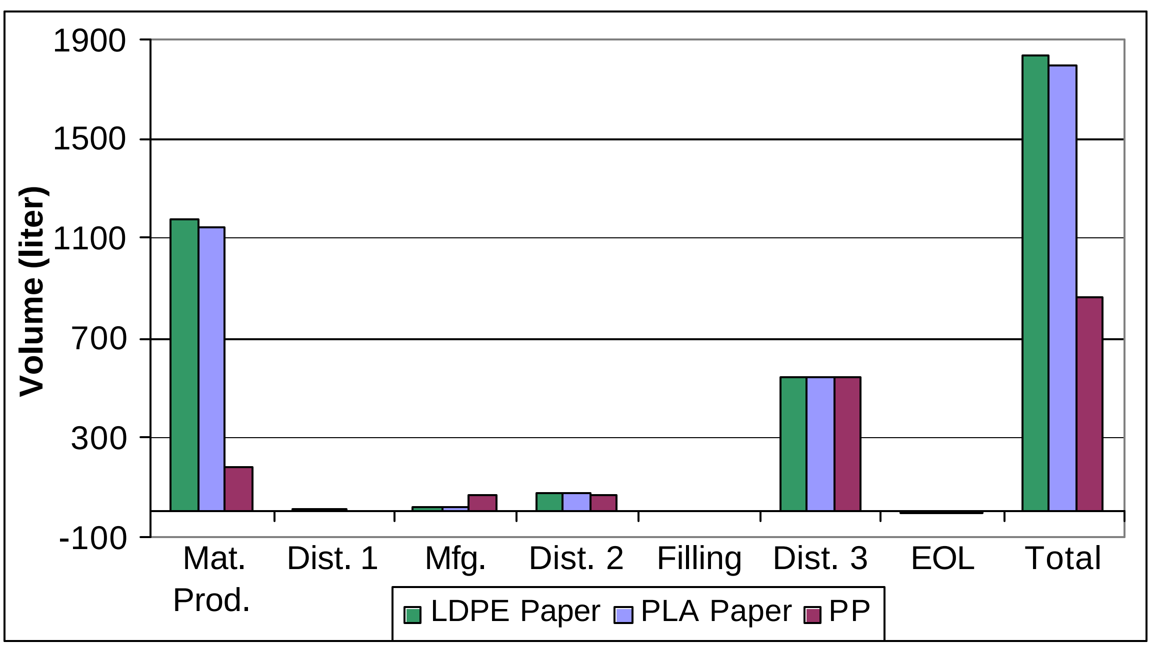
Figure 5-34: Life Cycle Emissions to Water - Coated Paperboard PDS



5.2.3.5 Coated Paperboard Life Cycle Water Use

The outcomes for total PDS water use followed the same pattern as PDS emissions to water. As Figure 5-35 shows, the current PP PDS again was the best performer by far in terms of life cycle water use. The PP PDS consumed 866 liters of water while LDPE coated paperboard and PLA coated paperboard consumed 1840 liters and 1800 liters, respectively. Like emissions to water, Material Production of paperboard was responsible for a significant portion of life cycle water use.

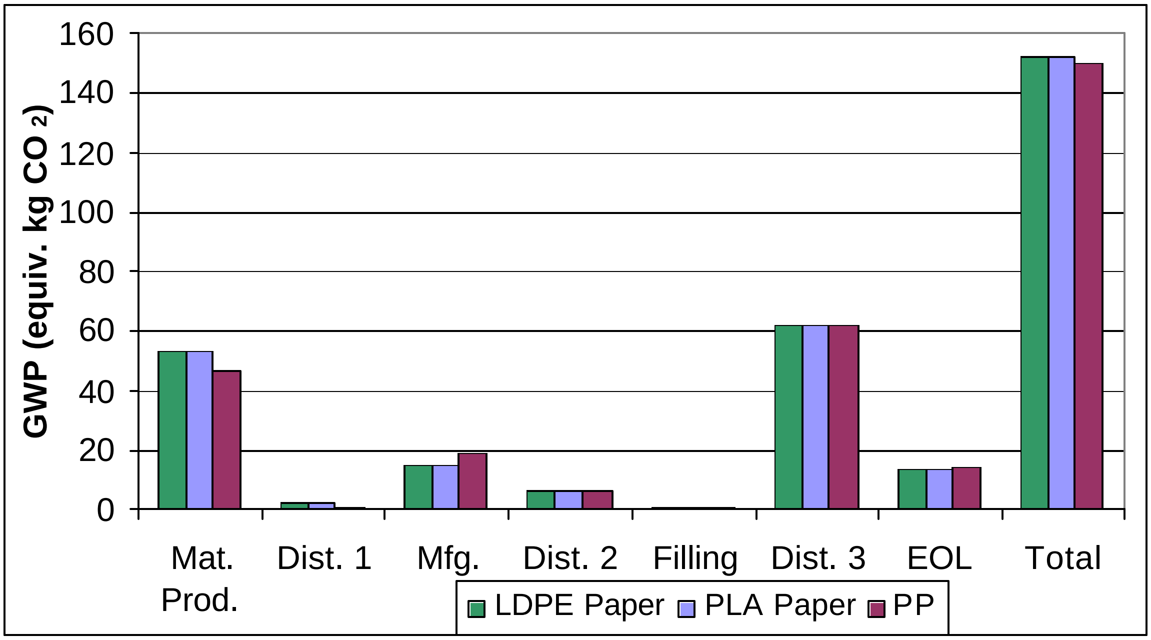
Figure 5-35: Life Cycle Water Use - Coated Paperboard PDS



5.2.3.6. Coated Paperboard Characterized Impact Categories

As shown in Figure 5-36, PP containers had lower Global Warming Potential than either coated paperboard container. Although PP consumes more energy, much of it is embodied in the material rather than burned as fuel. In paper, more of the energy is fuel energy and hence, the greater GWP. The total GWP is 149 equivalent kg of CO_2 for PP and 152 equivalent kg of CO_2 for both LDPE coated and PLA coated containers. (This assumes that the trees for the paperboard are grown on a plantation with credit given to the carbon sequestered as new trees are grown.)

Figure 5-36: Life Cycle GWP - Coated Paperboard PDS



While research and policy-making is ongoing, there is no recognized approach to account for changes in carbon stocks and flows. Further, the LCA methodology has not arrived at a consensus on how to account for the carbon cycle for forestry products such as paperboard. There are a number of approaches for quantification of the carbon cycle in LCA, each of which arrives at a different conclusion depending on the treatment of CO_2 uptake, decay, and reforestation. In "Handling of the Carbon Balance of Forests in LCA," Stefan De Feyter concludes that, "The current methodology of LCA...is not able to deal with the evaluation of the sink effects of carbon in timber products. ... This is because LCA is a static model (no time aspects)."[71] While carbon cycles and carbon sequestration are important topics for global warming, the LCA results in this study do not attempt to quantify the impacts of forest products used in the PDS beyond the data in the relevant modules.

The two life cycle phases responsible for most of the Ozone Depletion Potential (ODP) are Material Production and Distribution 3. The majority of ozone depleting substances associated with the PDS is released during the production of paper products. This close relationship between ODP and paper production is evident in Figure 5-37 below. ODP for both coated paperboard PDSs is nearly 10 times that of PP, and the total life cycle ODP for paperboard cups is more than double that of the

PP. The OPD for PP was 3.88 equivalent mg of CFC-11, 8.44 mg CFC-11 for LDPE coated paperboard and 8.54 mg CFC-11 for PLA coated paperboard.

Figure 5-37: Life Cycle ODP - Coated Paperboard PDS

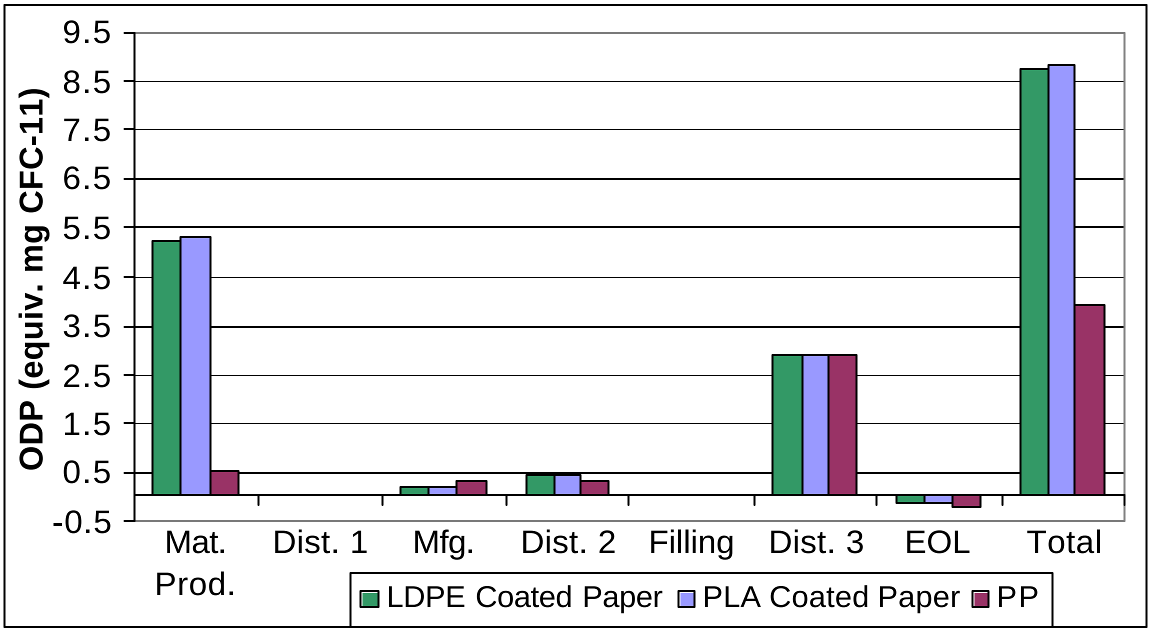
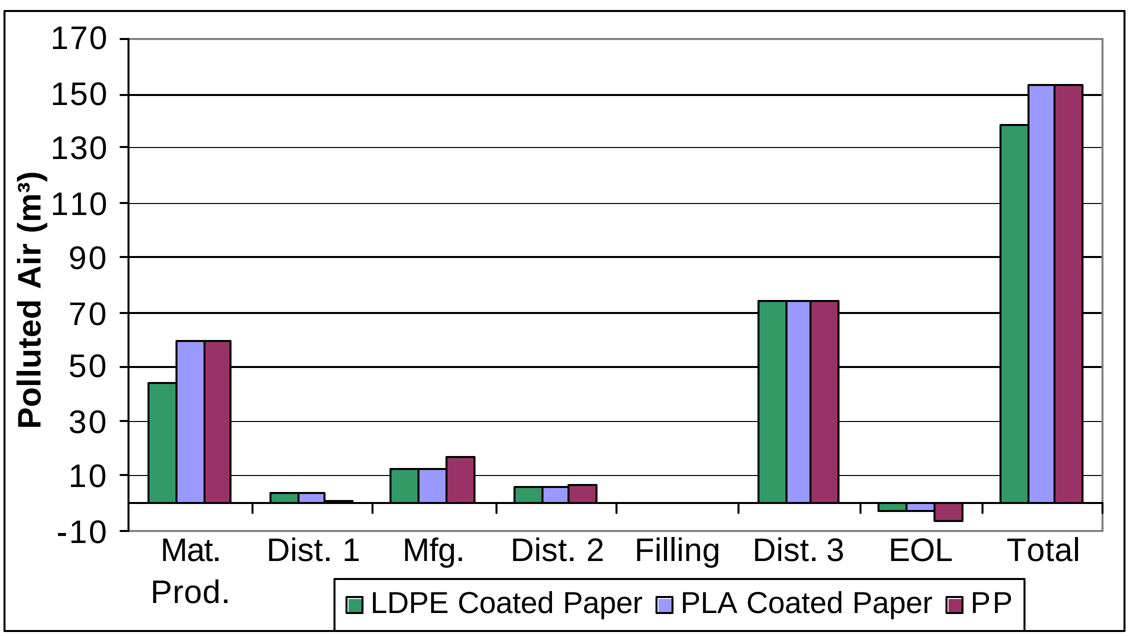


Figure 5-38 shows the polluted air volumes for each container PDS. The MAC was 136 m³ for LDPE coated cups, 150 m³ for PLA coated cups, and 153 m³ for PP. Of the three, PP had the highest SOx emissions, which partially accounts for it having the highest overall MAC value. As expected, Distribution 3 for all three containers contributed the most to total MAC values.

Figure 5-38: Life Cycle MAC - Coated Paperboard PDS



5.3 Comparison by Container Size

In this section, the results for each PDS are compared by container size. Presenting the results in this way illustrates that the preferred choice of PDS material or manufacturing process may vary by container size. The results for Life Cycle Energy, Renewable Energy and Solid Waste are included.

5.3.1. Energy Consumption

Of all the seven PDSs analyzed in this study, thermoformed PP and coated unbleached paperboard PDSs consumed lower amounts of energy than the other four alternatives. The thermoformed PP PDS ranked in the top three in all four comparison sizes. The coated paperboard PDS had the lowest life cycle energy in the 6 oz. and 8 oz. cup sizes. In fact, the thermoformed and coated paperboard containers in the 6 oz. and 8 oz. sizes were very close in total life cycle energy, with only a 0-2.4% difference separating them.

PLA containers outperformed all but the thermoformed PP PDS in the 4 oz. cup size. The PLA/LLDPE PDS consumed less life cycle energy than the current PDS for all sizes. HDPE consumed the most energy in all sizes. The current PDS using injection molded PP cups outperformed the coated paperboard PDSs in the 4oz. size.

It is important to note that the observed differences in energy consumption are dependent on the accuracy of the material production data and unfortunately no uncertainty bounds are available for these data.

Figure 5-39: Life Cycle Energy - 4 oz. PDS

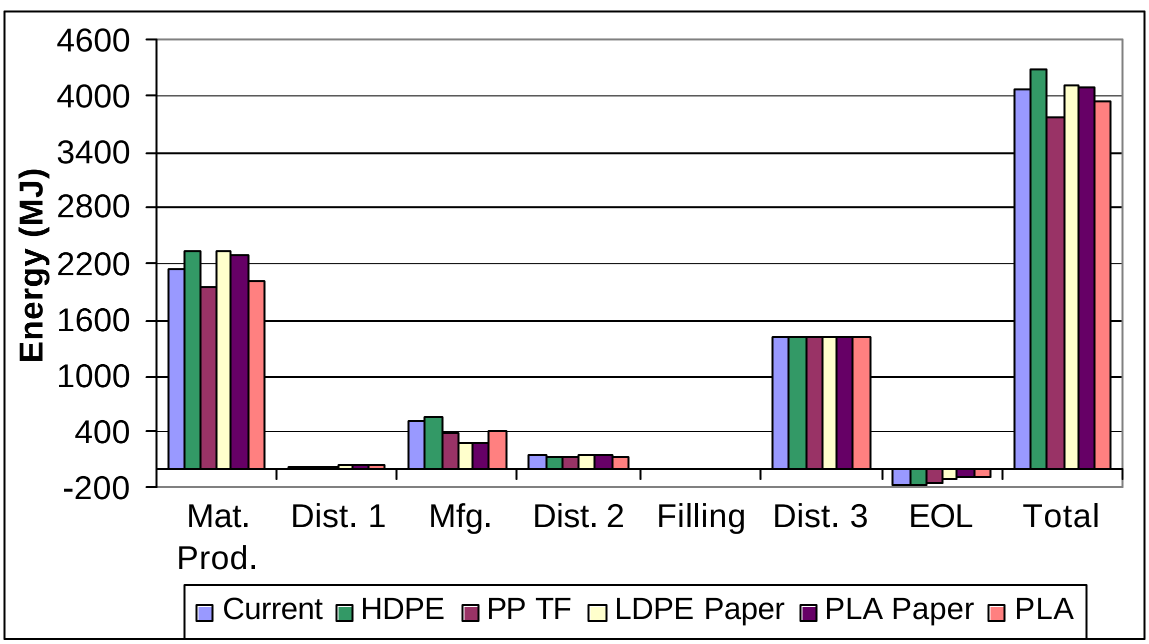


Figure 5-40: Life Cycle Energy - 6 oz. PDS

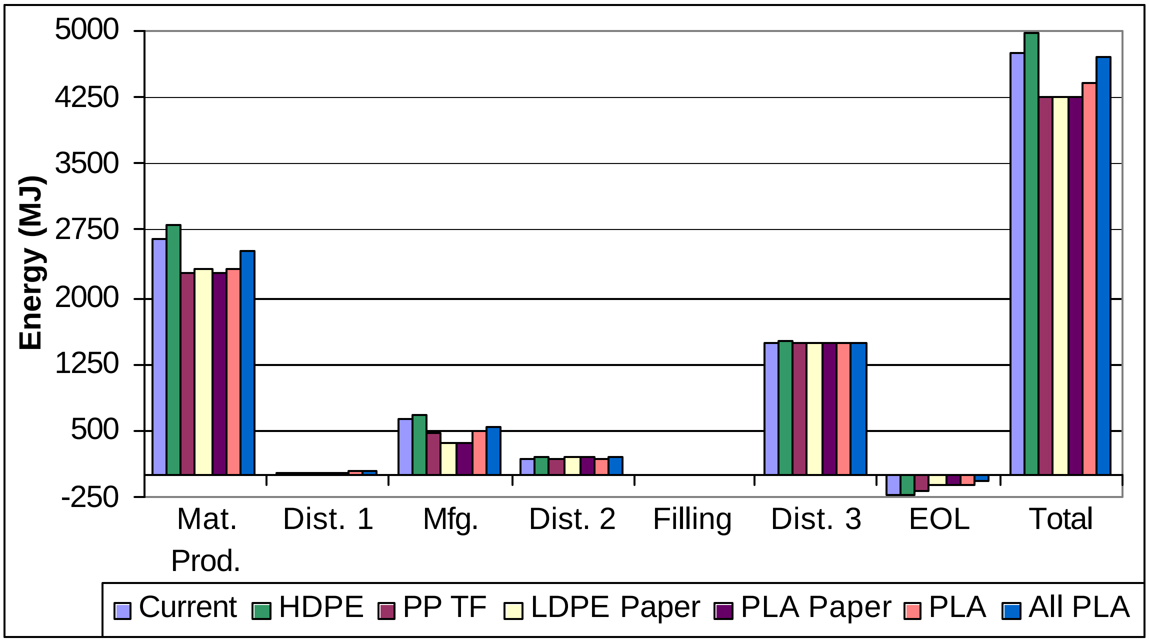


Figure 5-41: Life Cycle Energy - 8 oz. PDS

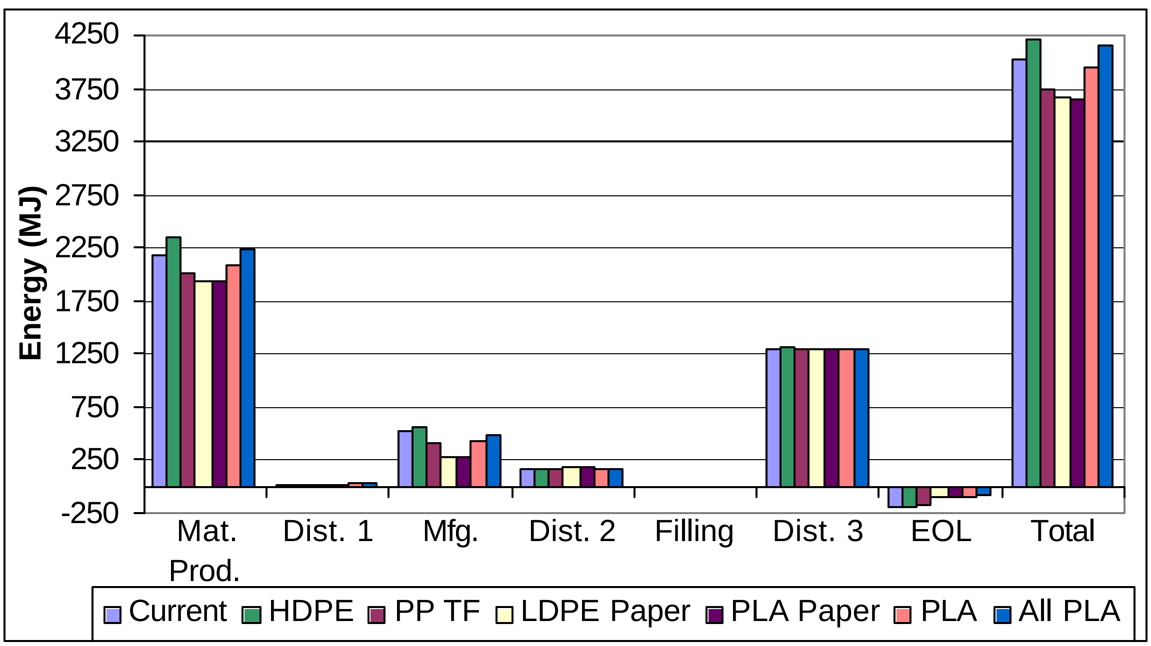
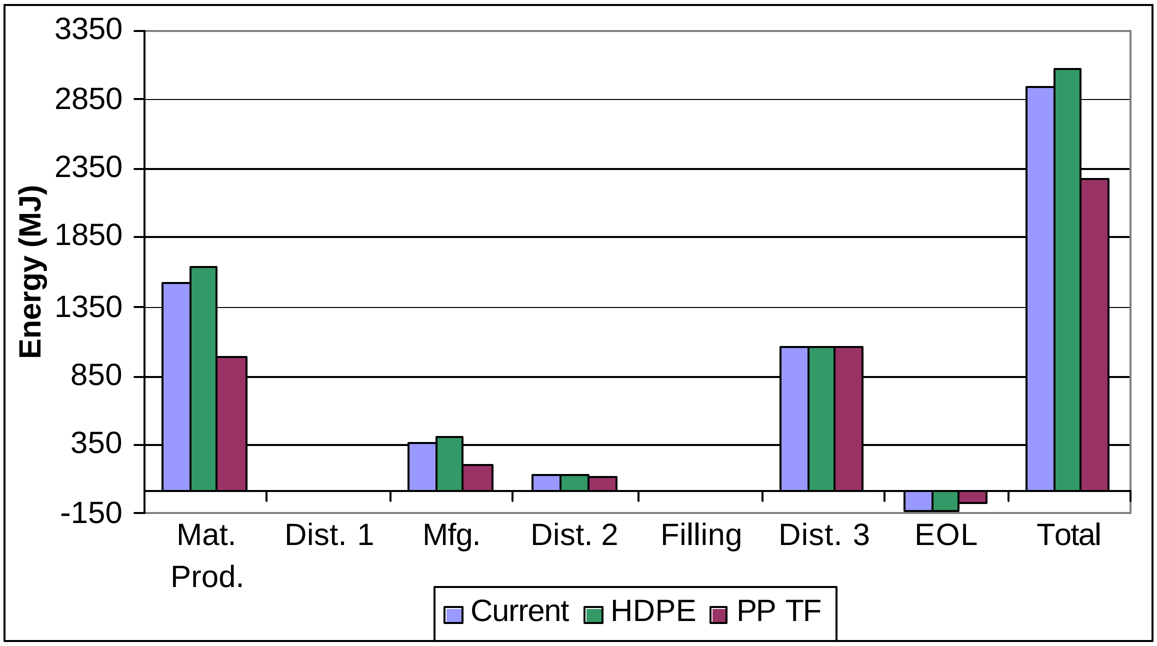


Figure 5-42: Life Cycle Energy - 32 oz. PDS



5.3.2. Renewable and Non-Renewable Energy

As discussed earlier, paper products tend to use a higher percentage of renewable energy than petroleum products. Consequently, the coated unbleached paperboard containers came out on top when comparing the composition of renewable and non-renewable energy used throughout the PDS life cycle. For coated paperboard containers, between 35-45% of total life cycle energy came from renewable resources. By comparison, only 17-26% renewable energy went into PP and HDPE containers. PLA fell somewhere in the middle with 27-34% renewable energy, depending on cup size.

