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LIFE CYCLE INVENTORY OF PACKAGING MATERIALS IN MEXICO

Final Report

Prepared for:

THE UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna, Austria

by

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December 27, 1994

This report is printed on recycled paper.

PREFACE

This work was conducted for the United Nations Industrial Development Organization (UNIDO), Vienna, Austria. The work was sponsored by an industry committee consisting of many major industrial enterprises and trade associations. The study was directed by Dr. Juan Careaga, of the Instituto Internacional del Reciclaje S.C. (IIR). Data collection in Mexico was performed by M.R. Servicios de Fomento Industrial S.A. de C.V. under the direction of Dipl. Ing. Manfred V. Rucker Koehling.

The study was performed by Franklin Associates, Ltd. under the direction of Kent J. Hart, Project Manager. Significant contributions were made by Melissa D. Huff, Carol C. Hildebrandt, Beverly J. Sauer, Daniel C. Janzen, and Terrie K. Boguski. William E. Franklin served as Principal-in-Charge.

This study was performed by Franklin Associates, Ltd. as an independent contractor. The results presented here are for the use of the client according to terms set forth in contractual agreements. The findings presented in this report are strictly those of Franklin Associates, Ltd. and represent a Life Cycle Inventory, only. Franklin Associates, Ltd. makes no comparisons or draws any conclusions based on these results.

This was the first attempt to gather national data for environmental life cycle studies in Mexico. The readers should be aware that because of the complexity of a national data procurement effort, there are inevitable data quality problems which result from incomplete reporting in any first effort of this type. More time is required to correct those problems. In many cases, data for manufacturing operations in Mexico were not received, or there were only one or two respondents. Where no data were received, U.S. data were used as surrogates. While all data for Mexican manufacturing systems were reviewed and checked for reasonableness by comparison to U.S. average data, validity of any conclusions drawn from analyses based upon these data need to be viewed with the data quality problems in mind.

TABLE OF CONTENTS

Page

Page

LIST OF TABLES

Page

LIST OF FIGURES

Chapter 1

STUDY APPROACH AND METHODOLOGY

OVERVIEW

The energy and environmental profiles presented in this study quantify the total energy requirements, energy sources, atmospheric emissions, waterborne emissions and solid waste resulting from the production of specific packaging products. The methodology used for this inventory was developed to conduct what is defined by the Society of Environmental Toxicology and Chemistry (SETAC) as Life Cycle Inventory (LCI) (Reference 1). This inventory is not an impact assessment. It does not attempt to determine the fate of emissions, or the relative risk to humans or to the environment due to emissions for the systems. No judgements are made as to the merit of obtaining natural resources from various sources.

By definition, LCI examines the entire production sequence of a product from acquisition of raw materials through consumption and final disposal of the product, referred to as "cradle-to-grave." The unique feature of this type of analysis is its focus on the entire life of a product, from raw material extraction to final disposition, rather than on a single manufacturing step or environmental emission. Figure 1-1 illustrates the general approach used in this analysis.

Purposes of the Study

The purpose of this study is to collect, analyze and present data and technical information on the resource and energy requirements and environmental emissions of 21 packages commonly used in Mexico to deliver products to consumers. The data and technical information are to be presented in such a manner that they can be attributed to different primary packaging components and to the country in which resources and energy are used and emissions are released.

System Scope

Only primary package components are examined in this study. Primary package components are assumed to be the components of a package that are used to directly contain the product being delivered (containers, closures, lids, seals and/or separators).

The analysis includes the following steps in the life cycle of each package component: extraction of raw materials from the earth, processing these materials into usable components, manufacturing the primary