Figure 5-43: Life Cycle Renewable Energy - 4 oz. PDS

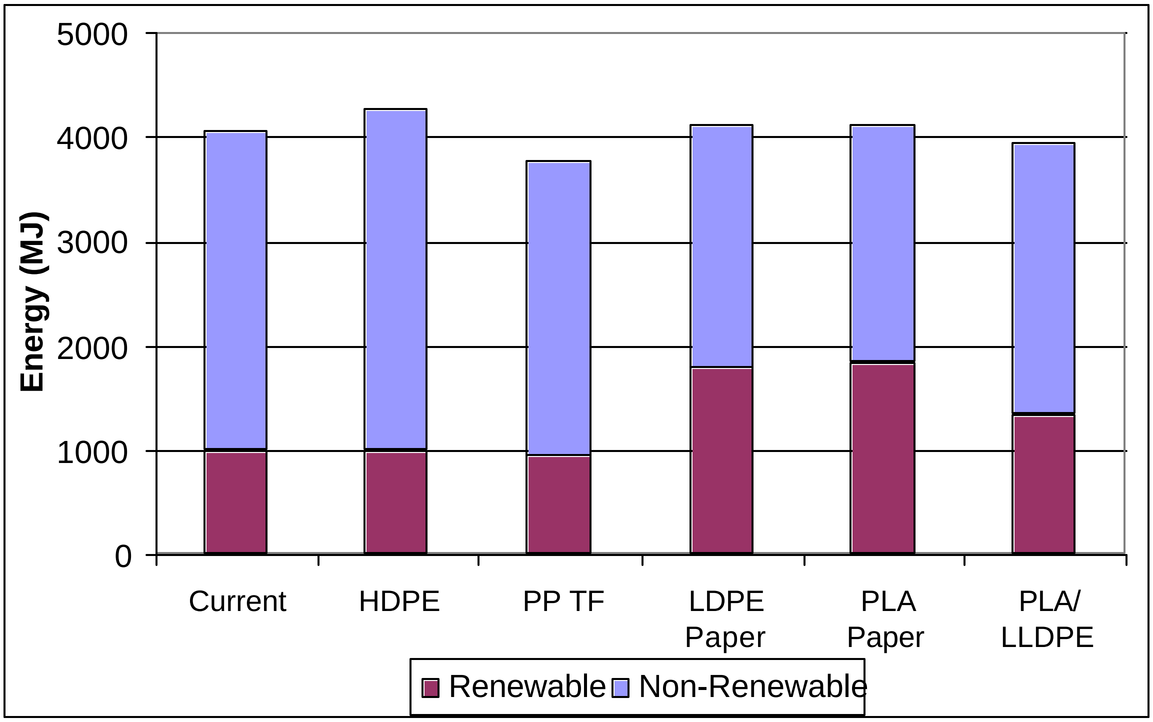


Figure 5-44: Life Cycle Renewable Energy - 6 oz. PDS

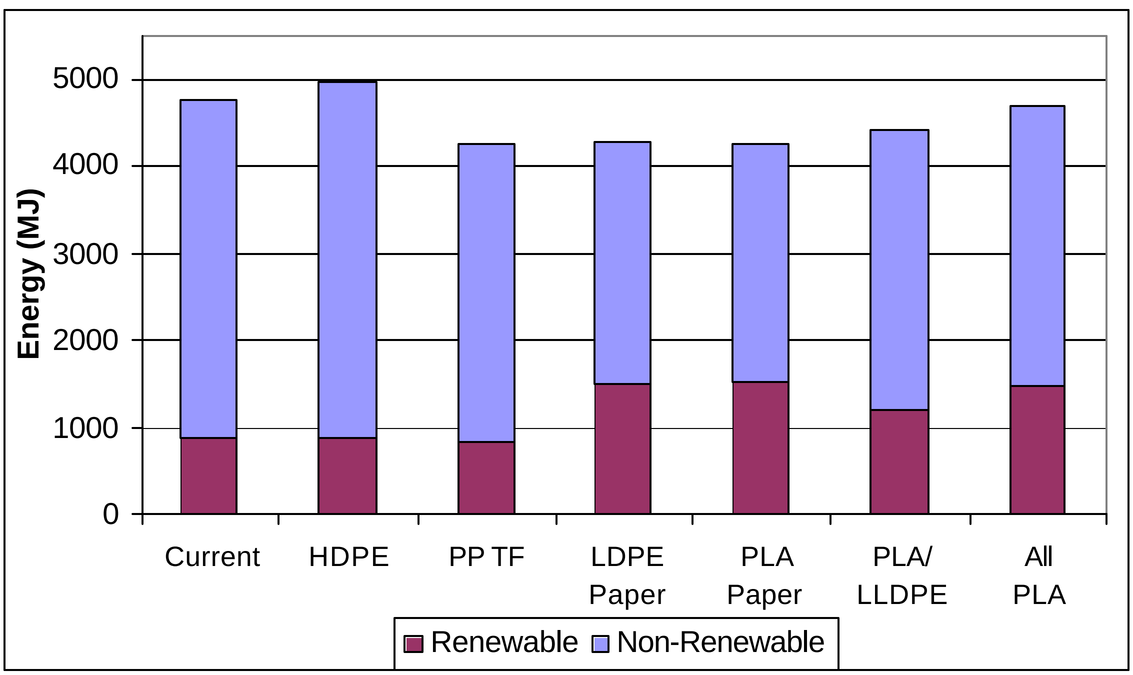


Figure 5-45: Life Cycle Renewable Energy - 8 oz. PDS

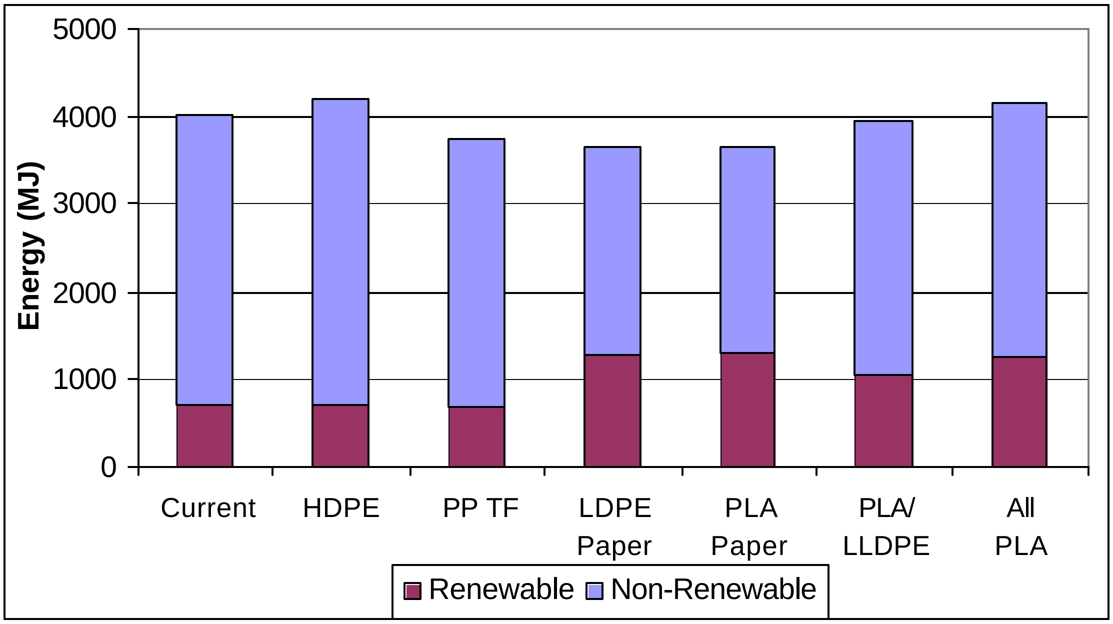
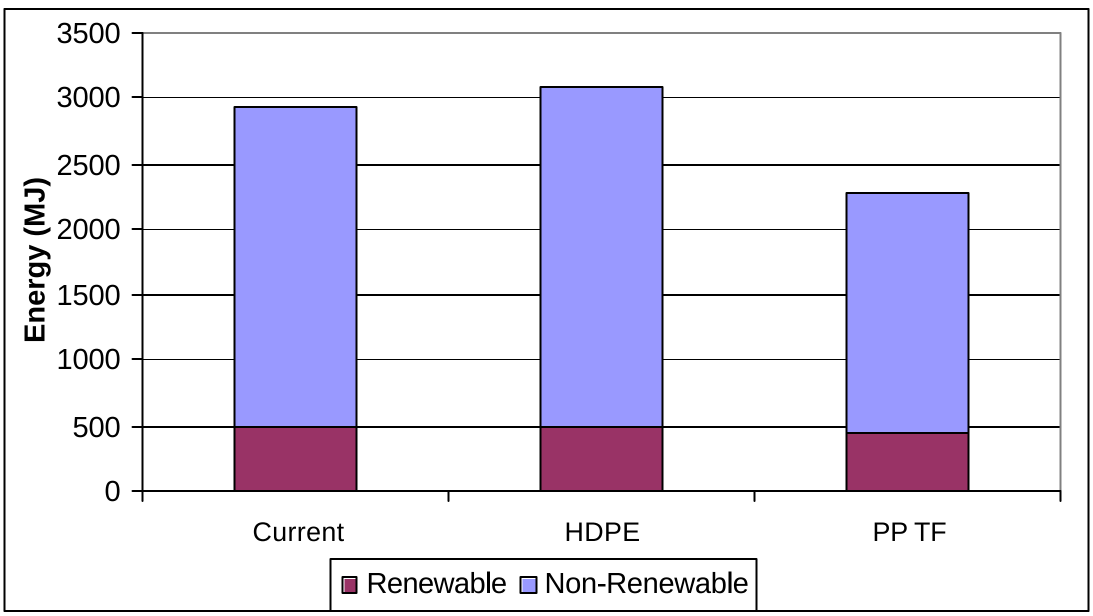


Figure 5-46: Life Cycle Renewable Energy - 32 oz. PDS



5.3.3. Solid Waste

PP and HDPE had lower life cycle solid waste than either PLA or coated paperboard containers. More specifically, thermoformed PP containers, which use the least amount of input material, had the least solid waste followed by injection molded PP and then the more material intensive HDPE. It is not surprising that PP and HDPE had the best results given that petroleum-based plastics receive a larger solid waste credit at End-of-Life and that paperboard has higher scrap rates and requires more secondary packaging for an equivalent number of containers. PLA had the highest solid waste across all PDSs. This was due to the large quantities of slag and ash produced during the generation of electricity used during the polymerization process.

Figure 5-47: Life Cycle Solid Waste - 4 oz. PDS

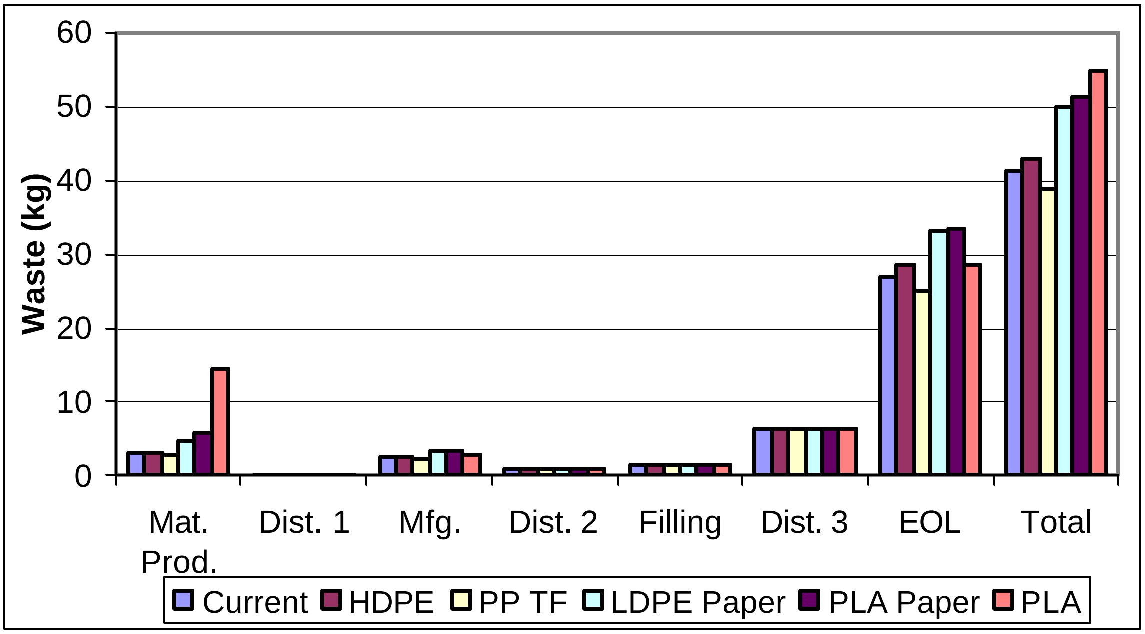


Figure 5-48: Life Cycle Solid Waste - 6 oz. PDS

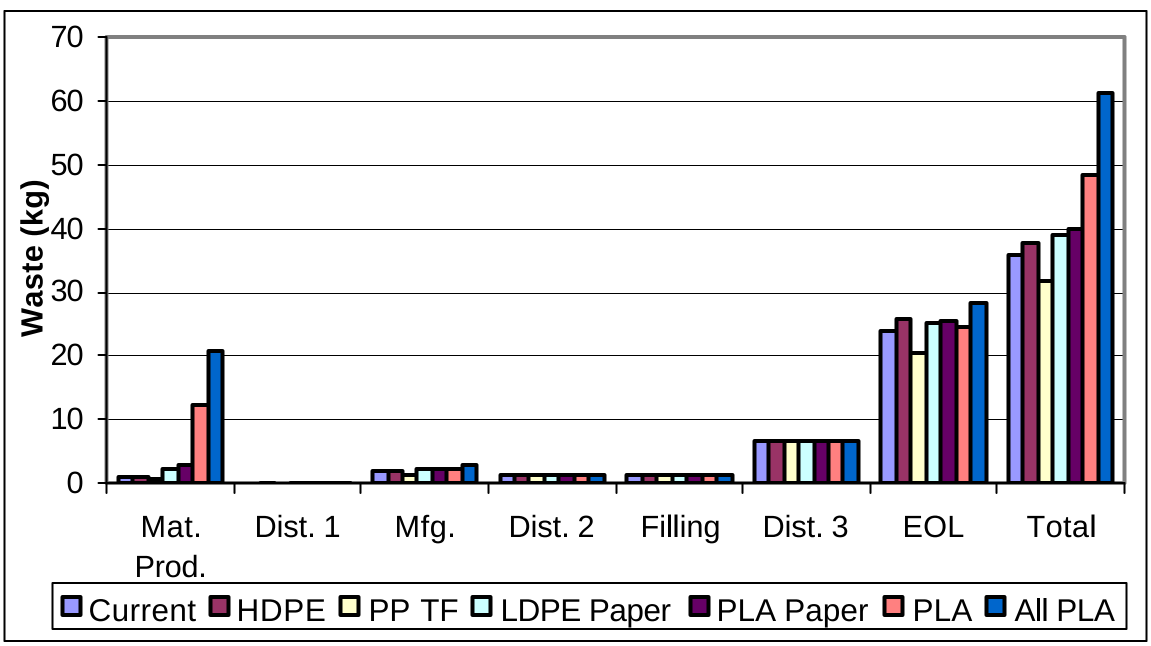


Figure 5-49: Life Cycle Solid Waste - 8 oz. PDS

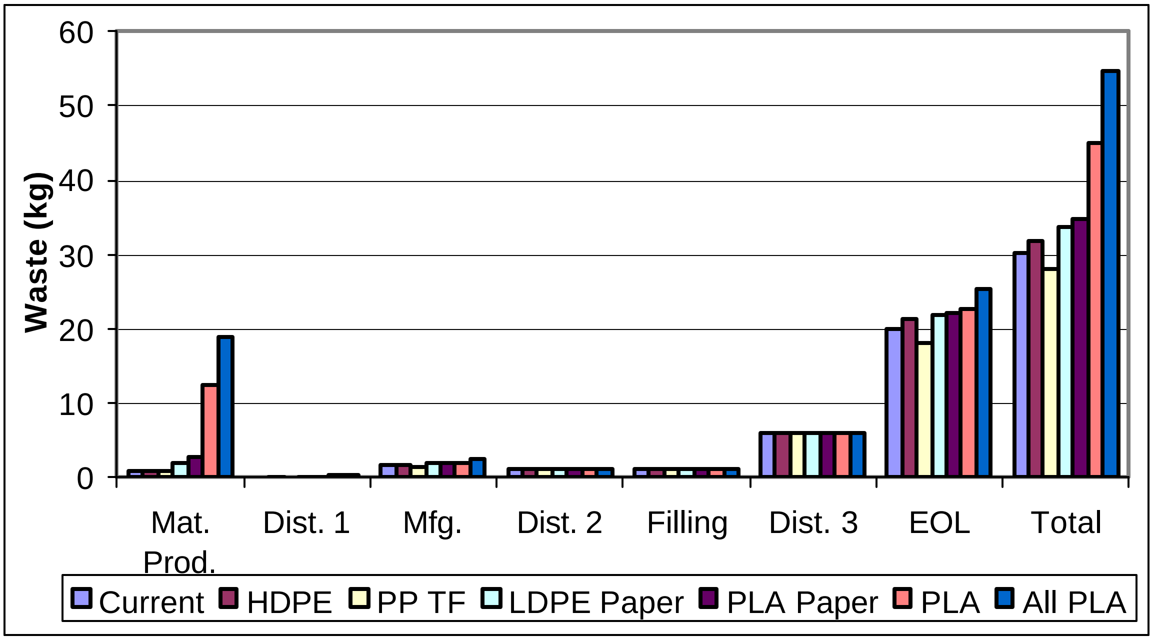
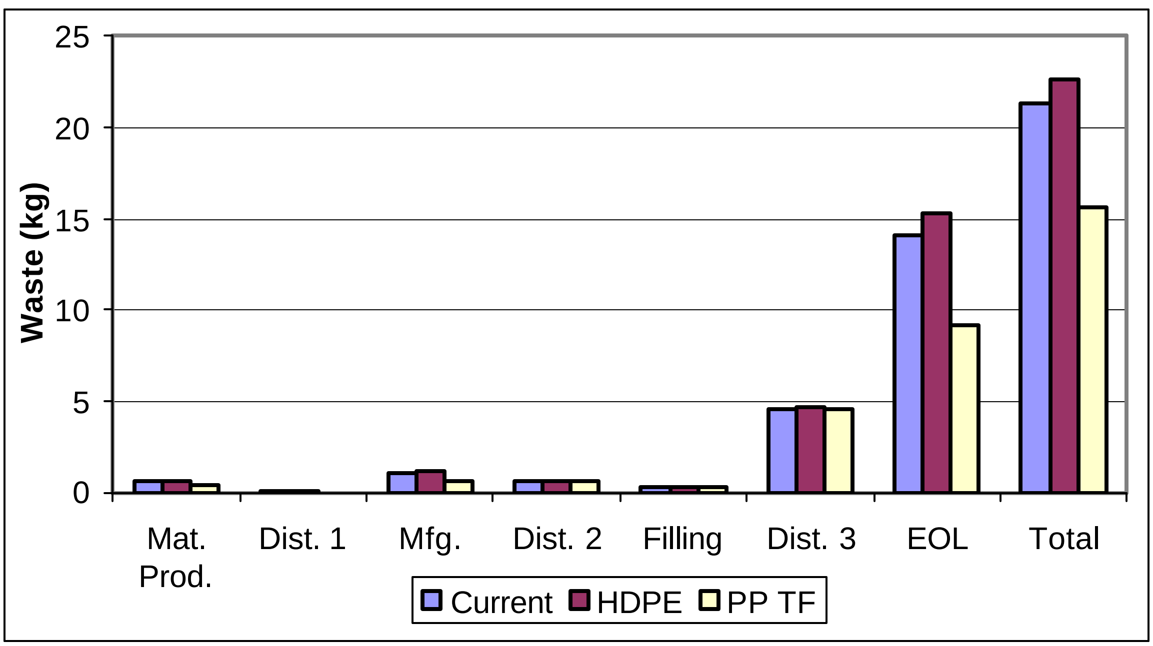


Figure 5-50: Life Cycle Solid Waste - 32 oz. PDS



6. Sensitivity Analysis

Various assumptions were made to complete the life cycle inventory calculations. This chapter of the report explores the significance of these assumptions by varying the assumed values and observing the calculation outputs. These tests were performed to demonstrate the robustness of the calculation model.

The sensitivity tests are broken into five categories: Product Delivery Distance, Primary Packaging Weights, Manufacturing, End-of-Life and Secondary Packaging Recycling. The sections below describe the tests run and discuss the findings.

6.1 Product Delivery Distance

Noting the 30% annual growth of Stonyfield Farm, it is safe to assume the average product distribution distance is increasing. The distribution 3 delivery distance, 552 miles, was determined using distances to distributors/retailers and the quantities of yogurt delivered, both given by Stonyfield. A sensitivity analysis was performed to determine the impact of increasing the delivery distance 10% and 25%. The results of these tests appear in Table 6-1.

The impact of increasing the distribution distance appeared to be significant, but reasonable considering the energy intensity involved with truck transportation and the weight of the packaged product. From the results, the generalization can be made that for every increase of 50 miles in the average delivery distance, approximately 50 MJ of addition energy (1.5% of total life cycle energy) would be required per functional unit.

Table 6-1: Sensitivity Analysis - Product Delivery Distance

Category/Environmental Flows	Units	Baseline	Test 1	Test 2
Variation				
Percent Change		0%	+10%	+25%
Distance	miles	552	607	690
Distribution 3 Energy				
Product Transport	MJ	501.2	546.8	615.2
Primary Packaging Transport	MJ	30.85	33.45	37.36
Secondary Packaging Production	MJ	675.7	675.5	675.5
Secondary Packaging Transport	MJ	38.64	42.29	47.77
Distribution 3 Total	MJ	1246	1298	1376
Percent Change		N/A	+4.1%	+10.4%
Life Cycle				
Energy	MJ	3713	3764	3842
Percent Change		N/A	+1.4%	+3.5%

6.2 Primary Packaging Weights

The weights of the containers were critical to the PDS calculation model constructed for this study. The input weights affected the material production energy, transportation burdens, end-of-life solid waste and others. Four different sensitivity analyses were performed where more than one plausible value was available for container weights. The first analysis looks at the specified weights of the current cups and lids versus weighed samples. The study results of this report were based on packaging weight specifications. The second case analyzes the effect of increasing and decreasing the wall thickness of HDPE cups to account for material properties. The third analysis tests the weight assumed for 4 oz. thermoformed cups. The last test compared the specified weights of the 2 oz. tubes with the actual weights measured by Stonyfield.

6.2.1 Weights of Current Cups and Lids

During the research phase of this study, Stonyfield Farm was asked to weigh 10 of each plastic component supplied by Polytainers. The average weights and standard deviations appear in the top section of Table 6-2. The sensitivity test compared the specified weights, which were used for the primary calculations, to the average weighed weight as well as plus and minus one standard deviation. The lower section of Table 6-2 shows the results for key environmental metrics based on analysis of the composite PDSs. In every category, burdens for the weighed containers were slightly (0.1% to 1.5%) higher than the burdens for the specified containers.

Table 6-2: Sensitivity Analysis - Weights of Current Cups and Lids

Component/Category	units	Baseline	Test 1	Test 2	Test 3
Variation (Scenario)		*Specification*	*Weighed*	*-Std. Dev.*	*+Std. Dev.*
4 oz. Cup	g	4.90	5.01	4.95	5.07
6 oz. Cup	g	7.80	7.66	7.44	7.88
6 & 8 oz. Lid	g	3.90	4.16	4.04	4.28
8 oz. Cup	g	9.10	9.06	8.57	9.55
32 oz. Cup	g	29.00	28.79	28.55	29.03
32 oz. Lid	g	8.10	7.86	7.63	8.09
Life Cycle					
Material Inputs	kg	56.39	56.54	55.95	57.13
Percent Change		N/A	+0.3%	-0.8%	+1.3%
Energy	MJ	3712	3728	3674	3782
Percent Change		N/A	+0.4%	-1.0%	+1.9%
Solid Waste	kg	29.56	29.68	29.23	30.13
Percent Change		N/A	+0.4%	-1.1%	+1.9%
Air Emissions	g	2267	2273	2244	2301
Percent Change		N/A	+0.3%	-1.0%	+1.5%
Emissions to Water	g	1011	1012	1009	1015
Percent Change		N/A	+0.1%	-0.2%	+0.3%
Water Use	liter	801.0	802.3	798.0	806.7
Percent Change		N/A	+0.2%	-0.4%	+0.7%
GWP	kg CO_2	136.0	136.2	134.6	137.9
Percent Change		N/A	+0.2%	-1.0%	+1.4%
MAC (polluted air)	m^3	140.7	141.0	139.5	142.4
Percent Change		N/A	+0.2%	-0.9%	+1.2%

6.2.2 Wall Thickness of HDPE Cups

Interviews with Polytainers personnel revealed that HDPE cups typically require thicker walls than PP cups due to the material's viscosity and other properties. In the Results and Interpretation section, it was assumed that the wall thickness of the HDPE cups was 105% of the PP cups. This sensitivity analysis compared this assumption to two other plausible values (100% and 110%). The cup weights used for each test and the results from the calculation model appear in Table 6-3. Nearly all environmental metrics considered experienced a significant impact from increasing the weight of the cups. The most notable was the energy, which rose 1.9% with a 5% increase in weight. The composite HDPE injection molded PDS was used for this analysis. Data for the composite PP injection molded PDS were included in Table 6-3 to be used as a benchmark.

Table 6-3: Sensitivity Analysis - Wall Thickness of HDPE Cups

Component/Category	units	Baseline	Test 1	Test 2	PP IM PDS
Variation					*Comparison*
Vol% of PP Cups		105%	100%	110%	N/A
4 oz. Cup	g	5.442	5.183	5.701	4.900
6 oz. Cup	g	8.664	8.251	9.076	7.800
8 oz. Cup	g	10.107	9.626	10.589	9.100
32 oz. Cup	g	32.210	30.676	33.744	29.000
Environmental Flows					
Material Inputs	kg	58.20	57.33	59.02	56.39
Percent Change		N/A	-1.5%	+1.4%	-3.1%
Energy	MJ	3878	3800	3950	3712
Percent Change		N/A	-2.0%	+1.9%	-4.3%
Solid Waste	kg	30.98	30.32	31.61	29.56
Percent Change		N/A	-2.1%	+2.0%	-4.6%
Air Emissions	g	2415	2368	2459	2267
Percent Change		N/A	-1.9%	+1.8%	-6.1%
Emissions to Water	g	1022	1018	1026	1011
Percent Change		N/A	-0.4%	+0.4%	-1.0%
Water Use	liter	929.3	917.6	940.3	801.0
Percent Change		N/A	-1.3%	+1.2%	-13.8%
GWP	kg CO_2	143.9	141.1	146.5	136.0
Percent Change		N/A	-1.9%	+1.8%	-5.5%
MAC (polluted air)	M^3	139.4	137.4	141.4	140.7
Percent Change		N/A	-1.5%	+1.4%	+0.9%

6.2.3 Weight of 4 oz. Thermoformed Cups

This sensitivity test dealt with conflicting data received for the expected weight of 4 oz. thermoformed cups. Polytainers provided reliable figures for the weights of other size thermoformed containers, but had no data for 4 oz. For the primary calculation, it was assumed the thermoformed cup was 13% less massive than its injection molded counterpart, by using the smallest percentage weight saving from the other sized containers. The sensitivity analysis compares the results if the weight savings were only 6.5% and if the weight was identical to the injection molded cup. The weights of the 4 oz. cup used in each test as well as the results are in Table 6-4. Also included in Table 6-4 are the results for the injection molded 4 oz. cup for comparison. If the weights were identical, thermoforming would be slightly less energy intensive and have slightly lower environmental burdens.

Table 6-4: Sensitivity Analysis - Weight of 4 oz. Thermoformed Cups

Component/Category	Units	Baseline	Test 1	Test 2	PP IM 4 oz.
Variation					*Comparison*
Wt. Change from IM Cup		-13%	-6.5%	+0%	N/A
4 oz. Cup	g	4.26	4.58	4.90	4.90
Life Cycle					
Material Inputs	kg	67.96	69.29	70.62	70.62
Percent Change		N/A	+2.0%	+3.9%	+3.9%
Energy	MJ	3764	3877	3991	4076
Percent Change		N/A	+3.0%	+6.0%	+8.3%
Solid Waste	kg	35.75	36.75	37.75	38.02
Percent Change		N/A	+2.8%	+5.6%	+6.4%
Air Emissions	g	2378	2443	2508	2552
Percent Change		N/A	+2.7%	+5.5%	+7.3%
Emissions to Water	g	1171	1177	1183	1193
Percent Change		N/A	+0.5%	+1.0%	+1.9%
Water Use	liter	919.6	926.2	932.7	983.4
Percent Change		N/A	+0.7%	+1.4%	+6.9%
GWP	kg CO_2	149.9	153.8	157.6	161.1
Percent Change		N/A	+2.6%	+5.2%	+7.5%
MAC (polluted air)	m^3	146.4	149.9	153.4	156.8
Percent Change		N/A	+2.4%	+4.8%	+7.1%

6.6.4 Weights of 2 oz. Tubes and Tape

This test of the model compares the specification weights of the primary packaging (tubes and tape) to the weighed weights provided by Stonyfield Farm. When the weights were adjusted other values also needed to change to accurately include the data collected for the 2 oz. PDS. Those variables are the number of tubes and tape segments per roll and the engineered scrap rate for the tube material. The carton weight was not included in this analysis because the weighed weight was value used for the baseline calculations.

The adjusted variables appear in the top section of Table 6-5 and the results are shown in the lower sections. From the results it appears that increasing the weight of the tubes and decreasing the weight of the tape cancel each other out. At most the calculation model results varied by 0.5% from the baseline.

Table 6-5: Sensitivity Analysis - Weights of 2 oz. Tubes and Tape

Component	Units	Baseline	Test
Variation (Scenario)			*Weighed*
Tube Weight	g	1.18	1.25
Tubes per Roll		38,744	36,792
Tube Engineered Scrap Rate		4.2%	3.0%
Tape Weight	g	0.178	0.147
Tape Segments per roll		12010	14,551
Life Cycle			
Material Inputs	kg	81.55	81.64
Percent Change		N/A	0.1%
Energy	MJ	3800	3810
Percent Change		N/A	0.3%
Solid Waste	kg	47.00	47.06
Percent Change		N/A	0.1%
Air Emissions	g	2540	2547
Percent Change		N/A	0.3%
Emissions to Water	g	1336	1335
Percent Change		N/A	-0.1%
Water Use	liter	1146.7	1143.3
Percent Change		N/A	-0.3%
GWP	kg CO_2	155.5	155.7
Percent Change		N/A	0.1%
MAC (polluted air)	m^3	149.9	150.3
Percent Change		N/A	0.3%

6.3 Manufacturing Energy

6.3.1 Thermoforming Electrical Consumption

Electricity consumption for the thermoforming manufacturing process was estimated using secondary data energy demand for polystyrene thermoforming and assuming the same natural gas consumption as injection molding. The natural gas consumption rate was considered reliable because natural gas is used for heating. Thermoforming was modeled to occur in Polytainers injection molding facility in Toronto. There was less confidence in the electricity consumption, which accounts for the balance of energy used in manufacturing. Therefore, a sensitivity analysis was performed to evaluate the effect of increasing the thermoforming electricity consumption. The results from the baseline calculations that assumed 5.85 MJ per kg of output (22.9% less than injection molding) are compared to 6.83 MJ/kg (10% less than IM) and 7.59 MJ/kg (equal to IM). The results of the sensitivity analysis appear in Table 6-6. Also included in the table is a column for the composite injection molded PDS to be used in comparison.

Table 6-6: Sensitivity Analysis - Thermoforming Electrical Consumption

Component/Category	units	Baseline	Test 1	Test 2	PP IM
Variation					*Comparison*
Percent of IM Electricity		-22.9%	-10.0%	0%	N/A
Mfg. Electrical Consumption	MJ/kg	5.85	6.83	7.59	7.59
Manufacturing					
Energy	MJ	336.8	364.4	385.8	463.8
Percent Change		N/A	+8.2%	+14.5%	+37.7%
Life Cycle					
Energy	MJ	3290	3317	3339	3713
Percent Change		N/A	+0.8%	+1.5%	+12.9%

6.4 End-of-Life

6.4.1 MSW Incineration Rates

Assumptions in the End-of-Life phase were made for the fraction of municipal solid waste incinerated and for the recycling of plastic container components. The incineration rate assumed for the calculation model, 23.5% of the MSW waste stream, was the U.S. average. However, this incineration rate may be low for this study due to the majority of incineration capacity being located in the Northeast where Stonyfield Farm sells the bulk of its products. So, a sensitivity analysis was done to compare 30% and 40% incineration rates to the U.S. average rate. The results that appear in Table 6-7 show a small decrease in life cycle energy and a substantial decrease in solid waste. The decline in energy has been attributed to the generation of electricity from the increased quantity of plastic available for incineration. Energy recovery from incineration was also responsible for the solid waste numbers. According to the DEAM modules used to calculate the environmental burdens of incineration, each kilogram of plastic offset the 2.74 kg of waste associated with the other forms of power generation.

Table 6-7: Sensitivity Analysis - MSW Incineration Rates

Component/Category	units	Baseline	Test 1	Test 2
Variation				
Incineration Rate		23.5%	30%	40%
End-of-life				
Energy	MJ	-157.2	-198.1	-260.9
Percent Change		0.0%	26.1%	66.0%
Solid Waste	kg	19.1	17.1	14.2
Percent Change		0.0%	-10.1%	-25.6%
Life Cycle				
Energy	MJ	3713	3672	3609
Percent Change		0.0%	-1.1%	-2.8%
Solid Waste	kg	29.56	27.64	24.68
Percent Change		0.0%	-6.5%	-16.5%

6.4.2 Primary Packaging Recycling Rates

The second sensitivity analysis for End-of-Life is for the recycling rate of PP and LLDPE packaging components. For the model, a rate of zero percent was assumed because programs to recycle wide-mouth PP containers do not exist in most communities. In the sensitivity analysis, zero percent recycling was compared to two rates given by the EPA for other packaging (5.9%) and other containers (16.4%). Table 6-8 contains the results of the recycling rate sensitivity analysis. As expected, increasing the recycling rate decreased the solid waste burden, but increased the life cycle energy by removing material from the incineration stream.

Table 6-8: Sensitivity Analysis - Primary Packaging Recycling Rates

Component/Category	units	Baseline	Test 1	Test 2
Variation (Scenario)			*Other Packaging*	*Other Containers*
Recycle Rate		0%	5.9%	16.4%
End-of-life				
Energy	MJ	-157.2	-151.0	-140.1
Percent Change		0.0%	-3.9%	-10.9%
Solid Waste	kg	19.1	18.4	17.3
Percent Change		0.0%	-3.4%	-9.5%
Recycled Material	kg	0.9	1.8	3.5
Percent Change		0.0%	+102.2%	+284.1%
Life Cycle				
Energy	MJ	3713	3719	3730
Percent Change		0.0%	+0.2%	+0.5%
Solid Waste	kg	29.56	28.91	27.76
Percent Change		0.0%	-2.2%	-6.1%
Recycled Material	kg	26.7	27.6	29.3
Percent Change		0.0%	+3.5%	+9.7%

6.5 Secondary Packaging Recycling Rates

The last sensitivity analysis assumed recycling rates of secondary packaging at the grocery distributors and retailers. The three varieties of packaging used in Distribution 3 are corrugated cardboard, stretch wrap and pallets. The recycling rates assumed for each type of packaging appear in the baseline column of Table 6-9. The first test, labeled “High”, assumed changes in the technical and business environment would translate to 100% recycling rates for corrugated and 15% recycling rate for stretch wrap. The “Low” scenario took the perspective that grocers had little incentive to recycle and that rates would fall below the current averages.

The results, in the lower sections of Table 6-9, show that solid waste generation and recycling quantities during the product distribution phase were very sensitive to variation in the secondary packaging recycling rates. Also, shown is the significance of Distribution 3 solid waste and recycling quantities in relation to the entire life cycle.

Table 6-9: Sensitivity Analysis - Secondary Packaging Recycling Rates

Component	units	Baseline	Test 1	Test 2
Variation (Scenario)			*High*	*Low*
Corrugated		95.0%	100%	85%
Stretch Wrap		7.3%	15%	5%
Pallets		71.0%	80%	60%
Distribution 3 Solid Waste				
Product Transport	kg	1.88	1.88	1.88
Primary Packaging Transport	kg	0.12	0.12	0.12
Secondary Packaging Production	kg	3.35	2.28	5.40
Secondary Packaging Transport	kg	0.14	0.14	0.14
Distribution 3 Solid Waste	kg	5.49	4.42	7.54
Percent Change		0.0%	-19.5%	+37.3%
Recycled Material	kg	20.9	22.0	18.9
Percent Change		0.0%	5.1%	-9.8%
Life Cycle				
Solid Waste	kg	29.56	28.49	31.61
Percent Change		0.0%	-3.6%	+6.9%
Recycled Material	kg	26.7	27.8	24.7
Percent Change		0.0%	4.0%	-7.7%

7. RECOMMENDATIONS

7.1 Introduction

As was shown in the Results and Interpretation section, the energy intensity of a PDS is directly correlated to the size of the containers, the mass of the materials used, the manufacturing processes and the material composition. It was also shown that the burdens associated with the transport of yogurt and the material production of the secondary packaging were very significant. Recommendations for reducing environmental burdens will focus on container size, manufacturing processes, material composition, as well as distribution and light-weighting of both the primary and secondary packaging materials.

This section will discuss recommendations broken into the following categories:

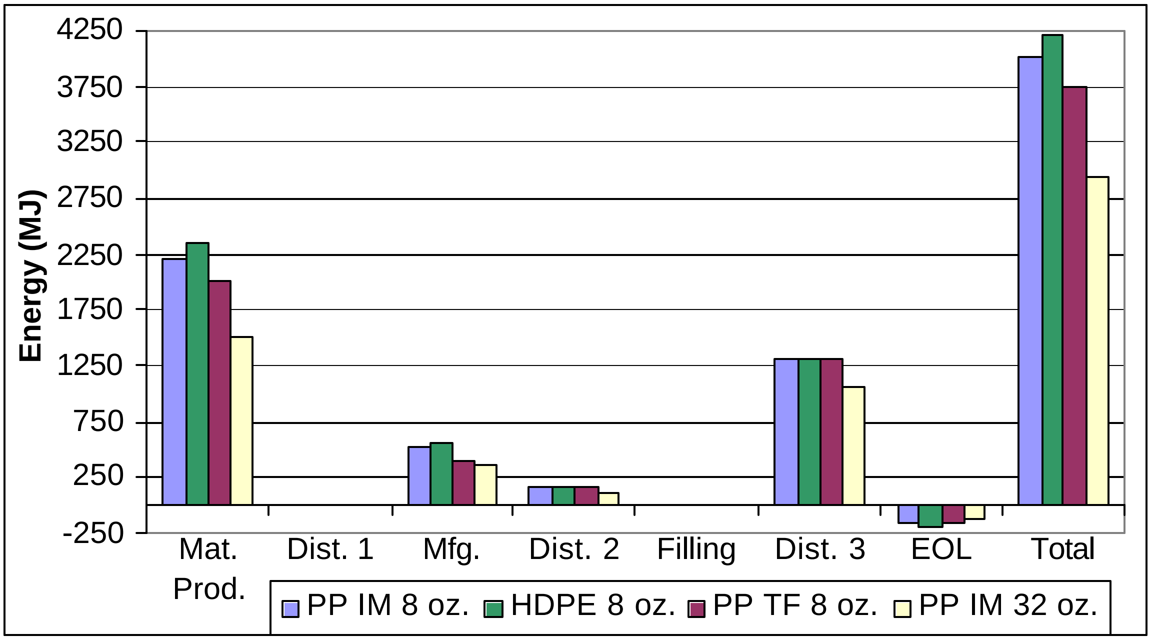
- Container size and configuration recommendations.
- Life cycle phase recommendations.
- Recommendations based on the comparison between injection molding and thermoforming manufacturing processes.
- Recommendations based on the comparison between the use of PP and alternative cup materials.

7.2 Container Size Recommendations

Smaller containers are attractive to consumers because they offer convenience, they come in a variety of flavors and their single serving size contributes to the preservation of freshness. However, it is important for both Stonyfield and yogurt consumers to be aware of the impact that container size has on the environmental burdens of the PDS. Given similar material composition, larger containers have significantly lower environmental burdens in every phase of the life cycle due to the lower quantity of both primary and secondary packaging required per functional unit. The use of 32 oz. containers results in a decrease in life cycle energy by up to 38% over other container sizes per functional unit. If Stonyfield Farm was able to switch all yogurt products to the 32 oz. container size, an annual energy savings equivalent to 11,250 barrels of oil could be achieved.

Although other business considerations exist, the results of this study could be used to educate consumers that the choice of container size has a greater impact on environmental burdens than either the choice of cup material or the cup manufacturing process. This is illustrated in Figure 7-1 where the total life cycle energy of the current and alternative 8 oz. PDSs were compared with the total life cycle energy of the current 32 oz. PDS. Analysis of the life cycle solid waste burdens also revealed significant (29%) savings can be realized when yogurt is sold in 32 oz. containers compared to the more popular 8 oz. containers.

Figure 7-1: Life Cycle Energy Comparison - 8 oz. and 32 oz.



The plastic film tube and paperboard carton configuration of the 2 oz. YoSqueeze packaging is the possible exception to this larger-container-is-better recommendation. The life cycle energy consumption for the 2 oz. (3753 MJ) is less than the other container sizes with the exception of the 32 oz. (2882 MJ). One of the downsides of the 2 oz. PDS is that the solid waste (59.3 kg) was substantially more than any of the other container sizes. The solid waste was primarily attributed to the production, manufacturing and end-of-life disposal of the paperboard carton. A recommendation for lowering the solid waste burdens would be to redesign the YoSqueeze carton to reduce the weight of the paperboard per functional unit. This can be achieved by increasing the number of YoSqueeze tubes per carton or by increasing the quantity of yogurt per tube. The following table shows the reductions in environmental burdens that would be achieved if 1) the existing carton were packed with ten (10) 2 oz. YoSqueeze tubes and 2) the existing carton were packed with eight (8) 2.25 oz. YoSqueeze tubes. This comparison does not account for changes to the mass of the carton or tubes/seals that would undoubtedly be required.

Table 7-1: 2 oz. PDS Alternative Configurations

Component/Category	units	Current PDS	10 per Carton	2.25 oz. Tubes
Variation				
Tubes per Carton		8	10	8
Tube Size	oz.	2.00	2.00	2.25
Environmental Flows				
Material Inputs	kg	81.55	71.90	72.49
Percent Change		0.0%	-11.8%	-11.1%
Energy	MJ	3800	3484	3433
Percent Change		0.0%	-8.3%	-9.6%
Solid Waste	kg	47.00	40.46	41.99
Percent Change		0.0%	-13.9%	-10.7%
Air Emissions	g	2540	2360	2329
Percent Change		0.0%	-7.1%	-8.3%
Emissions to Water	g	1336	1245	1233
Percent Change		0.0%	-6.8%	-7.8%
Water Use	liter	1147	1040	1046
Percent Change		0.0%	-9.3%	-8.7%
GWP	kg CO_2	155.5	140.9	142.3
Percent Change		0.0%	-9.4%	-8.5%
MAC (polluted air)	m^3	149.9	141.6	139.3
Percent Change		0.0%	-5.5%	-7.1%

7.3 Life Cycle Phase Recommendations

A scoring system was created for the purpose of prioritizing environmental burden reduction efforts for the seven life cycle phases of the current PDS. Each phase and segment was evaluated based on the percentage of total life cycle burdens associated with the phase. Five environmental burden categories were considered: Energy, Solid Waste, Air Emissions, Emissions to Water and Water Use. If the environmental burden exceeded 5% but was less than 25% of the total for each burden category, the phase was given one check mark. If the environmental burden was 25% or more, the phase was given two check marks. A score was then calculated by totaling the number of check marks per phase. The highest possible score was 10, representing the largest environmental burdens. Table 7-2 shows the results of this analysis. The sections following the table contain recommendations targeted after the phases with the highest environmental burdens. They are presented in order of significance.

Table 7-2: Life Cycle Phase Scorecard for Current Composite PDS

Life Cycle Phases	Energy	Solid Waste	Air Emissions	Emissions to Water	Water Use	Score (Out of 10)
Material Production	✓✓	✓	✓✓	✓	✓	**7**
Distribution 1						**0**
Material Transport						**0**
Prim. Pkg. Transport						**0**
Manufacturing	✓	✓	✓		✓	**4**
Distribution 2				✓	✓	**2**
Prim. Pkg. Transport						**0**
Sec. Pkg. Production						**0**
Sec. Pkg. Transport						**0**
Filling						**0**
Distribution 3	✓✓	✓	✓✓	✓✓	✓✓	**9**
Product Transport	✓	✓	✓✓	✓✓		**6**
Prim. Pkg. Transport						**0**
Sec. Pkg. Production	✓	✓	✓	✓✓		**5**
Sec. Pkg. Transport						**0**
End-of-life		✓✓	✓			**3**

Key:
✓ = Environmental burden is greater than or equal to 5% and less than 25% of total.
✓✓ = Environmental burden is greater than or equal to 25% of total.

7.3.1 Distribution 3

The scoring methodology shown in Table 7-2 identifies Distribution 3 as the phase with the highest environmental burdens. This phase accounts for 34% of the life cycle energy, 25% of the solid waste, 41% of the air emissions and 80% of the emissions to water. The energy consumed to produce the secondary packaging materials (19%) and the energy consumed to transport the yogurt (14%) exceed the energy required to manufacture the primary packaging (13%). For these reasons, it is recommended that the production of secondary packaging and transport of the yogurt be the foci of further study.

7.3.1.1 Production of Distribution 3 Secondary Packaging

Most of the burdens for the production of the secondary packaging were associated with the production of the corrugated boxes used to ship the yogurt. In fact, corrugated accounts for 43% of the life cycle mass of the PDS and 24.2 kg of corrugated are used for each functional unit (1000 lbs.) of yogurt delivered to market.

Although corrugated represents nearly one-half of the mass used in the PDS, it is necessary to understand the relationship between the primary and secondary packaging prior to attempting to reduce the quantity used. The primary and secondary packaging must be viewed as a system since combined, they provide the structural integrity required when stacking cases of yogurt for distribution. This system of cups and corrugated boxes is designed to carry a specific top load. If the corrugated box top load rating is reduced due to light-weighting, the load must be transferred to the cups. This transfer of load to the cups would require the cups to be more rigid and therefore potentially add weight to the cups. The shift in mass from corrugated to plastic could result in a more energy intensive PDS since the material production and manufacturing of plastic cups is more than twice as energy intensive as the material production and manufacturing of corrugated boxes.

On the other hand, efforts to reduce the weight of the primary packaging may result in poorer top load performance and therefore require the use of heavier corrugated boxes to support the additional top load. The relationships between mass, structural integrity and environmental burdens of both the primary and secondary packaging must be understood before the PDS can be optimized.

Efforts to reduce the secondary packaging used in Distribution 3 should include a study evaluating the life cycle environmental impacts of the entire PDS. With this in mind, additional research is required in the following areas:

- Optimization of the corrugated mass to primary packaging mass ratio with respect to environmental burdens, cost and performance.
- Changes to the material composition and shape configuration of both the primary and secondary packaging to achieve an optimized system with respect to environmental burdens.
- Use of reusable shipping containers to reduce top loading performance requirements of both primary and secondary packaging.

7.3.1.2 Product Transport

The transportation of yogurt from Stonyfield Farm to their distributors and retailers accounts for 14% of the life cycle energy and a disproportionate 29% of air emissions. These figures exclude the burdens associated with transporting the primary or secondary packaging. This study limited the scope to include only the burdens of transporting to the first destination. In most cases, the yogurt will be transported additional distances from the distributors' warehouses to the retail stores and then from the retail stores to the consumer homes.

Transportation distances, mode of transport and transport efficiencies are the major factors affecting the environmental burdens. Stonyfield Farm currently distributes all refrigerated products from its New Hampshire facility. The transportation mode is refrigerated diesel trucks and the average distance is 552 miles.[72]

This study has identified the following areas for further research:

- Reduction in average distance to the first destination with the strategic location of an additional facility or facilities.
- Use of more energy efficient modes of transport such as rail and alternate fuel trucks.
- Increases in efficiency of the current mode of transport through improvements in driver performance, aerodynamics, rolling resistance, drive train components and emissions control devices.

7.3.2 Material Production

The second most significant phase is Material Production, which accounts for 53% of the life cycle energy use, 39% of air emissions and 59% of water use. The composition and mass of the primary packaging are the major factors affecting material production burdens. The source of fuel energy used in the material production phase also has a significant effect on environmental burdens.

The primary packaging consists primarily of plastics, which are relatively energy intensive materials with high feedstock energy as well as high material production requirements.

The use of a paperboard wrap in lieu of LLDPE lids for the 4 oz. PDS results in reduced energy intensity as well as lower air and emissions to water as compared to the 6 oz. PDS size. This trend was also observed in the 2 oz. PDS where paperboard was the major component of the primary packaging. While the use of paperboard does not necessarily reduce the mass of the PDS, it does reduce energy consumption since the energy used during material production and manufacturing is less than that of LLDPE and other plastics. It should be noted that there is a trade-off because paperboard results in a greater amount solid waste and more emissions to water.

- Substitution of unbleached paperboard or other renewable materials for plastic material results in reductions in certain environmental burdens. Selection of a primary packaging material based on environmental performance would depend on the weighting assigned to the environmental data and impact categories.

- Materials derived from renewable resources may offer opportunities to reduce the amount of non-renewable inputs to the PDS. Polymers derived from corn and soybeans may be environmentally preferable substitutes for the conventional petroleum-based plastics used in the containers, seals and films, depending on the weighting assigned to the environmental data and impact categories.
- The environmental burdens associated with material production can be significantly reduced by choosing materials that are produced using clean and/or renewable fuel energy sources.

7.3.3 Manufacturing

Manufacturing accounts for 31% of the life cycle solid waste and 13% of the energy consumed. Environmental burdens of manufacturing are directly correlated to the mass of the products produced and therefore any reductions in the mass of the primary packaging would result in proportionate reductions in manufacturing burdens. Reduction in environmental burdens at the Manufacturing phase could be achieved in the following ways:

- Improve the accuracy and repeatability of the molding processes to achieve more consistent part weights.
- Improve efficiency of the manufacturing processes by upgrading to newer technologies.

7.3.4 Yogurt Consumption

When yogurt is kept in an energy efficient household refrigerator for six days, the energy consumed by refrigeration is approximately 10% of the total energy consumption of all other life cycle phases. When an older, less energy efficient refrigerator is used for the same task, it consumes closer to 15% of the total life cycle energy over the same time period. When heating water for dishwashing bowls and spoons is taken into account, the percentage of energy required during the Yogurt Consumption phase rises to 17% or more of the energy consumption of all other life cycle phases. Water consumption for dishwashing is also the single largest contributor to life cycle water use (although water used at Stonyfield Farm during Filling was not considered). Due to these findings, consideration should be given to the following recommendations:

- Educating yogurt consumers regarding the impacts of refrigeration of yogurt containers and the washing of utensils on the environment and the importance of energy efficient appliances in the home. Additionally, the message for the public could contain economic information about the cost savings associated with lower energy consumption.
- Researching and developing products that do not require refrigeration or as much washing. In many countries, milk is sold in aseptic packaging that does not require refrigeration. It is possible that packaging could be designed for yogurt that would also eliminate the need for refrigeration.