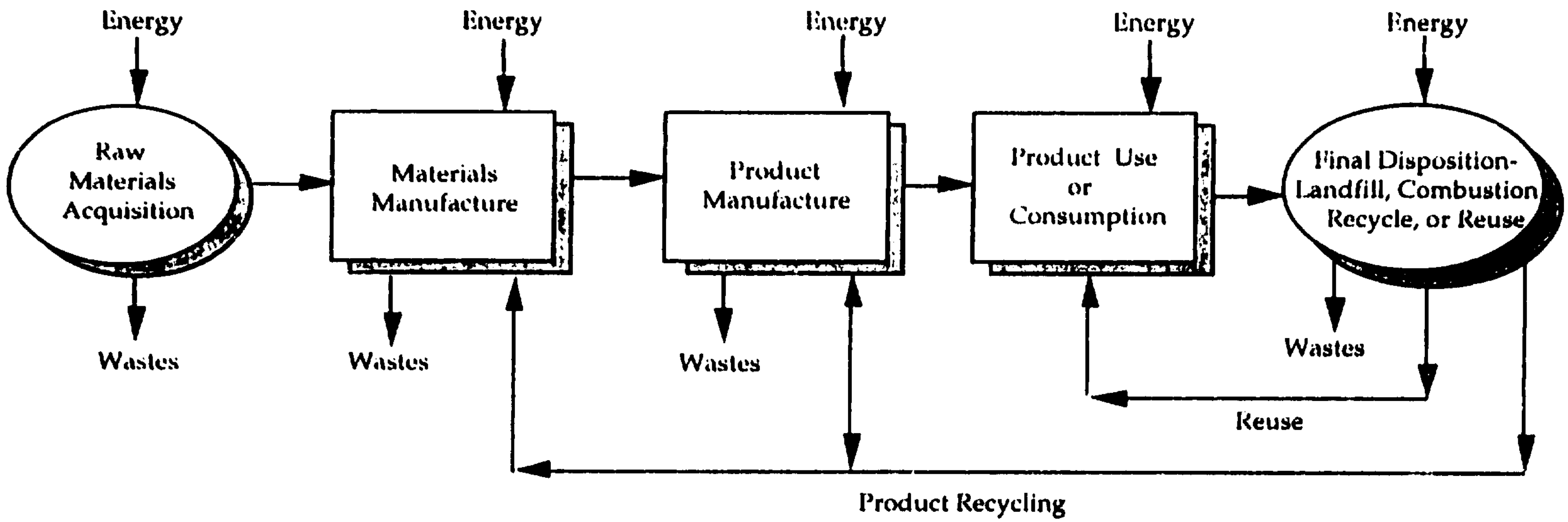

Figure 1-1. General materials flow for "cradle-to grave" analysis of a product system.

packaging, transportation of materials and products to the next processing step, and final disposition of the packaging components (whether recycled, reused or landfilled). Washing of refillable containers is also included.

Not included in this study are package filling, storage of the packaged product and delivery of the packaged material to the consumer. It is assumed that filling and storage should be allocated to the product and not the package. The resource requirements and environmental emissions for delivery of packaged products is determined by the weight and volume of the total package system. Included in the total package system are the delivered product, the primary packaging and any secondary and tertiary packaging needed to effectively contain, protect and present the packaged material. This study does not examine the requirements for secondary and tertiary packaging. It would be misleading to calculate the delivery of the total package system while only considering the primary packaging; therefore, delivery is not included in this study.

Packaging Systems Examined

The packaging systems examined in this study are presented in Table 1-1. The analysis examines the energy usage and environmental emissions associated with the manufacture and disposal of 100,000 units of each package.

Data are presented throughout this report at assumed current recycled content, recycling rates and/or trippage rates for each of the packages. Recycling is evaluated for the aluminum, tin-coated steel, glass, bleached kraft paper, clay-coated paperboard, and corrugated paperboard because these materials are currently being collected for recycling throughout Mexico, with the largest share in collection corresponding to the Mexico City area. Although wooden crates are not recycled in Mexico, there is some reuse of the product; however, reuse rates are not known and thus reuse is not included in this analysis. Glass and PETG refillable bottle systems are analyzed at an assumed average trippage rate.

METHODOLOGY

Franklin Associates, Ltd. has developed a methodology for performing life cycle inventories. This methodology has been documented for the U.S. Environmental Protection Agency and is incorporated in the EPA report **Product Life-cycle Assessment Inventory Guidelines and Principles.** The methodology is also consistent with the life cycle inventory methodology described by the Society of Environmental Toxicology and Chemistry in the documents **A Technical Framework for Life-Cycle Assessment** (1991) and **Guidelines for Life-Cycle Assessment: A "Code of Practice"** (1993). These are the customary peer-reviewed reference documents on this subject. The data presented in this report were developed using this methodology, which has been in common use for 23 years.