7.3.5 End-of-Life

Although consumers indicate that they are concerned with the solid waste generated at the End-of-Life phase, the results of this study indicate that reducing the environmental burdens at the End-of-Life phase should not receive top priority in efforts to reduce total life cycle burdens. The End-of-Life phase accounts for 28% of the life cycle solid waste and 5% of life cycle air emissions. Environmental burdens in the other three categories are negligible.

Solid waste can be reduced through the reduction of mass of the primary packaging, increasing the recycling rate or increasing the incineration rate. Reduction of the mass of the primary packaging would have the most significant life cycle effects since this would also reduce environmental burdens in the other phases as well.

Areas for further research include:

- Comparing the value of energy generated from the incineration of waste primary materials with the potential value of recycled material.
- Comparing the environmental burdens associated with energy generated from the incineration of waste materials with the burdens associated with the processing of the materials for recycling.
- Evaluating the effect that pigments and inks have on the recycled primary packaging materials.
- Solid waste burden at the end-of-life phase could be minimized with a compostable primary packaging material. Therefore, as municipal composting facilities are established, biodegradable materials should be investigated to replace the petroleum-based plastics currently used.

7.3.6 Other Phases

The remaining phases and segments have little opportunity for reducing the environmental impact of the PDS since they represent a small percentage of the overall burdens. The phases and segments with negligible environmental burdens include:

- Distribution 1 transport of materials and secondary packaging to manufacturing.
- Distribution 2 transport of primary and secondary packaging to Stonyfield Farm.
- Distribution 3 transport of primary and secondary packaging to distributors and retailers.
- Filling of the containers. (Much of the yogurt filling process was outside of the boundaries of this study.)

7.4 Material Composition:

7.4.1 HDPE vs. PP

This study concludes that in comparing the environmental burdens of a PDS utilizing HDPE cups to the current PDS, which uses PP cups, the PP PDS results in lower environmental burdens. Using the assumption that the HDPE cup would have 105% of the wall thickness of the existing PP cup, a composite HDPE PDS would be 5% more energy intensive than the current system. Nearly all other environmental burdens are also higher for the HDPE PDS.

Currently, neither HDPE nor PP wide mouth containers are widely recycled. However, even if HDPE cups were recycled by consumers at a rate of 31.3%, the current rate of blow molded HDPE milk bottles,[73] an HDPE PDS would produce 8.2% less life cycle solid waste than a non-recyclable PP PDS. This reduction in solid waste would come at the cost of increasing energy consumption by 5.4% due partly to the reduction of material sent for incineration. See Table 7-3 for energy, solid waste and recycled material comparison of the PDSs discussed in this paragraph.

Table 7-3: HDPE Recycling Scenarios

Component/Category	units	Current PDS	HDPE IM PDS	HDPE IM PDS
Variation				
Recycle Rate		0%	0%	31.3%
End-of-life				
Energy	MJ	-157.15	-168.68	-132.48
Percent Change		N/A	+7.3%	-15.7%
Solid Waste	kg	19.07	20.29	16.46
Percent Change		N/A	+6.4%	-13.7%
Recycled Material	g	0.91	0.91	6.40
Percent Change		N/A	0.0%	+602.3%
Life Cycle				
Energy	MJ	3713	3878	3914
Percent Change		N/A	+4.4%	+5.4%
Solid Waste	kg	29.56	30.98	27.15
Percent Change		N/A	+4.8%	-8.2%
Recycled Material	kg	26.7	26.8	32.3
Percent Change		N/A	+0.2%	+20.8%

The pricing for PP and HDPE resin was considered to be proprietary. However, since the density of HDPE is 5.8% higher than PP it is expected that prices per functional unit are comparable or that PP has the advantage. HDPE does have some performance advantages, such as better low-temperature characteristics, however, the benefit of these characteristics in yogurt containers is questionable.

7.4.2 Alternative Materials

In addition to HDPE, this study included life cycle assessments of PDSs utilizing coated unbleached paperboard and PLA cups. The coated paperboard PDS was modeled using both LDPE and PLA coatings. The PLA PDS was modeled using both LLDPE and PLA lids. In several data categories, these alternative materials performed better than the injection molded PP PDS. This was particularly noticeable in the energy use figures where the coated paperboard PDSs outperformed all other materials (6 and 8 oz. sizes). The PLA/LLDPE PDS also had lower life cycle energy use than the current PDS although it did have higher life cycle energy than the thermoformed PP PDS. The PLA and paperboard PDSs consumed less non-renewable energy than any of the petroleum-based PDSs. However, since the non-renewable energy consumed in the PLA and paperboard PDSs was almost entirely fuel energy, many of the energy related emissions were higher than the current PDS.

Paperboard is clearly a winner with respect to energy usage, benefiting from both low cup weight and the low energy intensity of paperboard. Even if the 8 oz. paperboard cup were to weigh as much as the current PP cup, the life cycle energy of the paperboard PDS would still be 4.6% less than that of the current PDS. In addition, 36% of the energy was from renewable resources while only 18% of the energy consumed in the current PDS was from renewable resources. Evaluation of PLA is more difficult. While PLA had a higher renewable energy percentage than the PP PDSs, it also had higher total energy usage than the thermoformed PP PDS.

The total quantity of air emissions is often thought to be correlated to the total energy consumption. Also, GWP is generally thought to be lower for higher ratios of renewable to non-renewable energy. With this in mind, the values for total air emissions and GWP for paperboard and PLA were somewhat surprising. The PLA PDS air emissions were substantially higher than the PP PDS in almost every category. The paperboard PDS also had higher GWP and ODP values. This was due in part to the fact that for PLA and paperboard, nearly all of the non-renewable energy was consumed as fuel. A significant portion of the non-renewable energy consumed in the PP PDS was feedstock energy.

While energy use was closely correlated to the mass of the packaging, solid waste was not. PLA had significantly higher solid waste despite having low cup weights. High levels of solid waste generated during Material Production account for this difference. Approximately 25% of the life cycle solid waste was slag and ash attributed to electricity use in the polymerization process. Since PLA is not currently being produced commercially, the accuracy of the LCA data with respect to burdens such as solid waste and water usage is a concern. It is recommended that the results in this report be considered preliminary and that the evaluation of PLA be repeated when Cargill Dow releases LCA data on PLA produced at the Blair, Nebraska facility.

Since PLA is not currently being produced commercially, the accuracy of the LCA data with respect to the energy sources and burdens such as solid waste and water usage is a concern. It was assumed that the majority of energy used during PLA production was electricity from the U.S. grid. Due to the significant amount of fuel energy required to produce PLA (52.5 MJ/kg), the source of energy will greatly affect the actual environmental impacts of PLA production. It is recommended that the results in this report be considered preliminary and that the evaluation of PLA be repeated when Cargill Dow releases LCA data on PLA produced at the Blair, Nebraska facility. CDP has the opportunity to reduce the material production fuel energy burdens significantly below the values used in this study through the choice of efficient, clean, renewable energy sources. The result would be that the PLA PDS would be a much more viable alternative.

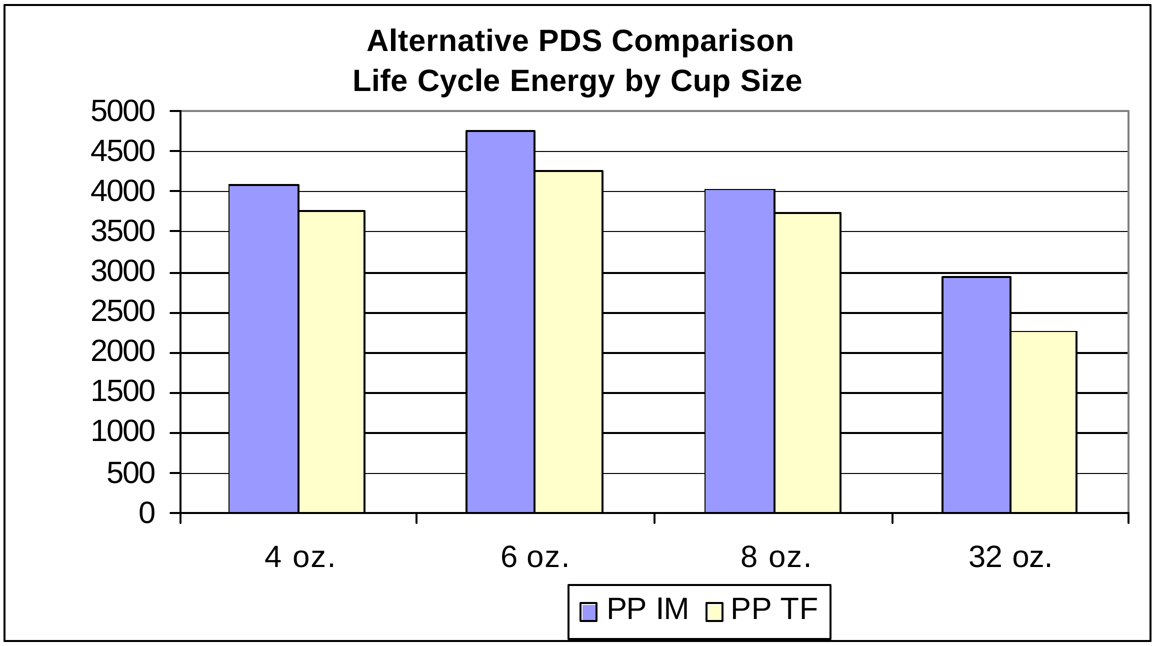
While a recommendation of a specific cup material is beyond the scope of this study, the analysis of alternative materials did support the recommendation that reduction of the packaging mass should be a priority when selecting materials and manufacturing processes. The importance of this can be illustrated by comparing the energy use of the PLA/LLDPE PDS with the PLA/PLA PDS. For the 8oz. container size, switching from the current PDS to the PLA/LLDPE PDS would reduce energy use by almost 2%. This reduction in energy use can be attributed to the 2% lower cup weight for the thermoformed PLA cups. This reduction in cup weight was assumed based on the fact that a thinner cup wall thickness can be achieved with thermoformed PLA than with injection molded PP. On the other hand, switching from the current PDS to the PLA/PLA PDS would increase energy use by nearly 4%. The reason for this difference is the increased weight of the PLA lid (4.7g) versus the LLDPE lid (3.9g). This increase in lid weight was assumed based on the higher specific gravity of PLA (1.25) versus LLDPE (.93). This example shows that, since PP and PLA have similar energy intensities, the PDS with the lowest energy related burdens will be the one that uses the material/manufacturing process combination resulting in the lowest packaging weight.

The Comparison by Container Size section reveals that the choice of cup material may vary by container size. For instance, if the choice of material were based on total energy usage, the thermoformed PP cups would be best for the 4 and 32 oz. sizes. The PLA coated paperboard would be best for the 6 and 8 oz. sizes. Performance and structural integrity with a given material could also vary by container size. For these reasons, it is recommended that the composition of the cups be evaluated individually for each size container. Optimization of each size PDS will result in the optimization of the composite PDS.

7.5 Manufacturing Processes

The thermoforming process appears to have significantly lower environmental burdens than the injection molding process for the manufacturing of yogurt cups. Lower energy consumption burdens can be seen in the Material Production and Manufacturing phases due to the reduced weight of thermoformed cups. The manufacturing process also appears to require less energy per mass than injection molding. The 32 oz. thermoformed cup currently produced by Polytainers is 31% lighter than the injection molded cup used by Stonyfield. Significant reductions are seen in the 6 oz. (23%) and 8 oz. (13%) sizes as well. Polytainers does not currently produce a 4 oz. thermoformed cup, however, based on the above trend, it is expected that using the thermoforming process would result in weight reductions in the 4 oz. cup as well. Figure 7-2 shows the resulting reductions in life cycle energy consumption by container size.

Figure 7-2: Injection Molding vs. Thermoforming Life Cycle Energy



As was shown in the Results and Interpretation section, the thermoforming process outperformed injection molding in all environmental burden categories. However, there are other factors that influence the choice of manufacturing process including economic feasibility, part quality and product performance. Table 7-4 evaluates thermoforming versus injection molding on various criteria. Although cup manufacturing costs could not be obtained for this study, the reductions in both material costs and energy consumption associated with the thermoforming process would be expected to correlate with a cost advantage over injection molding. Polytainers confirmed that this would be true for volumes over 100 million parts per year.

Table 7-4: Thermoforming vs. Injection Molding Comparison

	Thermoforming	Injection Molding
Cost		
Material Cost	Higher[1]	Lower
Material Consumption	More[2]	Less
Machinery Cost	Lower	Higher
Mold Cost	Lower[3]	Higher
Trimming Equipment Cost	Higher	Negligible
Overall cost	Lower[4]	Higher
Wall Characteristics		
Minimum Thickness	Approximately 0.002 in. (0.05 mm)	Approximately 0.04 in. (1 mm)
Uniformity	Difficult to control	Very uniform
Rigidity	Special techniques required for larger pieces	Excellent
Performance		
Compression Test Performance	Lower	Higher
Drop Impact Test Performance	Lower	Higher
Finish		
Gloss	Generally not very good	Excellent
Detail	Not very sharp	Excellent
Pre-decorating	Most pre-decorated finishes can easily be thermoformed	Pre-decorated finishes cannot be injection molded
Production Flexibility	Very high	Low
Setup Time	Very short	Up to 4 times as long as in thermoforming

Source: USI and Polytainers

Notes:

1. The cost of sheet is more than resin however, in-line sheet extrusion/thermoforming systems, such as those used by Polytainers use resin as the input material and therefore resin prices would be comparable.
2. Thermoforming processes produce up to 50% waste however this waste is typically reclaimed using an in-line, closed loop reprocessing system such as the system Polytainers uses.
3. Thermoforming molds can cost 1/10 of injection molding molds.
4. For yogurt cup volumes greater than 100 million per year.

The part quality of thermoformed cups would be expected to be inferior to the injection molded cups. In particular, the surface finish gloss and detail would be of a lower quality. Product performance of the thermoformed cups would also be inferior. Injection molded cups have superior characteristics with respect to Compression Tests and Drop Impact Tests.[74] Injection molded cups also have much higher top load performance due to better control over distribution of the plastic throughout the cup.

On the other hand, thermoformers of thin-walled PP yogurt, dairy product and other food containers have gained market share from injection molders due to improvements in their abilities to reduce wall thickness and ensure good top-load strength.[75] This trend would indicate that thermoforming may have an economic advantage as well as having achieved technology advances enabling the production of containers that meet yogurt packaging criteria.

In light of the lower environmental burdens associated with thermoforming, the degree to which the characteristics of thermoformed cups affect the feasibility, functionality and appearance of the PDS warrant further investigation.

8. CONCLUSION

This research evaluated Stonyfield Farm's current PDS and four alternative PDSs, and it generated recommendations for improvements to the current system. The Life Cycle Analysis also revealed important characteristics of the PDS that must be taken into account in any further efforts to improve the environmental performance of Stonyfield's yogurt PDS.

8.1 Current PDS

The results indicated that environmental burdens are inversely related to container size when the packaging configuration consists of a cup, seal, and lid. Therefore, the 32 oz. yogurt cups proved to be the best choice in every category among the 6 oz., 8 oz. and 32 oz. containers. The 2 oz. tubes and 4 oz. containers did not always fit the same "bigger is better" pattern. In particular, the multi-packs outperformed the 6 oz. in life cycle energy requirements, renewable energy, emissions to air, and maximum allowable concentration of air pollutants. However, the solid waste produced, water used, and ODP from the 2 oz. tube PDS and 4 oz. container PDS were by far the highest.

8.2 Alternative PDS

Of the alternatives evaluated in this study, no single material stands out as a superior primary packaging material for all container sizes in all burden categories. PP, PLA and coated unbleached paperboard were shown to be preferable over HDPE for a cup material, and thermoformed cups had lower burdens compared to injection molded cups. Also, PLA containers with PLA lids performed poorly overall. As a whole, the PDS that utilized thermoformed PP cups turned out to be a favorable alternative, as did the coated paperboard PDS.

On a more detailed level, each of the materials and configurations demonstrated strengths in some categories and weaknesses in others. For example, coated paperboard tended to have high solid waste burdens and water use but lower non-renewable energy input and total energy requirements. The comparison of all alternatives reveals that the preferred cup material may vary by container size and by Stonyfield Farm's priorities (relative importance of environmental impacts). Selecting the optimal PDS for each container size will result in the optimization of the composite PDS.

8.3 Recommendation

Interpretation of the results identified the segments of the PDS responsible for the largest environmental burdens and recommended these segments as areas for additional research. These segments are: distribution from Stonyfield Farm to distributors and retailers (Distribution 3), material production of the primary packaging and manufacturing of the yogurt containers.

8.4 Compass for Further Improvement

The systematic life cycle analysis revealed complex interrelatedness among the components of Stonyfield yogurt PDS. For example, the light-weighting of corrugated boxes could result in increased environmental burdens since this might result in the need to increase the weight of the energy intensive primary packaging to compensate for a decrease in the structural performance of the boxes. Another example of the complexity of the system is that an increase in the recycling rate of the plastic containers might increase the burdens since energy produced during the combustion of plastic waste at energy recovery plants offsets burdens. Therefore, it is imprudent to focus on one segment of the system in efforts to reduce specific environmental burdens. The LCA approach, which takes into consideration the PDS as a whole, will be a reliable and comprehensive tool in the further study to improve the total environmental performance of Stonyfield Farm's product delivery system.

9. GLOSSARY

Blow Molding – The production of hollow items using a process consisting of the following three stages: melting or plasticizing the resin; forming a parison or preform; and inflating the parison or preform in a blowing mold to produce the end product.

Co-extrusion – The process of producing multi-layered products such as film and sheet using two or more extruders.

Color Concentrate – Pelletized material consisting of pigment and a carrier resin used in plastic processing to add color to natural colored resins.

Conversion – The process of converting an intermediate product, such as sheet, into a final product, such as thermoformed containers.

Copolymer – Modification of the molecular structure of a polymer by the addition of one or more dissimilar monomers.

Cracking – The process of heating ethane gas to approximately 80°C to break it up into hydrogen and ethylene.

Distribution – Packaging systems and transportation networks used to contain, protect, and transport products and process materials.

Extrusion – The process of applying heat and pressure to melt the polymer resin and force it through a die to continuously produce products such as film, sheet, pipe and other profiles.

Feedstock Energy – Heat of combustion of raw material inputs, which are not used as an energy source, to a product system. [76]

System Function – A statement on the specification of the performance characteristics of the system.

Functional Unit – The functional unit, which is to be consistent with the goal and scope of the study, defines the quantification of the identified function. It provides a reference to which the input and output data are normalized.

Injection Molding – The production of plastic products using a process consisting of the following four stages: melting of the polymer into a homogeneous viscous liquid; injecting the molten polymer into a mold; cooling of the polymer; and ejection of the finished product from the mold.

Life Cycle Assessment (LCA) – "Life Cycle Assessment is a process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and materials used and releases to the environment; and to identify and evaluate opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing, extracting and processing raw materials; manufacturing, transportation and distribution; use, re-use, maintenance; recycling, and final disposal." [77]

Polyolefin – A polymer of an alkene (as polyethylene); a resin made by polymerizing olefin

Primary Energy – An energy source occurring in nature, such as coal or solar heat, before it is converted to a usable form.

Process Energy - Energy input required for a unit process to operate the process or equipment within the process excluding energy inputs for production and delivery of this energy. (ISO/FSIS 14041:1998(E))

Renewable Energy – Capable of being replenished quickly enough to meet present or near-term demand. Time and quantity are the critical elements in measures of renewability.

Recycling – The reformation, reprocessing, or in-process reuse of a waste material.

Sheet – Heavy gauge flat-film material that is more than 10 mils thick.

Thermoforming – The process of forming plastic products from polymer sheet. The sheet is heated above its glass transition temperature and drawing the sheet into a mold using either vacuum or pressure. The resulting product has a wall thickness that is less than the thickness of the original sheet.

U-board – Corrugated packaging used as a separator in corrugated box.

Unit Process – Product systems are subdivided into a set of unit processes. Unit processes are linked to one another by flows of intermediate products and/or waste for treatment, to other product systems by product flows, and to the environment by flows such as emissions to air or water.

10. ACRONYM LIST

ATSDR - Agency for Toxic Substances and Disease Registry

CDP – Cargill Dow Polymers

CERCLA - Comprehensive Environmental Response, Compensation, and Liability Act

DEAM - Data for Environmental Analysis and Management

EOL – End-of-Life

FDA – Food and Drug Administration

FU – Functional Unit

HDPE - High Density Polyethylene (0.940 gm/cu cm and higher)

GWP – Global Warming Potential

IM - Injection Molding

IPCC – Intergovernmental Panel on Climate Change

ISO – International Standards Organization

LCA – Life Cycle Assessment

LCI – Life Cycle Inventory

LCIA - Life Cycle Impact Assessment

LDPE - Low Density Polyethylene (0.910-0.925 gm/cu cm)

LLDPE - Linear Low Density Polyethylene (0.910-0.925 gm/cu cm)

MAC – Maximum Allowable Concentration

MJ – Megajoule

MSW – Municipal Solid Waste

ODP – Ozone Depletion Potential

PDS - Product Delivery System

PE - Polyethylene

PET - Polyethylene Terephthalate

PLA - Polylactide

PP - Polypropylene

PS - Polystyrene

PVC - Polyvinyl Chloride

SAEFL – Swiss Agency for the Environment, Forests and Landscape

SPI – Society of the Plastics Industry

SUS - Solid Unbleached Sulfate

TF – Thermoforming

UV – Ultra violet

VOC - Volatile Organic Compound

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APPENDIX A

Survey of Alternative Primary Packaging Materials

SURVEY OF ALTERNATIVE PRIMARY PACKAGING MATERIALS FOR THE STONYFIELD FARM PRODUCT DELIVERY SYSTEM

Prepared for Stonyfield Farm Inc.
Londonderry, New Hampshire

Research conducted by

The Center for Sustainable Systems
University of Michigan
Ann Arbor, Michigan

Dov Brachfeld
Tad Dritz
Shinsuke Kodama
Alan Phipps
Elyse Steiner

Dr. Greg Keoleian, Project Director

March 2001

ABSTRACT

As part of the project to model environmental burdens associated with the current Stonyfield Farm Product Delivery System (PDS) and to recommend strategies for reducing them, this survey examined alternative primary packaging materials that potentially could be used for refrigerated yogurt. Eleven materials, or groups of materials, were found to be reasonable candidates for the survey. Polypropylene, Stonyfield's current primary packaging material, was also included to benchmark the performance of the alternative materials. Each option was evaluated on three axes: Sustainability, Feasibility and Marketability in order to select the two packaging materials best suited for inclusion in the Life Cycle Assessment of the Stonyfield Farm PDS report.

Figure 1: Overall Material Evaluation

Low	Medium	High
•Polyhydroxalkanoate (PHA) •Polyethylene Terephthalate (PET) •Synthetic Biodegradable Polymers •Glass	•Aseptic Packaging •Polypropylene (PP) •Aluminum •Starch-based Biodegradable Polymers •Soy Works •Polystyrene (PS)	•LDPE Coated Paper •PLA Coated Paper •Polylactide (PLA)

A material evaluation integrating the three criteria categories (Sustainability, Feasibility, and Marketability) revealed the ranking diagramed above. Aseptic packaging and PS were above average performers, while non-renewable biodegradable plastics, and PHA demonstrated more moderate performance. Concerns about suitability for yogurt, package design requirements, filling equipment and the use of genetically modified organisms (GMO), however, made them less attractive.

The best candidates for further study were narrowed down to coated paper and PLA. While it does not *require* the use of GMO corn, as is the case with PHA, the greatest obstacle to recommending PLA is the inclusion of GMO corn in its current material composition. If PLA were made with certified GMO-free starch, it would potentially provide the best combination of environmental performance, strength, durability, and appearance.

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1. INTRODUCTION

In May 2000, Stonyfield Farm engaged the Center for Sustainable Systems at the University of Michigan to complete a Life Cycle Assessment (LCA) study of the current Stonyfield Farm Product Delivery System (PDS). The project also included an LCA study of the PDS using an alternative primary packaging manufacturing process (thermoforming versus injection molding of plastic containers), and three alternative container primary packaging materials. HDPE was selected as one of the three alternative materials at the outset of the project. The other two materials were to be selected for their superior environmental performance and food storage properties from a survey of alternative primary packaging materials that potentially could be used for refrigerated yogurt.

This document is the survey of alternative primary packaging materials. From the findings contained in the Material Information section of this document, the materials will be evaluated on three axes: Sustainability, Feasibility and Marketability. Sustainability captures environmental performance, such as lower life cycle energy demand and use of renewable resources. Feasibility considers economic and material performance factors including the need for Stonyfield Farm to modify or replace filling equipment. Lastly, Marketability attempts to evaluate consumer's response to a change in packaging material and Stonyfield Farm's ability to advertise their brand and customer education messages. Polypropylene (PP) was also included in the Material Evaluation section to benchmark the performance of the alternative materials.

Eleven materials, or groups of materials, were found by the team to be reasonable candidates for the survey. Analysis of each material using the methodology described above is used to select the two most appealing packaging materials. As noted, the selected materials will be analyzed and modeled to quantify the life cycle environmental burdens associated with a PDS using them in a report titled Life Cycle Assessment of the Stonyfield Farm Product Delivery System.

2. MATERIAL SELECTION

To conduct this survey, the candidate materials were selected from those currently available and other emerging alternatives, including biodegradable polymers.

The materials were selected with a primary focus on environmental performance. For the purposes of this survey, secondary packaging, transportation, and distribution were not considered. The environmental characteristics considered were:

1. Energy Consumption – focus on primary packaging energy requirement, but also a consideration of life cycle energy consequences.
2. Raw Material Sourcing – concentration on source reduction and the use of renewable resources.
3. End-of-Life Considerations – includes recyclability, compostability and other aspects that would minimize end-of-life and life cycle solid waste.
4. Other – captures all other environmental considerations, such as use of genetically modified organisms (GMOs).

With the above criteria in mind, other factors including economic feasibility, overall material performance and marketing potential were also taken into consideration. From the materials currently being used for food packaging, the following were selected. Included with each material is a brief justification for its selections.

1. Unbleached Coated Paper – made primarily from renewable resources, unbleached alternative eliminates release of dioxins during production
2. Aseptic Packaging – significant renewable material content.
3. Aluminum - high recyclability may reduce end-of-life solid waste burden.
4. Glass – high recyclability may reduce end-of-life solid waste, made from a very abundant resource.
5. Polyethylene Terephthalate (PET) - higher potential for recyclability and potential to reduce primary packaging weight.
6. Polystyrene (PS) – potential to decrease primary packaging weight.

Also evaluated in this report are natural resins and biodegradable polymers. Natural resins offer opportunities to drastically reduce the non-renewable inputs to the primary packaging. Biodegradable polymers offer the potential to significantly reduce the life cycle solid waste burdens through composting instead of landfilling at the end-of-life. These materials were evaluated in four (4) groupings with the three most promising materials (PLA, PHA and Soy Works) given their own section. Included with each material is a brief description and reason for selection.

1. Polylactide (PLA) – widely heralded as the most promising bioplastic, PLA is derived from renewable resources, compostable and recyclable.
2. Polyhydroxalkanoate (PHA) – describes a family of naturally occurring polymers that are synthesized through fermentation. They are derived from renewable materials.

3. Soy Works – in the early stages of development, as the name suggests, Soy Works is derived from soybeans.
4. Synthetic Biodegradable Polymers – although based on non-renewable resources, these materials are formulated to biodegrade at standard conditions. These include DuPont's Biomax™, BASF's Ecoflex® and Eastman's Eastar Bio COPE.
5. Starch-based Biodegradable Polymers – biodegradable polymers which are made by combining natural starch and synthetic biodegradable plastics. These materials, which include Novamont's Mater-Bi™, are partially renewably based and can also minimize solid waste at the end-of-life.

3. MATERIAL INFORMATION

This section of the survey contains an analysis of each material or family of materials for each of the following categories: Background, Environmental Performance, Consumer Perception, and Economic Considerations.

The materials are categorized according to their composition as follows:

- Conventional Paper-based Materials
- Mineral-based Materials
- Petroleum-based Materials
- Natural Resins and Biodegradable Plastics

3.1 Conventional Paper-Based Materials

3.1.1 Coated Paper

3.1.1.1 Background

The use of kraft paper coated with low-density polyethylene (LDPE) is quite common as a packaging for prepared foods. Poly-coated paperboard is used for milk, ice cream, juice, frozen TV dinners, and many other frozen and refrigerated food containers. It can be made into many different shapes and sizes and comes in a variety of grades and weights.

Prior to the 1980s, wax-coated paperboard containers were the standard for yogurt. However, falling prices and improved properties of high-density polyethylene (HDPE) and other plastics prompted many producers of refrigerated dairy products to switch to lighter weight plastic packaging materials. Manufactures of a new generation of coated paperboard are attempting to regain market share by offering an unbleached alternative that would eliminate the release of dioxins during material production.

In the course of this research, no yogurt was found packaged in unbleached poly-coated paper containers in the United States. However, unbleached paper containers coated with LDPE have been found suitable for frozen yogurt and ice cream, as evidenced by their adoption by Ben & Jerry's and Stonyfield Farm.

3.1.1.2 Physical Attributes

For this report, coated paperboard containers were assumed to include both the cups and lids. They were also assumed to have roughly the same dimensions and shape as the currently used PP cups. However, this is not necessarily the case since modern paper container processes can produce oblong and rectangular shapes that could improve the packing density of containers.[1] A hybrid container with a paper cup and plastic lid is also a possibility.

According to Sealright, the manufacturer of paper containers for Stonyfield Farm's frozen products, paper containers (cup and lids) outweigh their PP counterparts by over 50% for the 8 oz. container size. It should be noted that Sealright does not currently manufacture paper containers for refrigerated yogurt. Specs from a Japanese manufacturer of paper yogurt containers indicate that paper yogurt containers can be produced that are significantly lighter than Stonyfield's PP yogurt containers.

With a few exceptions, the other properties of paperboard play favorably with Stonyfield Farm's requirements. Paper can withstand both the hot and cold temperature extremes required in setting the yogurt and refrigerating the finished product. Paper containers provide UV protection and they can be made with resealable lids, although the seal attained by a paper lid may not be equivalent to that of a plastic lid since paper has the tendency to be deformed with use.

The only physical attribute that is a concern is the structural integrity. This is especially worrisome in the larger sizes. With frozen foods, such as ice cream, the product can bear some of the top loading weight and structurally support the walls of the container. This is not the case for refrigerated products that depend more on the structural integrity of the packaging. Heavier walls would likely solve this problem, but would negatively impact the PDS's environmental burdens. Also, paper is more susceptible to puncture than plastics.

Another possible configuration for paperboard containers would be to use a paper-based heat sealed, peelable lid like the one made by Stora Enso, a global forestry company based in Finland instead of a kraft paperboard lid. The "Ensolid" is reported to be effective for dairy applications such as yogurt cups and ice cream containers. It provides a barrier against oxygen, water vapors, and odor, and has good burst resistance and excellent printing capabilities.[2] The "Ensolid" would not be a good choice for larger multi-serving containers that need resealing capabilities.

3.1.1.3 Environmental Performance

3.1.1.3.1 Energy Use

A positive aspect of paperboard is the relatively low energy required to produce the material (57.4 MJ/kg) compared to PP (74.9 MJ/kg). However, the paperboard does require a coating of LDPE to create a suitable material for packaging food. LDPE makes up approximately 7% of the coated paperboard, and its material production energy (81.9 MJ/kg) is higher than that of PP. Overall, the material production energy of coated paper is 59.1 MJ/kg.

Another plus for paperboard is the amount of feedstock and process energy sourced from renewable resources. More than 65% (37.6 MJ/kg) of the material production energy is renewable compared to approximately 1% (0.81 MJ/kg) for PP.

3.1.1.3.2 Raw Material Sourcing

As required by FDA regulations, materials that come into contact with food must not contain recycled content. Therefore, the primary source of material for coated paperboard containers is pulp made from virgin cut timber. Despite this regulatory reality, paper and other forest products are based on a renewable resource. So for material sourcing, coated paperboard packaging is a more sustainable option than petroleum-based plastics.

3.1.1.3.3 End of Life Considerations

The LDPE coating on the paperboard puts the containers into a category of packaging that is not recycled in most communities. "Plastic coated paperboard is not designed so the end user can separate the plastic coating from the paperboard, making the material unacceptable in most recycling programs."[3] Thus, this area of customer concern is not likely to be satisfied by kraft paper containers at this time.

However, the development of new hydropulping facilities and technologies are making it possible to separate and reclaim polyethylene from paperboard in the future. One such example is Extraction Technologies in Brunswick Virginia. The company uses hydropulping to reclaim polyethylene and paper fiber from poly-coated paperboard.[4]

Another option that may be available in the near future is to replace LDPE in the coating with a biodegradable plastic, like one of the materials described in Section 3.4. With a biodegradable plastic coating, paperboard containers would be candidates for composting, which could substantially reduce the solid waste burden of the PDS. However, municipal composting opportunities for materials other than yard trimmings are relatively scarce.

3.1.1.3.4 Other

Most of the paper currently produced is bleached using chlorine compounds, which react with dioxin precursors in wood pulp to form dioxin. Dioxins are known carcinogens and are linked to a variety of other human health problems including severe reproductive and developmental problems and serious skin conditions.[5]

Paper mills have made significant reductions in dioxin emissions in the past two decades. These reductions have typically been achieved by switching from an Elemental Chlorine (EC) process, which utilizes chlorine gas, to an Elemental Chlorine-Free (ECF) process that uses chlorine-dioxide and other chlorine derivatives. While the ECF technology significantly reduces dioxin emissions, it does not eliminate them. This is a concern since even small quantities of dioxin can cause health problems. A third bleaching process, Totally Chlorine-Free (TCF), does not release dioxins and is being adopted by paper mills, particularly in Europe.[6]

In 1999, Ben & Jerry's, the New England ice cream and frozen yogurt manufacturer, found a source of chlorine-free, unbleached paper containers safe for packaging food and began using the "Eco-Pint" for its top-selling flavor, World's Best Vanilla.[7] This packaging appears to have eliminated the human health risks previously associated with bleached paperboard packaging and is now more widely available to other food manufacturers.

3.1.1.4 Consumer Perception

3.1.1.4.1 Marketing Potential

Color graphics and food labeling information are printed directly on the paper. It is assumed that this technology has the same flexibility of the technology currently used that allows the design to be changed with a small incremental investment. So Stonyfield would be able to continue to advertise environmental causes on the container lids.

Focus group testing conducted on behalf of Ben & Jerry's showed no consumer resistance to the brown interior of unbleached containers. While the brown interior differs from the white of the more common bleached container, the clay-coated and printed exterior looks the same.[8]

Generally, it is assumed that Stonyfield Farm consumers would find paperboard containers to be appealing because of the renewability of the feedstock and the potential for recycling or composting. They may also favor the "natural" aspect of paper versus the man-made plastics.

3.1.1.4.2 Perception of Quality

Paper containers will be more susceptible to dents and deformation. The sight of damaged yogurt cups could leave the consumers with the perception of lower quality when compared to plastic cups.

3.1.1.5 Economic Considerations

Pricing information for unbleached paperboard containers is considered proprietary by Sealright. Ben & Jerry's Manager of Natural Resources, stated that the unbleached material costs more than bleached kraft paper, largely because it is not available in the volumes that bleached board is.[9]

Another economic consideration is the need to modify or replace Stonyfield Farm current filling, casing and palletizing equipment. According to Sealright, the dimensions of paper containers are roughly equivalent to that of PP containers. It is possible that the existing machinery could continue to be used, but equipment requirements have yet to be determined.

3.1.2 Aseptic Containers

3.1.2.1 Background

Aseptic containers are cartons generally used in aseptic packaging systems to hold food and beverage products in a shelf-stable form that requires no refrigeration. The most common usage for aseptic containers has been for aseptically packaged juice and milk. Aseptic containers are also currently in use for such food items as diced tomatoes, and stews with chunks of vegetables and meat, demonstrating that the packaging is suitable for a variety of both beverage and food consistencies.

There are two major U.S. manufacturers of aseptic containers – Tetra Pak Inc. of Vernon Hills, Illinois and SIG Combibloc Inc. of Columbus, Ohio.

This survey includes aseptic containers as a potential PDS primary packaging material choice but does not assume that Stonyfield would adopt an aseptic packaging system. An aseptic packaging system would include elimination of bacteria in the packaged product and therefore could run counter to Stonyfield's yogurt processing requirements.

3.1.2.2 Physical Attributes

Aseptic containers are made of six flexible, folded layers of (in order) LDPE, paper, LDPE, aluminum foil, LDPE, and LDPE. In total plastic makes up 24%, aluminum (6%), and paperboard (70%).[10] The aluminum is completely covered by two layers of food-grade polyethylene, so the food product and the aluminum never come in contact. The multi-layer structure provides barrier protection from oxygen, bacteria and UV light exposure. The flexibility of the carton enhances its puncture and burst resistance under normal handling conditions. However, more rigid packaging materials such as plastic, glass or aluminum of sufficient thickness will exhibit greater structural top-loading strength. The most common rectangular (brick) shaped cartons are stackable when held with stretch-wrap and have a sufficient top-loading strength.

The exact weight of an aseptic container designed for yogurt was unavailable, however, by comparison, the total weight of a one-liter milk package is 28 grams.[11] Aseptic containers' relatively lightweight characteristics can be further illustrated when comparing various types of packages used to deliver product. For example, the 7.5 single-serve aseptic cartons it takes to deliver 64 ounces of liquid create seven times less end-of-life waste (by weight) than one 64-ounce glass bottle (119.8 g vs. 860.6 g).[12]

Plastic openings with airtight sealing capability are available from the two major aseptic container manufacturers for multi-serving applications. Resealable openings applicable for yogurt eaten with a spoon would require plastic openings of sufficient size to be convenient for consumer use, however, according to sales representatives of the two major manufacturers, such openings are not currently fabricated. Their feasibility was questioned, but both companies felt their design teams could investigate the possibility.[13]

3.1.2.3 Environmental Performance

3.1.2.3.1 Energy Use

Prior to filling, aseptic containers are stored flat or on rolls, rather than pre-formed like glass, metal and most plastic containers. As a result, they take up less space during transport. One standard semi-trailer truck can transport 1.5 million empty cartons versus only 150,000 glass bottles.[14] Similarly, once filled, the rectangular shape of common aseptic containers conserve more space than cylindrical packages thus, more product can be shipped in a given truck. These physical characteristics could translate into energy and pollution reductions.

Table 3-2: Material Production Energy of Aseptic Packaging

	Paperboard	LDPE	Aluminum (Primary)[15]	Aluminum (Secondary)	Total
Composition	70%	24%	3.1%	2.9%	100%
Material Production	57.4 MJ/kg	81.9 MJ/kg	240 MJ/kg	10.2 MJ/kg	67.6 MJ/kg

Three LCA studies that included aseptic containers have been conducted in the past ten years.[16] Each found aseptic containers to be a top performer on environmental metrics, however it is questionable how well the results of these studies would carry over to the Stonyfield PDS. As mentioned, yogurt containers may require different configurations (Addition of the modified plastic openings would increase the life cycle energy inputs of the packaging.) as well as need refrigeration if not packaged aseptically.

3.1.2.3.2 Raw Material Sourcing

The paperboard in aseptic containers is a renewable material. Some major brands use paperboard made with recycled content and do not use chlorine bleaching for the paperboard.[17] The remaining 30% of the material by weight, which includes LDPE and aluminum, are from non-renewable resources.

3.1.2.3.3 End of Life Considerations

The aseptic packaging industry has promoted recycling of aseptic containers, unfortunately, the recycling process is only offered in parts of 26 states. According to the Aseptic Packaging Council, over 11.7 million households have the ability to recycle aseptic packaging curbside as of January 1, 2001. The overall rate at which aseptic containers are recycled in America is unknown. Because of their plastic coating and aluminum content, aseptic cartons are neither biodegradable nor compostable.

The recycling process of aseptic containers uses a hydropulper that separates the paper fibers away from the layers of polyethylene and aluminum foil. Mills generally value the paper fiber received from aseptic containers because of its strength, length and brightness. No de-inking is required as the ink is separated off with the plastic. In some cases, the plastic/foil residual can also be recycled into high-end plastic lumber products. In others, the wet residue (containing mostly polyethylene and aluminum foil) that remains after the paper fibers are separated is enriched to about 17% aluminum content by eddy-current and magnetic separation. Then a thermal de-coating process is used to recover the aluminum foil.[18] If higher-quality, post-consumer pulp continues to be a popular and required commodity in the manufacturing of recycled content products the value of paper fibers recovered from aseptic containers will remain high and perhaps grow as more hydropulpers accept aseptic containers.

3.1.2.4 Consumer Perception

3.1.2.4.1 Food Security

Consumer concern over endocrine-mimicking chemicals that have been mentioned in the popular press in connection with breast cancer and male infertility, including bisphenol A (BPA), nonylphenol, and phthalates prompted testing of the LDPE that comes in contact with aseptic container packaged products. According to the Aseptic Packaging Council, tests on LDPE to determine if any plastic was leaching into the products contained in aseptic containers have shown that these chemicals are not present in the LDPE that comes in contact with products. Moreover, there is no leaching of aluminum or aluminum components through the plastic layer.

Some customers may feel less secure about tampering because the sidewalls of the aseptic container are not as rigid as other packaging and the technology is newer. However, tamper-proof devices are available on most aseptic container designs. Moreover, a consumer survey conducted by Tetra-Pak found that consumers pointed to the ease of handling of the aseptic package and the fact that it was shatterproof and tamper-evident as reasons for their preference.[19]

3.1.2.4.1 Marketing Potential

While they used to be almost exclusively in rectangular (brick) form, their design possibilities have evolved to include multiple shapes, sizes and openings. One concern regarding the shapes of aseptic containers is that consumers might find the packaging incommodious when trying to reach yogurt left in the corners of angled containers.

High quality uninterrupted printing is possible on at least the top, front and back panels of the box.

3.1.2.5 Economic Considerations

Even if Stonyfield did not adopt an aseptic packaging system, the use of aseptic containers would almost certainly require modification of its current filling and palletization equipment or even full-scale changeover to new custom designed filling machines.

Exact pricing could not be quoted for an aseptic carton for use with yogurt, but because of the complexity of the packaging, pricing could be a prohibitive factor.

Addition of the modified plastic openings and design inputs would be expected to increase the per unit cost of the packaging.

3.2 Mineral-Based Materials

3.2.1 Aluminum

3.2.2.1 Background

Aluminum containers have a long tradition as beverage and processed food containers. Recent technological advancements allow for containers to be produced using less metal and with lower manufacturing costs while maintaining the same properties as standard aluminum containers. Though aluminum cans are now produced with walls thinner than a plastic alternative, aluminum's specific gravity is more than 2.5 times that of PP; so more material is used on a weight basis.

3.2.2.2 Physical Attributes

Aluminum containers require no special precautions in handling since they are rigid, unbreakable, and they provide a strong barrier to gas, bacteria, and UV light. For yogurt, aluminum containers can be designed with full aperture easy-open ends and plastic closures for resealing of larger sizes. The top-loading strength of aluminum containers is very much dependant on wall thickness and configuration. For example, soda cans have thin walls but their design makes them capable of being stacked many layers on top of each other. Cans are also not restricted by cold or heat resistance.

3.2.2.3 Environmental Performance

3.2.2.3.1 Energy Use

At 240 MJ/kg, virgin aluminum is a highly energy intensive material, and it has a correspondingly high level of pollution associated with its production.[20] Recycled aluminum has significantly reduced energy and environmental burdens associated with its use. It should be noted that even with a high recyclate rate, however, the energy input levels are well above those of the other materials surveyed in this report.[21]

3.2.2.3.2 Raw Material Sourcing

Aluminum is a non-renewable resource. It is the third most abundant element in the earth's crust, however, due to its strong affinity to oxygen, it is not found in the form of a metal. The primary source of aluminum is bauxite, which is typically mined in open pits in tropical or subtropical climates. Australia, Guinea, Jamaica, Brazil, and India are major producers of bauxite.[22]

3.2.2.3.3 End of Life Considerations

The aluminum can is recycled in a closed loop process, which saves 95% of the energy needed to produce aluminum from ore.[23] Moreover, the percentage of aluminum recycled from beverage cans, surpasses all other recyclable packaging materials.[24] The average aluminum can contains more than 51.2% post consumer recycled content.

Aluminum packaging has always accounted for only a very small percentage of generated municipal solid waste (1%). An effective recycling infrastructure exists for the recycling of aluminum beverage cans, which is due in large part to "Bottle Bill" incentives. Currently, 60 percent of aluminum beverage cans are recycled.[25] Aluminum yogurt cans would not be likely to be included in Bottle Bill incentives and therefore the recycle rates would be expected to be similar to the recycle rates of other aluminum food containers (7%).

3.1.2.4 Consumer Perception

3.2.2.4.1 Food Security

A possible link between exposure to aluminum and Alzheimer's disease has been investigated for years. Research has produced conflicting results and the issue remains controversial. But, the perception remains that there may be some connection.

3.2.2.4.2 Marketing Potential

The labeling potential for aluminum is high, but most attributes of metallic packaging would be seen as negatives to Stonyfield Farm's target segment. Despite its recyclability, many consumers would likely see aluminum as an undesirable packaging alternative because it is not currently used for dairy products and it is derived from non-renewable resources.

3.2.2 Glass

3.2.2.1 Background

Glass has a long history as a packaging material. New glass is made from a mixture of sand, soda ash, limestone and other additives. In the case of bottles and jars, up to 80% of the total mixture can be reclaimed scrap glass, called cullet. The variety of glass bottles and jars used in food and beverage packaging ranges widely in volume, weight and shape as result of both marketing considerations and strength requirements. There has been a trend over the past few decades away from glass and towards plastics, for the purpose of light-weighting.[26] Nonetheless, some single-use clear glass yogurt containers are currently in use.

3.2.2.2 Physical Attributes

Glass packaging offers strong structural integrity, odor resistance, a barrier against gases and 100% recyclability. A glass yogurt container can be configured in a variety of ways: for example, sealed with a mason-style lid, foil, or plastic. Food products will not react chemically with a glass container. In addition to being chemically inert, glass provides impermeability such that diffusion or leakage is not possible unless the container is inadequately sealed. In theory, the durability of glass and possibility of high-temperature sterilization opens the prospect of reuse of packaging. However it is expected that both economic and environmental considerations would preclude this option for the Stonyfield PDS.

Glass is one of the heavier materials surveyed, it is breakable, and does not offer protection against UV light unless colored (amber or green). The material's relative weight influences energy use in material production and transportation as well as solid waste generation at end-of-life. The use of colored glass could have negative marketing implications. In addition, colored glass is a somewhat less valued variety of recyclate.

3.2.2.3 Environmental Performance

3.2.2.3.1 Energy Use

Material production of glass is 7.45MJ/kg. Keoleian, Spitzley, and McDaniel compiled results of several life cycle assessments of packaging options, which indicated that 1-liter single-use glass juice containers required higher life cycle energy and generated a greater mass of solid waste than containers made of the other materials surveyed in this report with the exception of aluminum. They also generated the highest level of airborne and waterborne pollutant emissions with the exception of aluminum. The high levels of environmental burdens were primarily a result of the weight of the containers.

3.2.2.3.2 Raw Material Sourcing

Though the raw materials needed to make glass, sand, soda ash and limestone are not renewable resources, the abundance of these ingredients is substantial.

3.2.2.3.3 End of Life Considerations

Glass packaging for yogurt would likely be single-use containers, however, glass can be recycled indefinitely, as the structure does not deteriorate when reprocessed. In fact, cullet usage in container manufacturing saves an estimated 23% of the energy required for virgin glassmaking; it reduces emissions to air, reduces furnace wear, and reduces solid waste.[27] The biggest challenge with glass recycling is that glass containers must be separated by color and this has been invariably a manual process. Thus the coloring agents used to protect the bottled product from the effects of UV rays also complicate the recycling process.

3.2.2.4 Consumer Perception

3.2.2.4.1 Food Security

Glass is chemically inert and provides an ideal barrier to contaminants. Consumers are familiar with the varied tamper-proof devices for glass food containers, such as plastic lid over-wraps and pop-up lids.

3.2.2.4.2 Marketing Potential

Glass can be produced in numerous different shapes and colors, and also be labeled using various technologies. In this way, bottles and jars can be customized to suit their contents. Pressure-sensitive, heat-transfer, and applied ceramic labeling all provide a no-label look, while roll-fed paper and polystyrene labels and shrink films provide 360° of graphic coverage. Pressure-sensitive labeling usually consists of inks printed on clear film, allowing consumers to see the product through the label.

3.2.2.4.3 Perception of Quality

Because of a long-held association between glass packaging and product quality, glass containers can enhance a product's image.[28] Glass packaging has been used in this way with popular new product categories such as new age beverages and drinks enhanced with herbal supplements. Consumers still see resplendent glass packages showcasing the finest perfumes, the most distinguished wines; these impressions reinforce the association of glass packaging with a quality product. At the same time, the use of glass packaging is also often equated with an expensive product, which may be negatively perceived by customers.

3.3 Petroleum-Based Plastics

3.3.1 Polyethylene Terephthalate (PET)

3.3.1.1 Background

Polyethylene-terephthalate (PET) is a petroleum-based polymer formed by combining the monomers modified ethylene glycol and purified terephthalic acid. PET is currently used for bottles, containers, films and trays for a wide variety of foods. PET containers are commonly used for small mouth bottles for products such as soda, mouthwash, salad dressings, and edible oils although wide mouth PET containers are becoming popular for foods such as peanut butter and pickles. PET is also widely used for cereal box liners, boil-in-the-bag pouches, and microwave food trays.