Table 1-1

SYSTEM CONFIGURATIONS

	Material	Weight/ Volume of Contents	Package Unit Weight (grams)	Weight per 100,000 containers (kg)
Three-piece can for chiles		198 grams	44.138	4,414
Can body	Tin-coated steel sheet		26.584	2,658
Can end or top (each)	Tin-coated steel sheet		8.777	878
Beer can		340 ml	15.66	1,566
Can body	Aluminum sheet		11.98	1,198
Can top	Aluminum sheet		3.68	368
Non-refillable soft drink bottle		355 ml	167.3	16,730
Bottle	Glass		165	16,500
Crown	Steel		2.3	230
Refillable soft drink bottle		500 ml	512.3	51,230
Bottle	Glass		510	51,000
Closure	Steel		2.3	230
Refillable soft drink bottle		1.5 liters	108.73	10,873
Bottle	Blow-molded PETG		106	10,600
Closure	Injected-molded polypropylene		2.73	273
Non-refillable, edible oil bottle		1.0 liters	41.0395	4,104
Bottle	Blow-molded PET		38.5	3,850
Closure	Injection-molded HDPE		2.5395	254
Shampoo bottle		400 ml	59	5,900
Bottle	Blow-molded HDPE		45	4,500
Closure	Injected-molded polypropylene		14	1,400
Water bottle		3.78 liters	113.5	11,350
Bottle	Blow-molded PVC		110	11,000
Closure	Injection-molded HDPE		3.5	350
Bread bag	LDPE film	650 grams	8.74	874
Sugar bag	Woven polypropylene fabric	50 kg	95	9,500
Pancake syrup container		354 ml	40.1	4,010
Bottle	Blow-molded polypropylene		34.25	3,425
Closure	Injection-molded HDPE		4.7	470
Cap for closure	Injection-molded HDPE		1.15	115
Yogurt container		240 ml	12.119	1,212
Container	Injection-molded polystyrene		11.7081	1,171
Foil seal	Aluminum foil		0.4109	41

(continued)

Table 1-1
(continued)

SYSTEM CONFIGURATIONS

	Material	Weight/ Volume of Contents	Package Unit Weight (grams)	Weight per 100,000 containers (kg)
Crate for grapes		21.23 liters	327	32,700
Box	Expanded polystyrene		215	21,500
Top	Expanded polystyrene		112	11,200
Sack for corn flour	Bleached semi-kraft paper	1 kg	15.7	1,570
Sack for cement	Multi-layered unbleached semi-kraft paper	50 kg	285	28,500
Folding carton cereal box	Clay-coated paperboard	350 grams	80	8,000
Box for egg trays		30 trays	1,222	122,200
Box	Corrugated paperboard		1,034	103,400
Inner separator	Corrugated paperboard		188	18,800
Metallized snack pack	Al. metallized BOPP film	25 grams	1.7314	173
Gable top milk carton	LDPE-coated paperboard	1 liter	31.85	3,185
Aseptic brick for milk	Al/LDPE/Paperboard laminate	1 liter	28.5	2,850
Fruit crate	Wood	35.2 liters	885	88,500

Source: Franklin Associates, Ltd.

The first step in performing a LCI is to determine which specific manufacturing processes must be evaluated for each system being studied. A standard unit of output, such as 1,000 kilograms, is often used as the basis for evaluating each manufacturing process. Energy requirements and emissions are determined for each process and expressed in terms of the standard unit of output. If marketable coproducts or byproducts are produced, adjustments are made in the resource and energy requirements and environmental emissions to reflect the portion of each attributable to the product being considered. The concept of coproduct credit will be considered later in this discussion.

Once the resource and energy requirements and environmental emissions have been established for the standard unit of output for each process of a system, a master flow chart is made. This flow chart shows the quantities of raw materials from each process that are required to manufacture the system components. The resource requirements and environmental emissions for the complete system are determined from the requirements and emissions for each subprocess that make up the system.

There is a general consensus among life cycle practitioners on the fundamentals of life cycle inventories. However, no generally accepted methodology has yet been defined for some specific aspects of life cycle inventory. LCI practitioners vary in their approaches to these issues. The following sections define some of these aspects and describe the approach to each issue used in this study.