PET bottles are formed in a two-stage process that involves injection molding a preform and then blow molding the preform into the bottles shape. PET trays are typically formed using a thermoforming process, while box liners use a film extrusion process.

3.3.1.2 Physical Attributes

PET bottles have taken over market share from glass bottles for a variety of reasons including economics, reduced container weight and shatter resistance. PET also provides a good barrier for both flavors and hydrocarbons. The heat resistance of PET varies with the grade of resin and processing method but will easily meet the specifications required for yogurt packaging. PET is translucent and therefore additives would be required to provide UV protection.

3.3.1.3 Environmental Performance

The primary criticism of PET as a packaging material is that it is a petroleum-based polymer and is therefore a non-renewable material. It does, however, have the advantage of providing opportunities for source reduction and post-consumer recycling.

3.3.1.3.1 Energy Use

The material production energy for PET (72.6 MJ/kg) is similar to PP (74.9 MJ/kg). Feedstock energy accounts for 36.3 MJ/kg of this total.[29] The material production energy from renewable resources is only 0.13 MJ/kg. The total of material production and manufacturing energy for PET bottles is 100 MJ/kg compared to 117 MJ/kg for injection molded PP.

3.3.1.3.2 Raw Material Sourcing

Use of PET in packaging has been increasing, particularly as a replacement for glass. This changeover is being driven by the fact that PET's physical properties allow for downgauging (reducing the wall thickness) when compared to glass, as well as other materials. Developments in PET molding technology have also enabled downgauging in existing PET containers. The weight of two-liter soda bottles has been reduced by 29% since 1978.[30] This downgauging results in source reduction and potentially lower environmental burdens.

3.3.1.3.3 End of Life Considerations

PET has an established recycling infrastructure and is one of the most recycled packaging materials. The recycle rate for PET soft drink bottles (37.3%) is higher than the recycle rate for HDPE milk and water bottles (31.3%). This relatively high recycle rate is due in large part to the existence of a Bottle Bill deposit on soft drink bottles in several states. The recycling rate for other PET containers is 10.4% compared to 18.5% for other HDPE containers.[31] The recycling rates of PET packaging, excluding bottles and containers, is negligible.

According to the National Association for PET Container Resources (NAPCOR), in 1998 20 reclamation plants produced 588 million lbs. of clean PET flake which was used in the manufacture of new PET bottles, fiber, film, sheet, strapping and compounds. In fact, half of all polyester carpet manufactured in the U.S. is made from recycled PET bottles. While recycled PET can be used in a wide variety of products, the market for recycled PET is dependent on the price of virgin PET.

3.3.1.4 Consumer Perception

PET is used in many food contact applications and is generally considered to be a safe material. Consumers are accustomed to purchasing food in PET containers and appreciate its recyclability. One health concern is that PET does contain phthalates, which are known to cause liver and kidney damage, reproductive damage and in some cases are carcinogens.[32] Phthalates are commonly used as plasticizers in flexible PVC. However, the phthalates in PET differ from those in PVC in that they are bound to the polymer itself, and do not readily leach out of

PET products.[33] PET products often require the use of other additives, such as UV stabilizers and flame retardants, which may pose other health concerns.

3.3.1.5 Economic Considerations

There are several characteristics of PET that negatively impact the economic feasibility of it as a yogurt container. PET is relatively expensive material when compared to PP or HDPE. According to Schmalbach-Lubeca, a leading PET packaging manufacturer, the additives required to protect the contents from UV light will add additional expense.[34] In addition, most PET containers have relatively expensive screw-top closures, not snap-on lids like the ones currently used for packaging yogurt. Most PET containers currently in use have paper or plastic film labels, which would also be an additional expense.

3.3.2 Polystyrene (PS)

3.3.2.1 Background

Polystyrene is made from styrene, a petroleum by-product, through a polymerization process. Polystyrene is commonly used for disposable products used in the food service industry, as well as many types of food containers. The polystyrene used in the food service industry is typically either foamed polystyrene, used for hot beverage cups and clamshell containers, or oriented polystyrene sheet (OPS) used for trays and salad boxes. General-purpose polystyrene (GP) and high impact polystyrene (HIPS) are often used in containers for yogurt and other dairy products.

Polystyrene thermoformed containers are used for single serving yogurt containers by Dannon and other yogurt manufacturers. Polystyrene yogurt containers are more common in Europe than in the U.S.

3.3.2.2 Physical Attributes

Polystyrene can be thermoformed with a deep draw, which enables yogurt containers to be manufactured with relatively thin walls. This downgauging can result in cups with lower weights than those made of PP; however, the rigidity and structural integrity of the cups is dependant on wall thickness and may also be reduced. The stackability and resealability characteristics are expected to be similar to those of PP containers.

PS has a lower impact resistance than PP and is therefore more prone to cracking. The impact resistance is dependent on the blend of PS (GP or HIPS) and the rubber content. PS yogurt containers in Europe typically have higher rubber content (8%-9%) than those produced in the US (5%-6%) and are therefore more impact resistant.[35]

PS has a higher specific gravity than PP (1.05 vs.0.90). Therefore, given the same wall thickness, a PS container would weigh 14% more than a PP container. However, PS has a higher stiffness than PP and therefore has better top loading performance.[36]

3.3.2.3 Environmental Performance

3.3.2.3.1 Energy Use

The material production energy for PS (84.7 MJ/kg) is slightly higher than PP (74.9 MJ/kg). Feedstock energy accounts for 44.7 MJ/kg of this total.[37] The material production energy from renewable resources is only 0.14 MJ/kg.

3.3.2.3.2 Raw Material Sourcing

Polystyrene is derived from petroleum resources and is therefore classified as a non-renewable material. It does have the advantage of providing opportunities for source reduction but unlike PET, recycled PS is not in great demand. The PS used in containers and packaging is recycled at a rate of less than 5%, and therefore most of the PS containers end up in the landfill.

3.3.3.3.3 End of Life Considerations

Waste-to-energy incineration may be a viable end-of-life alternative for PS. The Polystyrene Packaging Council states that when incinerated in a properly operated, modern incinerator, the high energy content of PS contributes to a more efficient and cleaner burn. Carbon dioxide, water and trace amounts of ash are the primary outputs from the incineration process. During incineration, polystyrene releases most of its energy as heat and the ash that remains represents a material reduction of more than 99% by volume.[38]

3.3.2.4 Consumer Perception

Polystyrene meets the U.S. FDA standards for food packaging, however, there are concerns about chemicals released during production and when PS is burned. Production of PS involves benzene, styrene and 1,3-butadiene, which are known or suspected carcinogens.[39] When PS is burned, there is the potential for the formation of styrenes and PAHs.

The thermoformed PS yogurt containers currently used by Dannon and other manufacturers have an overall appearance that may convey the perception of lower quality when compared with injection molded PP containers. The thin walls, rough edges and lower quality graphics all contribute to this perception. PS cups also have a lower gloss and less impact resistance than typical PP cups.

3.3.2.5 Economic Considerations

The design of the container significantly affects the cost of the container and the type of filling and palletizing equipment required. It would be expected, however, that the downgauging potential of the PS thermoforming process could reduce the cost of the yogurt containers when compared to injection molded PP containers. On the other hand, switching to a thermoformed PS container would probably require Stonyfield to make investments in filling and palletizing equipment since the shape and configuration of these containers can vary significantly from the existing injection molded PP containers.

3.4 Natural Resins and Biodegradable Plastics

The resins used to make biodegradale plastics fall into two broad categories: natural and synthetic. Natural resins (or bio-poylymers) are largely based on renewable resources such as starch and cellulose, and polyhydroxalkanoate (PHA) produced by microbes. Other polymers such as proteins and pectins may also potentially be developed for biodegradable plastics and polymers. Polyactides (PLA), i.e. alipatic polyesters formed by polymerization of lactic acid is usually included in this category since the monomer can be produced by fermentation. Synthetic polymers are made of petroleum-based and other feedstocks and include polyester and polyethylene polymers. Examples of biodegradable, synthetic polymers are polycaprolactone (PCL), a thermoplastic polyester resin, and polybuthylene.[40]

3.4.1 Polylactide (PLA)

3.4.1.1 Background

PLA is a renewable resource based thermoplastic material made up of long polymer chains of lactic acid. The lactic acid is produced through fermentation of sugar. The lactic acid then undergoes a polymerization process to create the polymer chains. The sugar used as the feedstock for PLA is typically derived from corn, wheat or sugar beets.

Cargill and Dow Chemical created a joint venture, Cargill Dow Polymers (CDP) to manufacture and market polymers based on renewable resources. PLA polymers are the first products of CDP and are marketed under the NatureWorks trademark. CDP is currently producing PLA in development quantities in the Savage, Minnesota facility. CDP is constructing a world-scale PLA manufacturing facility in Nebraska, which will have an annual capacity of 154,000 tons. It is expected to be completed in early 2002. CDP is the first company to manufacturer PLA in the United States. Worldwide, other companies have plans to produce PLA, such as Shimazu and Mitui in Japan.[41]

CDP's PLA polymer has already been used to manufacture yogurt cups. Danone began selling yogurt in a single serve thermoformed PLA cup in Germany in early 1998.[42] The PLA was produced in the U.S. using sugar beets imported from Spain. The sugar beets were used rather than corn since the corn grown in the U.S. was likely to incorporate genetically modified organisms (GMO's). Danone's motivation for using PLA for the yogurt cups was to bring compostable yogurt containers into the marketplace. Danone had a one-year exclusive agreement on the technology within the dairy industry. The PLA cup was withdrawn from the market in January 1999. Danone cited German recycling regulations as the reason for the withdrawal. Regulations required that the cups be disposed of with other plastic containers rather than with compostable kitchen scraps. As a result, the composting of the cups was not being achieved.[43] One possible obstacle in composting the cups was Danone's use of an aluminum foil seal. Cargill Dow is working on a PLA coated paper seal as a means of overcoming this obstacle.[44]

PLA is being used or targeted for use in a wide variety of applications. PLA's characteristics make it suitable for fiber and nonwoven applications, such as for apparel, furnishings and industrial fabrics. Properties such as clarity, gloss, heat sealability and printability make PLA a good candidate for flexible film applications. PLA has also been successfully used as a coating for paper food and dairy packagings.

3.4.1.2 Physical Attributes

Yogurt cups can be made out of PLA using both injection molding and thermoforming processes; however, the preferred process will likely be thermoforming. Injection molded PLA cups require up to 60% longer cooling times than PP injection molded cups, which would result in longer cycle times and increased manufacturing costs.[45] Thermoforming of PLA is likely to be possible on existing PS thermoforming equipment. PLA and PS have similar shrink properties making the use of the same cup molds a possibility. PP shrinks more than PLA or PS and therefore different molds are likely to be required. Another consideration is the motor size on the extruder. PLA extrusion requires approximately 20% more horsepower than either PP or PS and therefore an upgrade may be required.[46] On the other hand, PLA can be processed in extruders with shorter length-to-diameter (L/D) ratios than either PP or PS. This is an economic benefit since extruders with shorter L/D ratios are less expensive. The thermoforming rate of PLA is approximately the same as PS and 21% faster than PP.

Literature provided by CDP indicates that the wall thickness of thermoformed PLA containers can be downgauged compared to thermoformed polystyrene containers. This would indicate a reduction in the quantity of material used, however, it is important to consider the specific gravity of the materials as well since the environmental burdens and cost of a container are related to weight rather than wall thickness. The specific gravity of PLA (1.25) is higher than both PS (1.10) and PP (0.90). Therefore, with a given wall thickness, the PLA container would weigh 12% more than the PS container and 28% more than the PP container. However, Cargill Dow claims that thermoformed PLA cups can have up to a 10% reduction in wall thickness compared to thermoformed PS cups. This is due in part to the higher stiffness of PLA, which contributes to PLA's superior top load strength.

Assuming that the configuration of the PLA containers would be similar to the current configuration, attributes such as stackability and resealability would be expected to be similar to those of the current cups. The impact resistance of PP is higher than PLA, which may be a concern, particularly for the 32 oz. container size. PLA also becomes brittle at freezing temperatures and therefore may not be suitable for frozen products.

PLA has good UV stability and is not susceptible to oxidization and therefore would not require UV stabilizers or antioxidants when used in yogurt cup applications. PP and HDPE both require the use of antioxidants when used for yogurt applications. PLA is a transparent material and therefore would require a pigment additive to achieve the desired opaqueness. If a pelletized color concentrate is used, the carrier resin should be a biodegradable polymer in order to maintain the biodegradable properties of the containers. Danone used a PLA-based color concentrate. The pigment itself was titanium dioxide, the same pigment currently used in Stonyfield Farm containers. Cargill Dow said that the titanium dioxide would not prevent the PLA cup from being classified as biodegradable.

According to Cargill Dow, Danone successfully used a yogurt fill temperature of 113˚F with the PLA cup. It is important to note that PLA does undergo severe shrinkage at 116-122˚F. High filling temperatures and printing that uses heat during the drying process are therefore concerns. Cargill Dow said that the UV cure inks currently used on the Stonyfield Farm cups would not pose problems. They also noted that a crystalline version of PLA is capable of withstanding exposure to boiling water.

PLA has the potential to be used in many components of Stonyfield Farm's yogurt PDS. In addition to the cup, lids can also be injection molded or thermoformed. Seals can be produced using a PLA coated paper. PLA may also be used to coat the paper containers used for frozen products.

3.4.1.3 Environmental Performance

PLA has been touted as having environmental benefits that include reduced fossil fuel use, reduced carbon dioxide emissions and reduced solid waste when compared to petroleum based polymers. The life cycle environmental burdens, however, depend significantly on the sources of process energy and the method of disposal at end of life.

3.4.1.3.1 Energy Use

The material production energy for PLA is expected to be 56 MJ/kg, excluding feedstock energy.[47] Much of this energy comes from coal and natural gas, which are the primary fuels used in the corn-farming and corn-processing industries. This is compared with 30.2 MJ/kg of material production fuel energy for PP, of which fossil oil is the primary source. Feedstock energy of PLA is 19.5 MJ/kg, which is significantly less than the 44.7 MJ/kg of feedstock energy for PP. The feedstock energy of PLA is also from renewable resources.

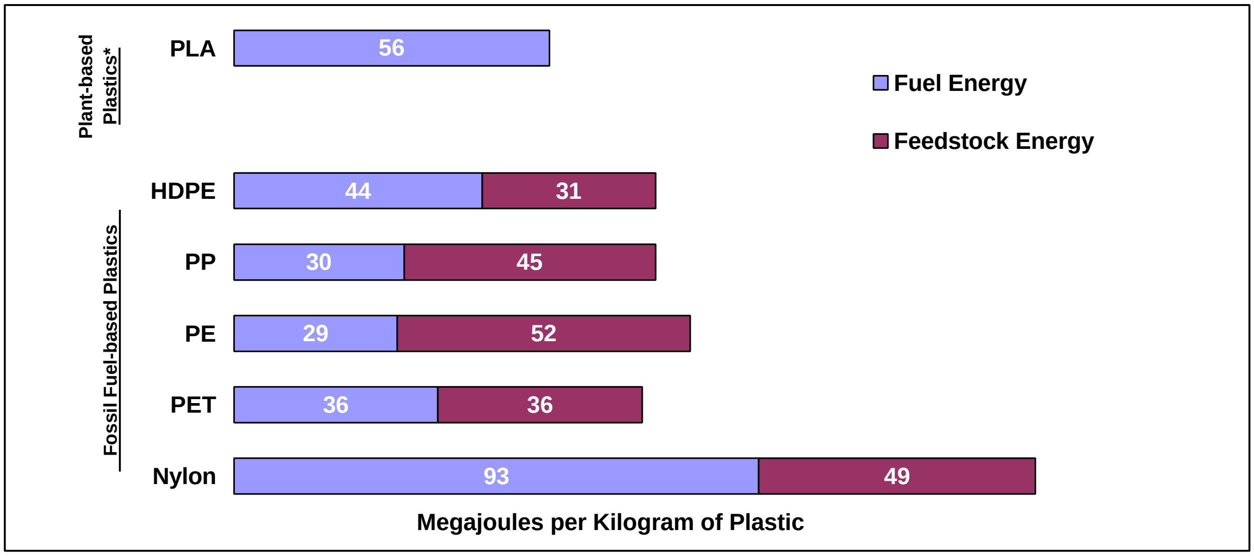

Figure 3-1: PLA Energy Requirements

*** Plant-based plastic energy data source: Scientific American, August 2000**[48]

3.4.1.3.2 End of Life Considerations

The potential for reduced solid waste burdens for PLA is due to the fact that PLA is both biodegradable and recyclable. Before this potential can be realized, however, communities must develop an infrastructure that provides for the composting and recycling of PLA at end-of-life. This is a major hurdle since the composting is not currently available in most communities and a market for recycled PLA does not exist.

Waste to energy incineration is another end-of-life option for PLA since PLA burns much like paper, cellulose and carbohydrates. It does not contain aromatic groups or chlorine and produces 0.01% ash.

3.4.1.3.3 Genetically-Modified Inputs

Since PLA relies on fermentation to convert sugar to lactic acid, the raw materials do not require genetic modification. CDP states that its PLA does not contain genetically modified material, however, the corn that currently constitutes the feedstock is harvested from Iowa (95%) and Nebraska (5%) and contains a mix of genetically modified and conventional corn.[49]. Danone used sugar beets from Spain to avoid the use of genetically modified organisms in its Eco-Cup. The challenge for Stonyfield Farm would be to find a raw material source that was both GMO-free and economical.

3.4.1.4 Consumer Perception

The consumer acceptance of PLA as a yogurt container material would be expected to be good on the basis that it is derived from renewable resources rather than fossil fuels. It also has the advantage of not requiring additives other than a pigment.[50]

Health concerns would also be somewhat appeased by the fact that it has been affirmed by CDP and a panel of outside experts to be Generally Recognized as Safe (GRAS), permitting use in direct contact with aqueous, acidic and fatty foods under 140°F and aqueous and acidic drinks served under 195°F.[51] CDP is currently conducting research on the use of PLA for a variety of food container applications and results of this research should be available in 2002 when PLA becomes commercially available. PLA does not currently have FDA approval, however, CDP stated that the GRAS certification would allow it to be used for food contact applications.

Consumers may have concerns about the use of genetically modified corn as feedstock. However, unlike some other biopolymers, PLA does not require the use of GMO feedstock crops. Given Stonyfield's opposition to GMOs, sources of non-GMO feedstock crops may be required.

Photos of the PLA yogurt container in the CDP brochure indicate that container designs could portray an image of quality. Multi-color printing is possible and the container would have space for graphics in line with those used on Stonyfield's current yogurt containers.

3.4.1.5 Economic Considerations

The price of PLA polymer is expected to be significantly higher than that of PP or PS in the short term; however, prices are expected to become more competitive as the new CDP plant comes on-line and efficiencies of scale are achieved. Cargill Dow says that production in the Savage, Minnesota plant is sold-out for 2001. The price for PLA is currently approximately $1.50 per pound. With the Nebraska plant coming online in 2002, prices are expected to drop to $0.90 per pound. Over the next five to ten years, prices are expected to reach $0.70 per pound.

The manufacturing costs would be expected to be competitive with PP and PS thermoforming considering that PLA polymers are suitable for use with existing fabrication methods. It would not be expected that changes to the filling and palletizing equipment currently used by Stonyfield would be required since the container design can be similar to current design.

3.4.2 Polyhydroxalkanoate (PHA)

3.4.2.1 Background

PHA is an abbreviated chemical name for a naturally occurring form of polyester. The first PHA was identified in 1925 in France and since then, over one hundred different forms of PHA have been discovered and described in the scientific literature.[52] In response to the oil crises of the 1970s, Imperial Chemical Industries (ICI) established the first industrial-scale process to convert plant sugar into several tons of PHA a year.[53]

Two distinct processes are employed to produce PHA: 1) production directly in plant matter and 2) fermentation of sugars. The fermentation process is the older of the two, and it holds more promise due to its lower process energy requirement. See figure 3-2 for a graphical representation of the processes used to make PHA.

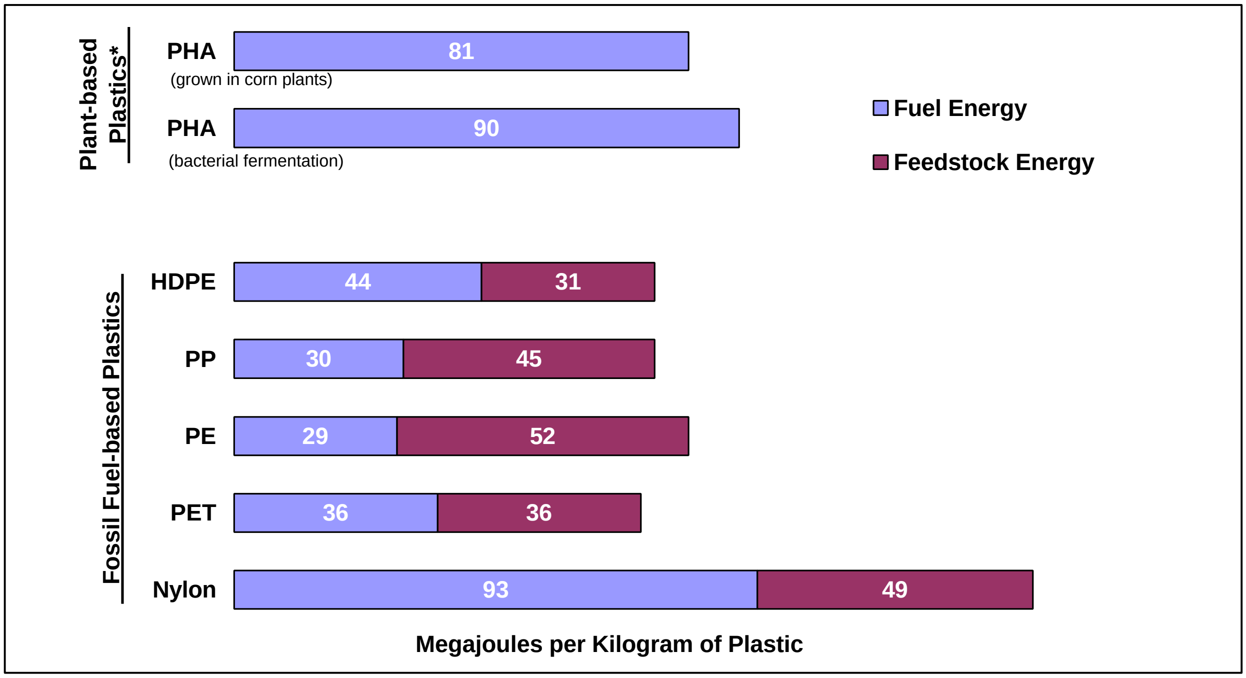

Figure 3-2 PHA Energy Requirements

*** Plant-based plastic energy data source: Scientific American, August 2000**[54]

According to Metabolix, a company that plans to produce PHA on an industrial scale using transgenic organisms, variants of the material are suitable for extrusion, injection molding, and coating applications.[55] Commercially, PHAs have been used for cosmetic bottles and paper coatings. Other uses of PHA include biomedical applications, such as long-term drug delivery or orthopedic repair.[56]

In 1993, a promising variety of PHA, polyhydroxybutyrate (PHB), was developed by ICI (later Zeneca) and eventually acquired by Monsanto.[57] After the acquisition, Monsanto planned on producing a bioplastic under the trade name Biopol™. However, in October 1998, Monsanto made the decision to withdraw from this business due to higher than expected production costs compared to conventional polymers.[58]

3.4.2.2 Physical Attributes

PHAs come in a wide range of physical properties, from stiff thermoplastics to more flexible rubbery materials. Also possible is the blending of PHAs with other polymers to achieve tailored properties for selected applications.[59] Considering PHAs' variety of properties, it can be used for yogurt cups, lids and even seals.[60]

Because PHA has not previously been used for yogurt containers, it is difficult to determine the minimum wall thickness and the weight of the containers. Other physical properties, such as temperature resistance and top loading strength, also remain unknown. However, with the range of physical properties stated above, it is probably safe to assume that characteristics similar to PP can be achieved. So, opaqueness, resealability and other attributes should meet Stonyfield Farm's specifications.

3.4.2.3 Environmental Performance

3.4.2.3.1 Energy Use

The fuel energy of PHA at 90 MJ/kg for production inside plants and 81 MJ/kg for the fermentation process is comparable to the entire material production energy of commercial plastics such as PP and PET. Figure 3-2 shows the energy required for each process and compares the totals to selected polymers. Today, research is being performed on the use of transgenic plants that may reduce the energy required to produce PHA. Until there is a technological breakthrough, more fossil fuels will be consumed to produce PHA than PP and other commercial scale plastics.

3.4.2.3.2 Raw Material Sourcing

A positive attribute of PHA is that it is produced from all renewable resources. For the fermentation process, naturally formed sugars (sucrose and dextrose) are the only raw material. And in the case of transgenic plant crops the only inputs to the feedstock are the fuels of photosynthesis, carbon dioxide and sunlight.

3.4.2.3.3 End of Life Considerations

The recycling potential of PHA is not known, but with sufficient demand for this material it is supposed that PHA has the same recycling potential as PET or other plastics currently on the market. Another end of life management option is PHA's ability to be composted or to biodegrade with a wide range of microorganisms. Theoretically a biodegradable packaging could virtually eliminate the solid waste burden at the end of life. However, today there exist only a few municipal composting programs in the U.S. for other than yard trimmings.[61] Waste PHA can also be decomposed using a hydrolysis process.

3.4.2.3.4 Genetically-Modified Inputs

A major concern about the production of PHA is that the most promising technologies utilize genetically modified organisms (GMO).[62]

3.4.2.4 Consumer Perception

3.4.2.4.1 Food Security

Yogurt containers made from PHA would likely retain the same configuration and design as the current containers, which have a cup, lid and seal. So, the packaging will continue to be tamper resistant.

A near term concern is that PHA is not approved by the FDA for food packaging. Metabolix believes that approval will be possible if an application is made. Also, the properties of PHAs are commonly manipulated using copolymers and additives. The type and concentration of the additives may raise concerns about the possibility of toxic migration and the material's ability to be composted.

3.4.2.4.2 Marketing Potential

Since the same container design would be used, the space to communicate environmental messages would remain unchanged. Printing PHA should be similar to decorating PP, so it offers the same flexibility to change design. However, the glossiness of PHA containers is not known.

The main appeal of PHA would be that it does not require non-renewable, petroleum inputs. Also a plus is the material's biodegradability. However, many Stonyfield Farm customers may reject PHA due to the potential use of GMOs in its production.

3.4.2.4.3 Perception of Quality

Assuming that the finish on PHA containers rivals that of PP, there should be no concern as to the perceived quality of the product.

3.4.2.5 Cost

The costs of PHAs have been higher than petroleum-based plastics limiting them to certain niche markets. Low yields and subsequent high costs are the reasons cited by Monsanto when they abandoned the PHA market in 1998. The current price quoted is approximately four times that of commercially produced plastics.[63]

However, the price of PHA is expected to fall in the near future with the use of transgenic technologies. The trade-off between high costs and the use of GMOs may forever plague PHA for use in selected niche markets.

3.4.3 Soy Works

3.4.3.1 Background

Soy Works is the company that acquired exclusive worldwide commercial rights the patented technology developed at Iowa State University (ISU) to turn soybeans into plastic. Although the company is still young and in the early stages of product development, Roy Taylor, the founder and managing member, says that "The list of potential products is endless -- anything that is made out of plastic -- but we're focusing on disposable, single use or short-life types of products."[64] In a phone interview, Taylor said that the material is suitable for use with thermoforming, injection-molding, and compression-molding machinery. Some of the first products Taylor expects to be good candidates for soy plastics are disposable ID cards and labels, disposable cutlery, food packaging, visual tags for bulk commodities, replacement liners for paper bags, insulated beverage cups and hay and silage wraps.[65] The material does not yet have an official trademark name. According to Soy Works literature, BioPlastics Polymers and Composites, Inc. (founded by Prof.

Narayan of Michigan State University) will handle large-scale piloting, some manufacture of resin pellets, and production of some molded articles.[66]

3.4.3.2 Physical Attributes

The main ingredients in the material formulations are standard grades of commercially available soy protein extracts (isolates, concentrates, and flour). The underlying technology is a process that uses soy protein and soy composite materials for the manufacture of thermoplastic resins and molded items. The soy protein is combined with water and a proprietary blend of other ingredients, then extruded and pelletized. The resulting resin pellets are subsequently hot melted and processed into a variety of molded items.

The Soy Works material is not currently FDA approved for food packaging, although one group of formulas is all food grade or GRAS, the other group consists of composites with other biodegradable materials. Small amounts of synthetic biodegradable polymers are added to some composites to enhance physical properties for specific applications. It is not a requirement for all formulations.

Also, thus far, only smaller size cups (under 4 oz.) have been designed for non-food applications. The company has yet to research larger container sizes and test for performance (brittleness and flexibility), durability, and top-loading strength. Materials are all 100% biodegradable and compostable. They are marine degradable, as well. In one lab composting study of extruded sheets there was 100% weight loss in less than 60 days. The product also has not been tested with live bacteria cultures. More research would be necessary to determine if the biodegradable, starch-based container would be suitable for refrigerated yogurt.

Competitively, the ISU technology yields products that are distinctive with respect to other identified degradable products. The material claims to offer a combination of many desirable technological components and environmentally friendly characteristics:[67]

Derived from non-petroleum, renewable resource	YES
Low energy consumption of manufacturing process	YES
Aerobic and anaerobic biodegradability/compostability	YES
Marine degradable	YES
Animal edible formulas possible	YES
Processed using standard equipment	YES
Low capital investment required for market entry	YES
Degradation by-products non-toxic	YES

One of the few limitations on this material is that it cannot create something which is transparent, nor a bright white (the natural colors are shades of brown). The material can be colored and applying graphics or labels should not be an issue. They have successfully laminated paper to the material during the molding process and without the use of adhesives. A paper laminate version would have unlimited color and graphics potential. Taylor is optimistic that applications will be scalable and that there will be few barriers to commercialization of Soy Works products.

3.4.3.3 Environmental Performance

3.4.3.3.1 Energy Requirement

Regarding energy requirements, the company's materials are processed at much lower temperatures than conventional plastics. "Our resin is prepared at essentially room temperature. Some heat is applied when the resin mixture (think pasta dough) is run through an extruder to create "noodles" which are either fed into a pelletizing machine (that simply cuts the strands into little pellets) or fed directly into a molding machine (e.g., injection molding). If you are making resin at one site and molding at another, you ship resin pellets that are subsequently hot melted and fed through another extruder. Resin pellets are hot melted before molding at around 150 degrees Celsius. Because we start at a lower temperature, and because the material cools rapidly, cycling times on machines should be able to be quicker than for conventional plastics."[68] No LCA data is available for Soy Works materials.

3.4.3.3.2 Genetically-Modified Inputs

In 1999, 47% of the soybean crop grown in the United States was genetically modified.[69] GMO-free soy products are widely available in the U.S., and Soy Works has already verified that by the time it goes into commercial production, there will be no problem obtaining non-GM soy. It could even be organic if desired, although that could impact pricing.[70]

3.4.3.4 Economic Considerations

The company projects its resin prices to be very competitive with plastic resins and likely to be cheaper than other biopolymers developed for comparable applications. Taylor thinks he will have resins well under $2.00 per pound, and some formulations could be in the $1.00 per pound range.[71]

Because there appear to be so many potential applications for Soy Works products, decisions are still being made as to where to invest company time and resources. There are no immediate plans to develop plastic food containers further, unless there is a demonstrated market and sufficient demand. If Stonyfield Farm were interested in pursuing this option, Taylor did express his willingness to discuss further collaboration. He said, "We are actively seeking to partner with commercial companies interested in collaborating on development of specific products. While we have not begun commercial production, no major technical obstacles have been identified. In the short term we will outsource resin manufacture with one or more companies with whom we have already formed alliances."[72]

3.4.4 Synthetic Biodegradable Polymers

3.4.4.1 Background

Synthetic, petroleum-based polymers can be made to biodegrade in the natural environment. The first material in this class was PCL, which was discovered in 1934. Since then many other materials have been developed including BASF's Ecoflex, Dupont's Biomax® and Eastman Chemical's Eastar Bio COPE. Synthetic biodegradable polymers can be used in a wide range of applications from films to paper coatings to injection molding.

Biomax® is hydro/biodegradable and fully compatible with recycling technologies73. Biomax® is intended mainly for disposal by composting and in-soil degradation. Biomax is suited for single use products such as: films for food packaging, paper coating, injection molding applications and thermoforming applications.

BASF produces Ecoflex®, a biodegradable LDPE-like plastic. BASF reports sharp demand growth for its Ecoflex® copolymer[1]. It introduced Ecoflex® in 1998 for use in biodegradable coatings, foam, and textile fibers applications. BASF says the food-packaging sector will be a key future market for Ecoflex®. Unfortunately, Ecoflex is used only in film applications and is not suitable for yogurt containers, although, it could be considered for a coating for paper containers to make the entire pack compostable.

3.4.4.2 Physical Attributes

Like the many of the other plastic materials described in the survey, biodegradable polymers would likely maintain the same configuration currently used. However, it is likely that the primary packaging would be heavier due to Biomax (1.35g/cm^3) being a significantly denser material than PP (0.90g/cm^3). It is possible that a cup using Biomax could have a thinner wall, but it is unlikely that it could be 40% thinner than the already slim wall containers.

A common concern with biodegradable packaging is their shelf life. However, yogurt and other similarly perishable products are a good match for Biomax's 6 to 12 month storage life. Other properties, such as melting point, stackability and opaqueness, either meet or exceed the parameters specified by Stonyfield Farm.

3.4.4.3 Environmental Performance

3.4.4.3.1 Energy Requirement

No reliable information regarding the material production energy of this class of polymers could be located.

3.4.4.3.2 Raw Material Sourcing

The feedstock for Biomax and other synthetic biodegradable polymers is oil and natural gas. So, no advantage can be found over the existing PP cups in the area of raw material sourcing. In actuality, more petroleum may be used since the packaging would likely be heavier.

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[1] Ecoflex is called "copolymer" because it is produced by mixing renewable materials such as starch and conventional polymers.

3.4.4.3.3 End of Life Considerations

At disposal, these biodegradable polymers have the ability to drastically reduce the life cycle solid waste burden since the are harmless to the environment at every stage of the decomposition process. However, these plastics and other biodegradable materials will not decompose in landfills. To reap the full benefit from biodegradable polymers, they must be properly composted. Unfortunately, composting infrastructure in the U.S. for materials other than yard trimmings is underdeveloped. Biomax® is also fully compatible with other recycling technologies, such as hydrolysis[74].

3.4.4.4 Consumer Perception

3.4.4.4.1 Food Security

Producers of biodegradable polymers are enthusiastic about the potential to use these materials for food packaging. Eastar Bio COPE meets compositional requirements for a variety of food-contact applications[75]. And Biomax is suitable for food packaging films. BASF says the food-packaging sector will be a key future market for Ecoflex[76]. However, since this research could not identify the technical information about toxicity of these materials, further investigation will be required to identify the safety for the direct-food contact and FDA approval status.

Tamper-proofing and toxic migration issues of synthetic resins are similar to that of PP and other petroleum-based plastics. More information about the additives required in the production of yogurt containers would need to be investigated.

3.4.4.4.2 Marketing Potential

Although synthetic biodegradable plastics do not reduce the non-renewable material input into their production system, their compostable features should appeal to the environmentally conscious consumers. It is assumed the performance in printing, design, and graphic space for communication is the same as those of PP, however further investigation is required.

3.4.4.4.3 Perception of Quality

From the research performed for this survey, it seems that biodegradable synthetic materials are largely unknown by the majority of consumers. Therefore, it would be important to communicate with customers about the features of these synthetic biodegradable polymers.

3.4.4.5 Economic Considerations

The price of Biomax® is slightly higher than conventional polymer materials[77], and it is likely that more material is needed than the existing cups. Therefore, it is expected that replacing PP cups with synthetic biodegradable polymers would raise packaging costs.

3.4.5 Starch-based Biodegradable Polymers

3.4.5.1 Background

This is a new category of polymers made from both renewable (vegetable starch) and non-renewable (petroleum) materials. The most notable producer of starch-based polymers is Novamont, who produces Mater-Bi™ at its plant in Terni, Italy.[78] Research on this family of plastics is also proceeding in the U.S. at Michigan State University and other locations. Unfortunately, today no commercially available starch-based biodegradable polymers are suitable for yogurt containers.

The Novamont product, Mater-Bi™, is made of corn-based starch, polycaprolactone (PCL - a synthetic biodegradable polymer) and natural additives. This starch-based polymer is a thermoplastic material, which can be processed with the same machines traditionally, used to process conventional plastics. Its physical and chemical properties are similar to those of polyethylene (PE), but Mater-Bi™ is completely biodegradable.[79] Although, cutlery made from Mater-Bi™ has been used for the past two years by McDonald's restaurants in Austria and Sweden, experts at BiocorpUSA, the U.S. dealer of reSource™[80] confirmed that this starch-based polymer was not suitable for yogurt containers.[81]

During the research phase of the survey, Dr. Ramani Narayan a professor of Chemical Engineering at Michigan State University and expert in biodegradable plastics was contacted. He has developed a polymer that combines modified starch and modified PCL using a reactive extrusion process. This material was alleged to achieve higher performance than Mater-Bi and be suitable for yogurt packaging. At the time this report was written, this material had only been produced on a small scale, but Dr. Narayan believed that this technology would be licensed for commercial production in the near future.

4. MATERIAL EVALUATION

In deciding which materials would make the most appropriate choices for further study, three broad categories were defined and used to compare the various options: Sustainability, Feasibility, and Marketability. Figure 4-1 shows the criteria evaluated in each of these three categories. The figure also includes the weighting factors that were used to favor criteria judged to be most important to Stonyfield Farm.

Figure 4-1: Evaluation Criteria

Criteria	Weighting Factor
Sustainability	
GMO-Free	10
Weight	10
Energy Use	8
Renewable Material	7
Recyclability	6
Renewable Energy	6
Biodegradability	3
Feasibility	
Availability	10
Material Cost	8
Durability	6
Switching Cost	6
Structural Integrity	4
Opaqueness	2
Marketability	
Customer Perception	10
Appearance	8
Food Security	6
Labeling	6
Quality of Printing	4

Sustainability encompasses the environmental performance and characteristics of surveyed materials. Specifically, material renewability, recyclability, biodegradability, energy efficiency, weight, and genetically-modified inputs were all taken into consideration. In this category, LDPE Coated Paper and PLA Coated Paper performed well, since the primary material input is wood, which is renewable and GMO-free. Aseptic packaging also performed well since it has low weight, significant renewable content and is GMO-free. Synthetic Biodegradable Polymers performed poorly because they are derived from a non-renewable material source and are not recyclable. PHA received a low score due to its reliance on GMO crops.

Figure 4-2: Sustainability Evaluation

Low	Medium	High
• Polystyrene (PS) • Aluminum • Starch-Based Biodegradable Polymers • Polyhydroxalkanoate (PHA) • Synthetic Biodegradable Polymers	• Polylactide (PLA) • Polyethylene Terephthalate (PET) • Glass • Soy Works • Polypropylene (PP)	• LDPE Coated Paper • PLA Coated Paper • Aseptic Packaging

Feasibility examined the relative cost, durability, strength, material availability, switching costs, and other packaging performance criteria. This category was intended to illuminate which materials could reasonably be substituted for polypropylene without exorbitant costs, supplier concerns, or compromised performance. Polystyrene performed on par with PP with its low container weight contributing to lower material costs. PLA ranked high for Feasibility because it can be used with existing molding technologies and will be available in 2002. Aseptic packaging performed poorly due to questions about its availability for yogurt containers and high switching costs. Soy Works was ranked low because it is not currently available.

Figure 4-3: Feasibility Evaluation

Low	Medium	High
• LDPE Coated Paper • PLA Coated Paper • Polyhydroxalkanoate (PHA) • Soy Works • Aseptic Packaging	• Polyethylene Terephthalate (PET) • Aluminum • Starch-Based Biodegradable Polymers • Synthetic Biodegradable Polymers • Glass	• Polystyrene (PS) • Polypropylene (PP) • Polylactide (PLA)

Finally, *Marketability* was the category used to characterize packaging appearance and consumer acceptance. Labeling requirements and printing quality, food security, and customer preferences were all part of Marketability. The renewable and biodegradable materials scored the highest. While the scores for most materials were good, aluminum and PET were by far the lowest performers. It was generally assumed that renewable plastics would have labeling and printing quality comparable to PP. Paper and renewable plastics also appeal to consumers' preferences for renewable material. Aluminum and PET were marked low in customer perception because they are sourced from non-renewable materials. These materials also scored low in labeling and appearance.

Figure 4-4: Marketability Evaluation

Low	Medium	High
• Polyethylene Terephthalate (PET) • Aluminum	• Polypropylene (PP) • Polyhydroxalkanoate (PHA) • LDPE Coated Paper • Aseptic Packaging • Polystyrene (PS) • Glass	• Soy Works • Polylactide (PLA) • Starch-Based Biodegradable Polymers • Synthetic Biodegradable Polymers • PLA Coated Paper

5. Conclusion

From the results of this packaging materials survey, it is apparent that there is no perfect packaging that fulfills all criteria, has superior environmental performance, and appeals to consumer preferences at a competitive cost. Similar to other business decisions, there are trade-offs and compromises that must be made with respect to yogurt packaging. The overall material evaluation below integrates the three categories (Sustainability, Feasibility, and Marketability) used to compare the various options. The goal of the survey lead to weighting the Sustainability criteria more heavily than Feasibility or Marketability.

Figure 5-1: Overall Material Evaluation

Low	Medium	High
• Soy Works • Polyhydroxalkanoate (PHA) • Synthetic Biodegradable Polymers • Polyethylene Terephthalate (PET) • Aluminum	• Polystyrene (PS) • Aseptic Packaging • Starch-Based Biodegradable Polymers • Glass	• LDPE Coated Paper • PLA Coated Paper • Polylactide (PLA) • Polypropylene (PP)

Overall, the best candidates for further study could be narrowed down to LDPE Coated Paper, PLA Coated Paper and PLA. PLA and PP received identical scores with PS falling close behind. Paper, PLA PP and PS have each been used for yogurt packaging so it was not surprising that they came out on top. The greatest obstacle to recommending PLA is the GMO corn issue. If PLA were made with certified GMO-free starch, it would potentially provide the best combination of environmental performance, strength, durability, and appearance.

The following summaries provide support for the further study of coated paper and PLA.

Coated Paper
- Renewable
- Energy efficient
- No GMOs
- Available supply
- Positive consumer perception
- Good labeling and graphics
- Moderate switching costs
- Opaque material

PLA
- Renewable
- Compostable
- Durability and structural integrity
- Meets labeling and printing criteria
- Ensures food safety
- Easily resealable
- Supply is increasing to meet market demand

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APPENDIX B

Use Phase Calculation

RESULTS OF YOGURT CONSUMPTION PHASE ANALYSIS

Refrigeration Calculations

Energy Use for a New Household Refrigerator

To calculate the energy required to refrigerate one functional unit (1,000 lbs.) of yogurt for each day it remains in the average new household refrigerator, the energy efficiency and total electricity demand for the appliance was calculated and then allocated to yogurt based on volume. Average energy efficiency for an appliance manufactured after 1995 was found to be 11.2 ft^3/(kWh/day) or 0.089 kWh/ft^3/day, and daily energy was 1.96 kWh/day for a 19 cubic foot refrigerator, including the freezer section.[1,2]

The refrigerator was assumed to contain a total volume of 9 ft^3 of food on average and 10 ft^3 of unused refrigerated space. The energy used to cool the unused space was allocated to the contents on a proportional basis to account for all electricity used by the appliance. The yogurt containers were assigned a portion of the energy based on their relative volume to the total food volume in the refrigerator.

The dimensions and volume for each container size or pack are shown in the table below. The 2 oz. squeezable product is sold eight to a carton, and the 4 oz. container is sold in a six-pack. All other sizes are sold individually. The volume calculated in Table B-1 for the 2 oz. and 4 oz. sizes is for the entire carton/pack. The volume calculated for all other sizes is for a single container.

Table B-1: Dimensions of Yogurt Packaging

Container Size	Height (ft)	Width (ft)	Length (ft)	Radius ft)	Volume (ft^3)
2 oz	0.3125	0.1667	0.6979		0.0364
4 oz	0.2046	0.4063	0.6510		0.0541
6 oz	0.2275			0.1304	0.0122
8 oz	0.2717			0.1304	0.0145
32 oz	0.4458			0.19	0.0505

Based on the container volume, the total volume (container and allocated unused space) was found for each size. The combination of container and the allocated space is approximately double the container volume alone. Once the total volume was known, the energy could be calculated. The calculation for energy was simply the volume multiplied by .089 kWh/ft^3/day. The results for one container or pack are as follows.

Table B-2: Volume and Energy for Single Container (or Pack)

Container Size	Container Volume (ft^3)	Space Allocated (ft^3)	Total Volume (ft^3)	Energy (kWh/day)
2 oz	0.0364	0.0404	0.0767	0.0069
4 oz	0.0541	0.0601	0.1142	0.0102
6 oz	0.0122	0.0135	0.0257	0.0023
8 oz	0.0145	0.0161	0.0306	0.0027
32 oz	0.0505	0.0562	0.1067	0.0095

Note: Energy reported is the kWh/day used for refrigeration, not the primary (embodied) energy from natural resources.

Next, the energy was converted to primary energy using an efficiency factor for electricity generation for the United States of 32%.[3] Primary energy is the energy embodied in resources (coal, natural gas, biomass, etc.) as they are found in nature and that is consumed to deliver electricity. Mathematically, primary energy is equivalent to the electric energy divided by the efficiency factor. Primary energy in kWh/day was then converted into MJ/day. Finally, the primary energy in MJ/day was multiplied to find primary energy per day per functional unit (FU) of yogurt.[4]

Table B-3: Energy for One-Day Household Refrigeration

	Energy		
Container Size	**kWh/day**	**MJ/day**	**MJ/day/FU**
2 oz	0.0214	0.0771	77.08
4 oz	0.0319	0.1147	76.49
6 oz	0.0072	0.0258	68.71
8 oz	0.0086	0.0308	61.53
32 oz	0.0298	0.1072	53.58

Note: Energy reported is the primary (embodied) energy from natural resources.

Comparison to PDS Life Cycle Energy

Once the primary energy requirements were for household refrigeration computed, they were compared to PDS total life cycle energy requirements, excluding any refrigeration or dishwashing. For a single day of storage, household refrigeration is approximately 2% of total life cycle energy. When yogurt containers are kept in the refrigerator longer, the energy demand and percentage of total energy naturally increases, as well. Table 5-10 below shows the impact of keeping yogurt refrigerated for one, three, and six days and how that compares to total energy for the other life cycle phases. The "Total Life Cycle" column in the table refers to the sum of energy consumed during Manufacturing, Material Production, Filling, End-of-Life, and all Distribution phases excluding household refrigeration. Refrigeration at the distributors/ retailers and during transport was not included the scope of this study.

Table B-4: Household Refrigeration and Life Cycle Energy Comparison

Container Size	Energy in MJ/FU			
	Household Refrigeration			Total Life Cycle
	1 Day	3 Days	6 Days	
2 oz	77.08	231.24	462.49	3,800
4 oz	76.49	229.48	458.97	4,080
6 oz	68.71	206.12	412.23	4,760
8 oz	61.53	184.60	369.20	4,020
32 oz	53.58	160.75	321.50	2,930

Comparison to Older Refrigerator

In 1987, the National Appliance Energy Conservation Act set minimum standards for 13 product types, including refrigerators. At that time, the energy efficiency was approximately 7.3 ft^3/(kWh/day) or 0.137 kWh/ft^3/day and, on average, refrigerators were slightly smaller.[5] Using an 18-ft^3 refrigerator, including freezer space and total food volume of 9 ft^3, energy requirements to chill yogurt in an older refrigerator were computed and compared to newer refrigerators. On average, new refrigerators consume over 45% less energy to keep an equivalent amount of yogurt cold.

Table 5-11: Energy Comparison for Old and New Refrigerators

Container Size	Energy (Old) MJ/day/FU	Energy (New) MJ/day/FU	Energy Savings MJ/day/FU
2 oz	112.04	77.08	34.96
4 oz	111.18	76.49	34.69
6 oz	99.86	68.71	31.16
8 oz	89.44	61.53	27.90
32 oz	77.88	53.58	24.30

This comparison shows that consumer decisions and purchasing behavior do have an important effect on total life cycle energy consumption. It could be communicated to the public that energy and visible cost savings are achievable by upgrading to more energy efficient appliances and electronics. They could be educated on programs such as Energy Star to make sound decisions that can both benefit the environment and lower their utility bills. Yogurt that does not require refrigeration is another possibility for reducing environmental burdens associated with electricity generation.

Dishwashing Calculations

Energy for Dishwashing

When yogurt is purchased in the 32 oz. container size, it is commonly transferred to another container or bowl for consumption. After the yogurt has been finished, the bowl must be washed for reuse. Consequently, there are additional water and energy requirements for dishwashing. There are a variety of possible household dishwashing techniques and scenarios (temperature, quantity of water). The following calculation gives the energy and water burdens for one typical case. Assuming it takes 24 oz. of warm water to properly wash a bowl, the following calculations were performed to quantify these burdens.

The mass of 24 oz. of water is 1.564 lbs. and the estimated temperature change from cold to warm water is 50°F.[6] With 1 Btu per 1°F increase, the energy is found by multiplying mass by temperature change. The result is 78.2 Btu. Using an efficiency factor for a natural gas-fired hot water heater of 70%, the total combustion energy is 111.7 Btu.

The next calculation finds the total fuel cycle energy (combustion and pre-combustion) using a pre-combustion (i.e., extraction, processing, and distribution) energy factor for natural gas.[7] The outcome is that the total energy for dishwashing one bowl is 125.25 Btu or 0.132 MJ/wash. If four bowls are used per 32 oz. container, the energy is 0.528 MJ/container and 264.12 MJ/FU of 1,000 lbs. of yogurt.[8] This is approximately 8% of total life cycle energy for the 32 oz. PP container. The water consumption per 1,000 lbs. of yogurt is approximately 375 gallons. This is a significant quantity of water considering that water used in other phases of the life cycle is around 155 gallons.