Partitioning/Coproduct Credit

An important feature of life cycle inventories is that the quantification of inputs and outputs are related to a specific amount of product from a process. However, it is this feature that sometimes causes controversy in LCI studies because many processes produce more than one product. It is often difficult or impossible to identify which inputs and outputs are associated with one of multiple products from a process. The practice of allocating inputs and outputs to one of multiple products from a process is often referred to as "partitioning" (Reference 2) or "coproduct credit" (Reference 3).

Coproduct credit is done out of necessity when raw materials and emissions cannot be attributed to one of several product outputs from a system. It has long been recognized that the very practice of giving coproduct credit is less desirable than being able to identify which inputs lead to particular outputs. Coproduct credit is a method of last resort.

In many cases, it is necessary to allocate energy and emissions among multiple products based on some calculated ratio. The method of calculating this ratio is subject to much discussion among LCA researchers, and various methods of calculating this ratio are discussed in literature (References 2, 3, 4, 5, 6).

Where allocation of energy and emissions among multiple products based on a calculated ratio is necessary in this study, the ratio is calculated based on the relative **mass** outputs of products, unless stated otherwise in the process description in the Appendix.

Agricultural and Industrial Waste

As a general rule in this study, a waste is considered to be a material generated from a process which is discarded into the environment in such a way as to disturb natural cycles. This discarded material can be in the form of atmospheric emissions, waterborne discharges or solid waste. However, it is difficult to form a hard and fast rule defining solid waste because of the many forms that make up this category. Occasionally, a process will produce an output which appears to be neither a product nor a waste. Agricultural wastes serve as an interesting example of the difficulty in identifying and accounting for products and wastes in an LCI.

Some waste materials from processing are returned to the field, a form of active disposal, but they are distributed on the land. In some cases they may even aid production by providing nutrients or soil conditioning. For example, stover (corn stalks left after corn harvesting) can potentially be used as animal fodder. However, the potential for use is not sufficient for consideration as a coproduct. Because corn stalks are usually discarded and left to be plowed back into the field, they fail the definition of a coproduct. On the other hand, they require no waste treatment and are often simply left in the field to decompose and cause no alteration of natural cycles.

The temptation exists to create a separate category for agricultural discards. However, these issues are not limited to only agricultural processes. For example, overburden from mining operations is often returned to the mine after the mine is depleted. Another example is brine extracted from oil wells along with petroleum. The brine is often injected back into the well. In both of these examples, material removed from the Earth are returned to their natural cycles. Therefore, agricultural discards are not treated differently in this study than these types of industrial discards.

Coproducts in this inventory include those materials that are currently recycled, reused, or marketed in some beneficial way. Emissions, energy requirements and raw materials for a process must be allocated among all of these coproducts. The distinction between a coproduct and a waste is often a very fine line which may change over time depending on infrastructure, markets, and economics. For those materials that only marginally qualify as coproducts, the difficulty is not in categorizing the output. The difficulty is determining a reasonable method of coproduct credit or partitioning.

Using a simple ratio of mass outputs to allocate inputs and outputs to these marginal coproducts is not logical. As discussed in the previous section, the ratio method of allocation should be the method of last resort. Instead, no raw materials are allocated to these marginal coproducts. Likewise, no emissions are allocated to the marginal coproduct other than its own mass. Again using the example of corn harvesting, the stover is ignored as both an input into the process and as an output. All energy and emissions for corn harvesting are assigned to the corn. Similarly, overburden returned to the mine site is not included as waste and brine that is injected back into the oil well is not considered as a waste.

Energy of Material Resources

For some raw materials, such as petroleum, natural gas and coal, the amount consumed in all applications as fuel far exceeds the amount consumed as raw materials for products. The primary use of these materials is for energy. The total amount of these materials can be viewed as an energy pool or reserve. This concept is illustrated in Figure 1-2.