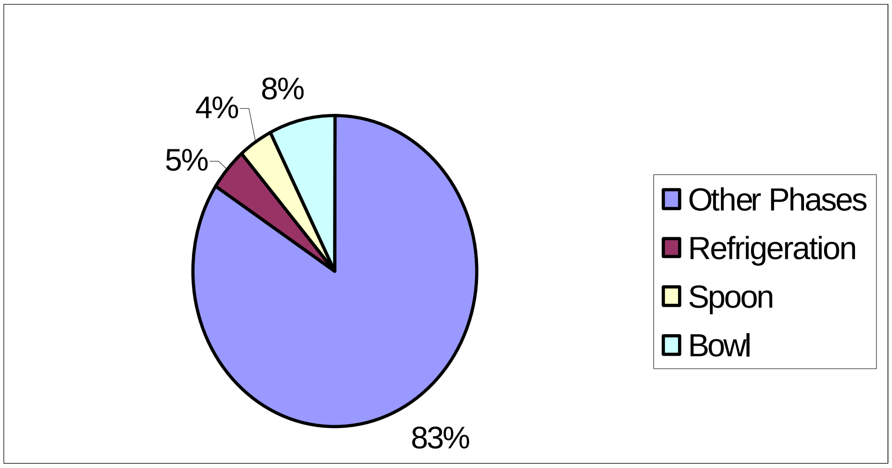
This figure of 0.132 MJ/wash is consistent with a study performed on washing cups in a dishwasher. The study concluded that an energy efficient dishwasher gave a median value of 0.184 MJ per cup per wash. In that study, the Canadian electricity generating efficiency factor was used, rather than the U.S. efficiency factor.[9]

Energy for Utensils

A similar methodology was used to calculate the water and energy used for washing spoons after eating yogurt. Only the YoSqueeze products do not require the use of spoons for consumption. All other packaging requires the use of a disposable or reusable spoon.

For this study, it was estimated that reusable spoons require half the amount of water, or 12 oz, for washing. All other numbers remain essentially the same. Therefore, washing a single spoon takes 0.066 MJ/wash and 132.06 MJ per functional unit, or 2,000 spoon washings.[10] Water used is equal to 187.5 gallons. Again, this is a considerable amount of water. Washing spoons accounts for roughly ¼ the total life cycle water use of a 32 oz. container. It would be around 50% of total life cycle water consumption for both 6 oz. and 8 oz. container sizes and an even higher percentage (60%) for 4 oz. containers. Figures 5-51 and 5-52 show the composition of life cycle energy and water, respectively, for the 32 oz. containers when the consumption activities of refrigeration and dishwashing are added. The energy percentages assume that yogurt is kept in the refrigerator for an average of three days. Note that the label "Other Phases" in the figures below refers to the total of Material Production, Manufacturing, Filling, End-of-Life, and all Distribution combined. The bar graphs in the figures below show the detail for each of the "Other Phases" separately, as well as for the Consumption phase.

Figure B-1: Life Cycle Energy for 32 oz Container



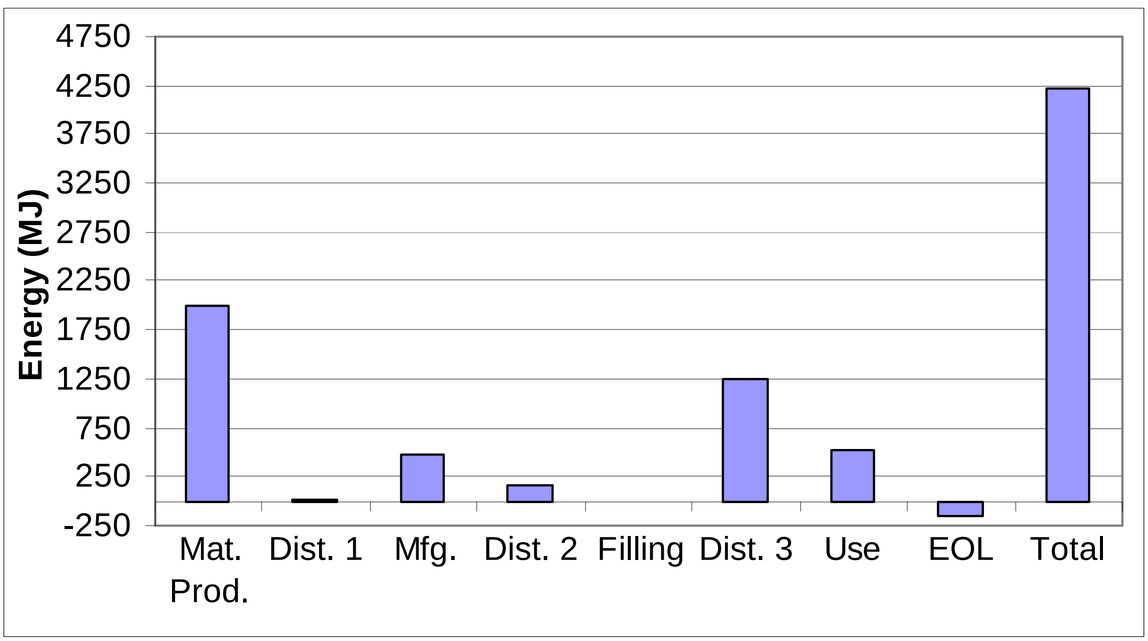
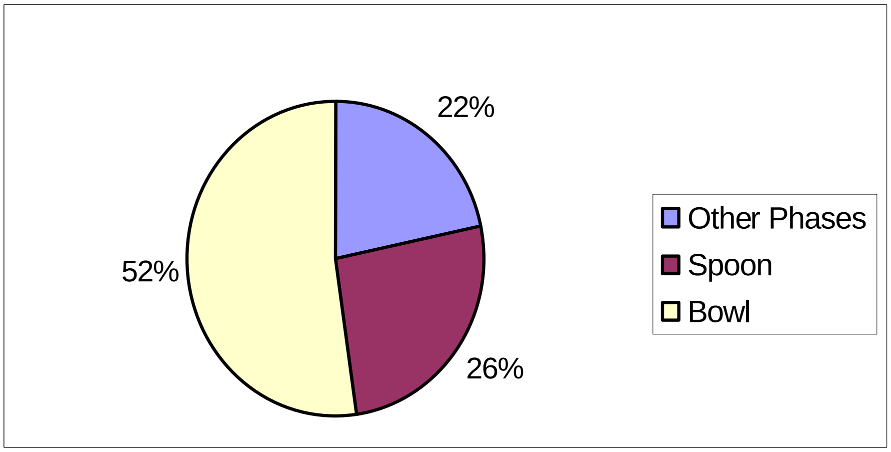
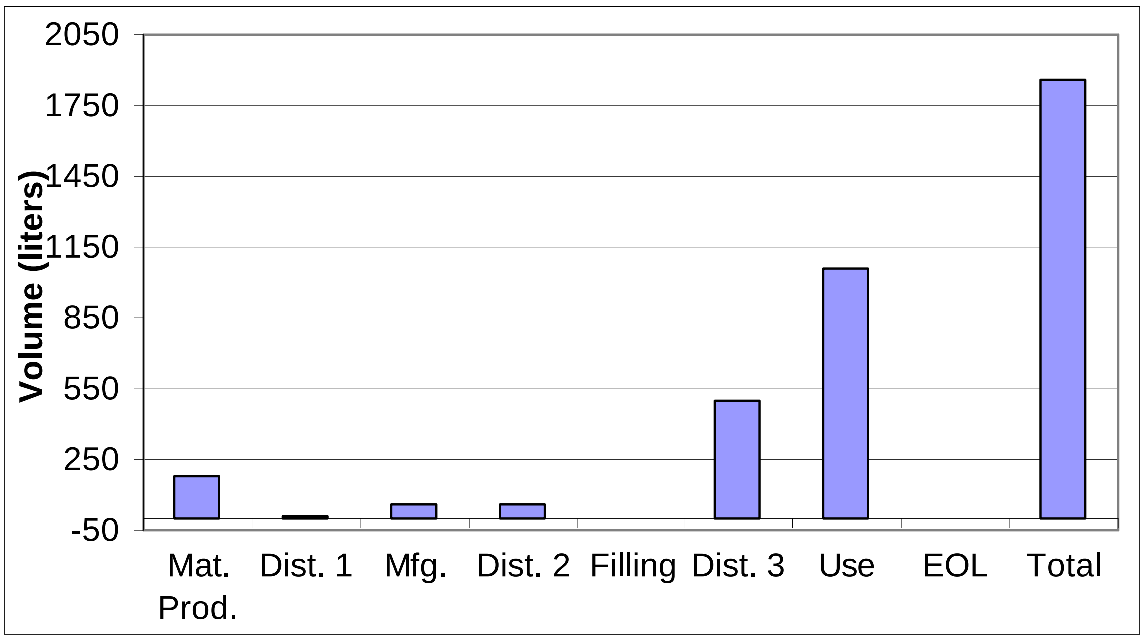


Figure B-2: Life Cycle Water Consumption for 32 oz Container





Alternatively, if a disposable polystyrene spoon is used to consume the yogurt and then thrown away without washing, the environmental impacts are not the same. In this case, the energy used in manufacturing a 4.2g polystyrene spoon was found to be 0.366 MJ/ spoon or 732 MJ per functional unit, or 2,000 spoons. This number is over 5 ½ times the energy needed for washing and results in greater impacts on the environment. It also contributes to the overall solid waste burdens.

This result suggests that consumers should use reusable spoons, not disposable ones. They can save up to 600 MJ per functional unit (for 8 oz. servings), and even more for smaller sizes where more spoons get used. In summary, these results demonstrate that consumer decisions and behaviors, not just producer decisions, do matter and deserve consideration as part of the full life cycle.

REFERENCES / BIBLIOGRAPHY

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[1] Department of Energy- Energy Information Administration. Efficiency of an Average New Refrigerator in the United States. http://www.eia.doe.gov/emeu/25opec/sld026.htm
[2] Department of Energy- Energy Information Administration. Residential Energy Consumption Survey, 1978, 1987, 1997.
[3] Franklin Associates, Ltd. Energy Requirements and Environmental Emissions for Fuel Consumption, 1992, p. A-15.
[4] There are 1,000 Yo'Squeeze cartons, 666.67 multi-packs, 2,666.67 6 oz. containers, 2,000 8 oz. containers, and 500 32 oz. containers per functional unit or 1,000 lbs. of yogurt.
[5] Department of Energy- Energy Information Administration. Efficiency of an Average New Refrigerator in the United States. http://www.eia.doe.gov/emeu/25opec/sld026.htm
[6] Cold water temperature of 55°F and hot water temperature of 105°F used.
[7] (1+ .0125x10^6 btu pre-combustion/ 1.0303x10^6 btu combustion) x combustion energy
[8] There are 500 32 oz. containers per functional unit of 1,000 lbs. of yogurt.
[9] Hocking, Martin B. Disposable Cups Have Eco-Merit. Nature. 12 May 1994.
[10] Functional unit of 1,000 lbs. could be made up of different serving sizes and number of spoons used. Calculation assumes an average of an 8-oz serving for a total of 2,000 spoons.

APPENDIX C

Lists of Tracked Air Emissions
& Emissions to Water

AIR POLLUTANT EMISSIONS

(a) Acenaphthene (C12H10)
(a) Acenaphthylene (C12H8)
(a) Acetaldehyde (CH3CHO)
(a) Acetophenone (C8H8O)
(a) Acrolein (CH2CHCHO)
(a) Aldehyde (unspecified)
(a) Aluminum (Al)
(a) Ammonia (NH3)
(a) Anthracene (C14H10)
(a) Antimony (Sb)
(a) Aromatic Hydrocarbons (unspecified)
(a) Arsenic (As)
(a) Barium (Ba)
(a) Benzene (C6H6)
(a) Benzo(a)anthracene
(a) Benzo(a)pyrene (C20H12)
(a) Benzo(b)fluoranthene
(a) Benzo(bjk)fluoranthene
(a) Benzo(ghi)perylene
(a) Benzo(k)fluoranthene
(a) Benzyl Chloride (C7H7Cl)
(a) Beryllium (Be)
(a) Bromoform (CHBr3)
(a) Butane (C4H10)
(a) Cadmium (Cd)
(a) Calcium (Ca)
(a) Carbon Dioxide (CO2, biomass)
(a) Carbon Dioxide (CO2, fossil)
(a) Carbon Disulfide (CS2)
(a) Carbon Monoxide (CO)
(a) Carbon Tetrachloride (CCl4)
(a) CFC and HCFC
(a) Chlorides (Cl-)
(a) Chlorinated Matter (unspecified, as Cl)
(a) Chlorine (Cl2)
(a) Chloroacetophenone (2-C8H7ClO)
(a) Chlorobenzene (C6H5Cl)
(a) Chloroform (CHCl3, HC-20)
(a) Chromium (Cr III, Cr VI)
(a) Chrysene (C18H12)
(a) Cobalt (Co)
(a) Copper (Cu)
(a) Cumene (C9H12)
(a) Cyanide (CN-)
(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)
(a) Dibenzo(a,h)anthracene
(a) Dichlorobenzene (1,4-C6H4Cl2)
(a) Dimethyl Benzanthracene (7,12-C20H16)
(a) Dimethyl Sulfate (C2H6O4S)
(a) Dinitrotoluene (2,4-C7H6N2O4)
(a) Dioxins (unspecified)
(a) Diphenyl ((C6H5)2)
(a) Ethane (C2H6)
(a) Ethyl Benzene (C6H5C2H5)
(a) Ethyl Chloride (C2H5Cl)
(a) Ethylene Dibromide (C2H4Br2)
(a) Ethylene Dichloride (C2H4Cl2)
(a) Fluoranthene
(a) Fluorene (C13H10)
(a) Fluorides (F-)
(a) Fluorine (F2)
(a) Formaldehyde (CH2O)
(a) Furan (C4H4O)
(a) Halogenated Hydrocarbons (unspecified)
(a) Halogenated Matter (unspecified)
(a) Halon 1301 (CF3Br)
(a) Hexane (C6H14)
(a) Hydrocarbons (except methane)
(a) Hydrocarbons (unspecified)
(a) Hydrogen (H2)
(a) Hydrogen Chloride (HCl)
(a) Hydrogen Fluoride (HF)
(a) Hydrogen Sulfide (H2S)
(a) Indeno (1,2,3,c,d) Pyrene
(a) Iron (Fe)
(a) Isophorone
(a) Lead (Pb)
(a) Magnesium (Mg)
(a) Manganese (Mn)
(a) Mercaptans
(a) Mercury (Hg)
(a) Metals (unspecified)
(a) Methane (CH4)
(a) Methyl Bromide (CH3Br)

(List continued on next page)

(a) Methyl Chloride (CH3Cl)
(a) Methyl Cholanthrene (3-C21H16)
(a) Methyl Chrysene (5-C19H15)
(a) Methyl Ethyl Ketone (MEK, C4H8O)
(a) Methyl Hydrazine (CH6N2)
(a) Methyl Methacrylate (CH2C(CH3)COOCH3)
(a) Methyl Naphthalene (2-C11H10)
(a) Methyl tert Butyl Ether (MTBE, C5H12O)
(a) Methylene Chloride (CH2Cl2, HC-130)
(a) Molybdenum (Mo)
(a) Naphthalene (C10H8)
(a) Nickel (Ni)
(a) Nitrogen Oxides (NOx as NO2)
(a) Nitrous Oxide (N2O)
(a) Organic Matter (unspecified)
(a) Particulates (PM 10)
(a) Particulates (unspecified)
(a) Pentane (C5H12)
(a) Phenanthrene (C14H10)
(a) Phenol (C6H5OH)
(a) Phosphorus (P)
(a) Polycyclic Aromatic Hydrocarbons (PAH, unspecified)
(a) Propane (C3H8)
(a) Propionaldehyde (CH3CH2CHO)
(a) Pyrene (C16H10)
(a) Selenium (Se)
(a) Silicon (Si)
(a) Sodium (Na)
(a) Styrene (C6H5CHCH2)
(a) Sulfur Dioxide (SO2)
(a) Sulfur Oxides (SOx as SO2)
(a) Sulfuric Acid (H2SO4)
(a) Tetrachloroethylene (C2Cl4)
(a) Toluene (C6H5CH3)
(a) Trichloroethane (1,1,1-CH3CCl3)
(a) Trichloroethylene (CCl2CHCl)
(a) Vanadium (V)
(a) Vinyl Acetate (C4H6O2)
(a) Vinyl Chloride (CH2CHCl)
(a) Xylene (C6H4(CH3)2)
(a) Zinc (Zn)
(ar) Radioactive Substance (unspecified)

WATER POLLUTANT EFFLUENTS

(w) Acids (H+)
(w) Aluminum (Al3+)
(w) Ammonia (NH4+, NH3, as N)
(w) AOX (Adsorbable Organic Halogens)
(w) Aromatic Hydrocarbons (unspecified)
(w) Arsenic (As3+, As5+)
(w) Barium (Ba++)
(w) Benzene (C6H6)
(w) BOD5 (Biochemical Oxygen Demand)
(w) Cadmium (Cd++)
(w) Calcium (Ca++)
(w) Carbon Tetrachloride (CCl4)
(w) Carbonates (CO3--, HCO3-, CO2, as C)
(w) Chlorides (Cl-)
(w) Chlorine (Cl2)
(w) Chlorinated Matter (unspecified, as Cl)
(w) Chloroform (CHCl3, HC-20)
(w) Chromium (Cr III, Cr VI)
(w) COD (Chemical Oxygen Demand)
(w) Copper (Cu+, Cu++)
(w) Cyanide (CN-)
(w) Dissolved Matter (unspecified)
(w) Dissolved Organic Carbon (DOC)
(w) Ethyl Benzene (C6H5C2H5)
(w) Ethylene Dichloride (C2H4Cl2)
(w) Fluorides (F-)
(w) Halogenated Matter (organic)
(w) Hydrocarbons (unspecified)
(w) Inorganic Dissolved Matter (unspecified)
(w) Iron (Fe++, Fe3+)
(w) Lead (Pb++, Pb4+)
(w) Magnesium (Mg++)
(w) Mercury (Hg+, Hg++)
(w) Metals (unspecified)
(w) Methylene Chloride (CH2Cl2, HC-130)
(w) Molybdenum (Mo II, Mo III, Mo IV, Mo V, Mo VI)
(w) Nickel (Ni++, Ni3+)
(w) Nitrate (NO3-)
(w) Nitrogenous Matter (unspecified, as N)
(w) Oils (unspecified)
(w) Organic Dissolved Matter (unspecified)
(w) Organic Matter (unspecified)
(w) Phenol (C6H5OH)
(w) Phosphates (PO4 3-, HPO4--, H2PO4-, H3PO4, as P)
(w) Phosphorous Matter (unspecified, as P)
(w) Polycyclic Aromatic Hydrocarbons (unspecified)
(w) Potassium (K+)
(w) Salts (unspecified)
(w) Selenium (Se II, Se IV, Se VI)
(w) Silver (Ag+)
(w) Sodium (Na+)
(w) Sulfate (SO4--)
(w) Sulfide (S--)
(w) Suspended Matter (unspecified)
(w) Tetrachloroethylene (C2Cl4)
(w) TOC (Total Organic Carbon)
(w) Toluene (C6H5CH3)
(w) Trichloroethylene (CCl2CHCl)
(w) Vinyl Chloride (CH2CHCl)
(w) Water: Chemically Polluted
(w) Water (unspecified)
(w) Xylene (C6H4(CH3)2)
(w) Zinc (Zn++)
(wr) Radioactive Substance (unspecified)

APPENDIX D

Human Health Results

HUMAN HEALTH RESULTS

Table D-1: Water Quality Concern Chemicals

Environmental Flows	Units	Quantity Released
(w) Acids (H+)	g	1.80
(w) Aluminum (Al3+)	g	1.052
(w) Ammonia (NH4+, NH3, as N)	g	1.261
(w) Arsenic (As3+, As5+)	g	0.0020
(w) Barium (Ba++)	g	0.2601
(w) BOD5 (Biochemical Oxygen Demand)	g	60.5
(w) Carbonates (CO3--, HCO3-, CO2, as C)	g	0.00
(w) Chlorides (Cl-)	g	255.6
(w) Chlorine (Cl2)	g	0.0006
(w) Chlorinated Matter (unspecified, as Cl)	g	0.0064
(w) Chromium (Cr III, Cr VI)	g	0.0107
(w) COD (Chemical Oxygen Demand)	g	205.6
(w) Copper (Cu+, Cu++)	g	0.0056
(w) Cyanide (CN-)	g	0.0003
(w) Dissolved Matter (unspecified)	g	4.27
(w) Dissolved Organic Carbon (DOC)	g	0.1229
(w) Iron (Fe++, Fe3+)	g	1.128
(w) Lead (Pb++, Pb4+)	g	0.0102
(w) Mercury (Hg+, Hg++)	g	0.0007
(w) Metals (unspecified)	g	9.69
(w) Nickel (Ni++, Ni3+)	g	0.0057
(w) Nitrate (NO3-)	g	49.9
(w) Nitrogenous Matter (unspecified, as N)	g	1.068
(w) Oils (unspecified)	g	6.15
(w) Organic Dissolved Matter (unspecified)	g	6.45
(w) Organic Matter (unspecified)	g	0.0007
(w) Phenol (C6H5OH)	g	0.1257
(w) Phosphates (as P)	g	0.1617
(w) Phosphorous Matter (unspecified, as P)	g	0.1314
(w) Polycyclic Aromatic Hydrocarbons (PAH)	g	0.0010
(w) Salts (unspecified)	g	48.0
(w) Sodium (Na+)	g	243.6
(w) Sulfate (SO4--)	g	39.2
(w) Sulfide (S--)	g	0.0029
(w) Suspended Matter (unspecified)	g	57.2
(w) TOC (Total Organic Carbon)	g	6.11
(w) Toluene (C6H5CH3)	g	0.0095
(w) Zinc (Zn++)	g	0.0113

Table D-2: Known and Reasonably Considered Carcinogens

Environmental Flows	Units	Quantity Released
(a) Acetaldehyde (CH3CHO)	g	0.0004
(a) Arsenic (As)	g	0.0013
(a) Benzene (C6H6)	g	1.037
(a) Benzo(a)anthracene	g	9.20E-08
(a) Benzo(a)pyrene (C20H12)	g	6.08E-05
(a) Benzo(b)fluoranthene	g	3.24E-08
(a) Benzo(bjk)fluoranthene	g	7.30E-08
(a) Benzo(k)fluoranthene	g	3.24E-08
(a) Beryllium (Be)	g	0.0001
(a) Cadmium (Cd)	g	0.0015
(a) Carbon Tetrachloride (CCl4)	g	1.85E-05
(a) Chloroform (CHCl3, HC-20)	g	0.0001
(a) Chromium (Cr III, Cr VI)	g	0.0020
(a) Di(2-ethylhexyl)phthalate (DEHP, C24H38O4)	g	0.0000
(a) Dibenzo(a,h)anthracene	g	2.23E-08
(a) Dichlorobenzene (1,4-C6H4Cl2)	g	2.06E-05
(a) Dimethyl Sulfate (C2H6O4S)	g	0.0000
(a) Dioxins (unspecified)	g	3.20E-07
(a) Ethylene Dibromide (C2H4Br2)	g	7.96E-07
(a) Ethylene Dichloride (C2H4Cl2)	g	0.0011
(a) Formaldehyde (CH2O)	g	0.0435
(a) Furan (C4H4O)	g	4.99E-08
(a) Halogenated Hydrocarbons (unspecified)	g	8.62E-12
(a) Indeno (1,2,3,c,d) Pyrene	g	7.35E-08
(a) Methyl Chrysene (5-C19H15)	g	1.46E-08
(a) Methylene Chloride (CH2Cl2, HC-130)	g	0.0323
(a) Naphthalene (C10H8)	g	4.19E-05
(a) Nickel (Ni)	g	0.0258
(a) Polycyclic Aromatic Hydrocarbons (unspecified)	g	0.0017
(a) Silicon (Si)	g	5.91E-04
(a) Tetrachloroethylene (C2Cl4)	g	0.0164
(a) Vinyl Chloride (CH2CHCl)	g	0.0121
(ar) Radioactive Substance (unspecified)	kBq	27880
(w) Arsenic (As3+, As5+)	g	0.0020
(w) Benzene (C6H6)	g	6.68E-08
(w) Cadmium (Cd++)	g	1.55E-04
(w) Carbon Tetrachloride (CCl4)	g	6.68E-08
(w) Chloroform (CHCl3, HC-20)	g	7.44E-05
(w) Chromium (Cr III, Cr VI)	g	0.0107
(w) Ethylene Dichloride (C2H4Cl2)	g	6.68E-08
(w) Methylene Chloride (CH2Cl2, HC-130)	g	1.07E-07
(w) Nickel (Ni++, Ni3+)	g	0.0057
(w) Polycyclic Aromatic Hydrocarbons (PAH)	g	9.62E-04
(w) Tetrachloroethylene (C2Cl4)	g	6.68E-08
(w) Trichloroethylene (CCl2CHCl)	g	6.68E-08
(w) Vinyl Chloride (CH2CHCl)	g	1.34E-07