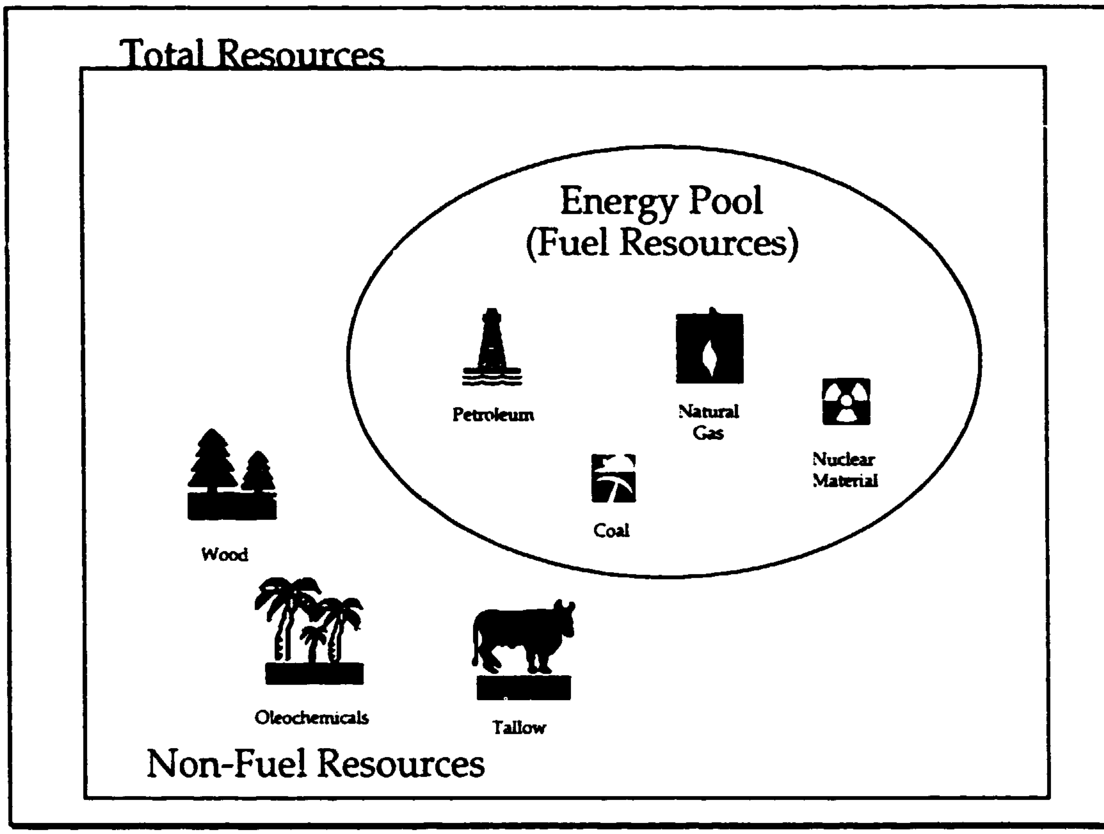

Figure 1-2. Illustration of the Energy of Material Resource concept.

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

The energy of material resource is the energy content of the fuel materials input as raw materials. The energy of material resource is *not* the energy value of the final product.

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

The energy of material resource value assigned to a material is the energy value of the material at the point of extraction from its natural environment. The energy of material resource values for petroleum, natural gas and coal are calculated from the higher heating value of crude oil, raw natural gas and mined coal, respectively.

Recycling and Re-Use

Both closed-loop and open-loop recycling are means to divert products from the municipal solid waste streams. Closed-loop, open-loop or a combination of closed- and open-loop recycling are considered as recycling methods in this study.

In a closed-loop system, material is diverted from disposal by its unlimited recycling or reuse. For example, aluminum from aluminum cans is recycled and fabricated into cans again. Since recycling of the same material can occur over and over, it may be permanently diverted from disposal. Figure 1-3 presents a graphical description of how individual processes can be viewed in a closed-loop system. This figure illustrates that, at the ideal 100 percent recycling rate, the energy requirements and environmental emissions from virgin raw material acquisition/processing and disposal become negligible. In contrast, if closed-loop recycling does not occur or is less than 100 percent, then virgin raw materials must be acquired and processed, and disposal of the postconsumer wastes continues each time a product is produced.

In an open-loop system, a product made from virgin material is manufactured, recovered for recycling, and manufactured into a new product which is not recycled. This extends the life of the initial material, but only for a limited time. Figure 1-4 illustrates how the processes in an open-loop recycling system are analyzed.

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

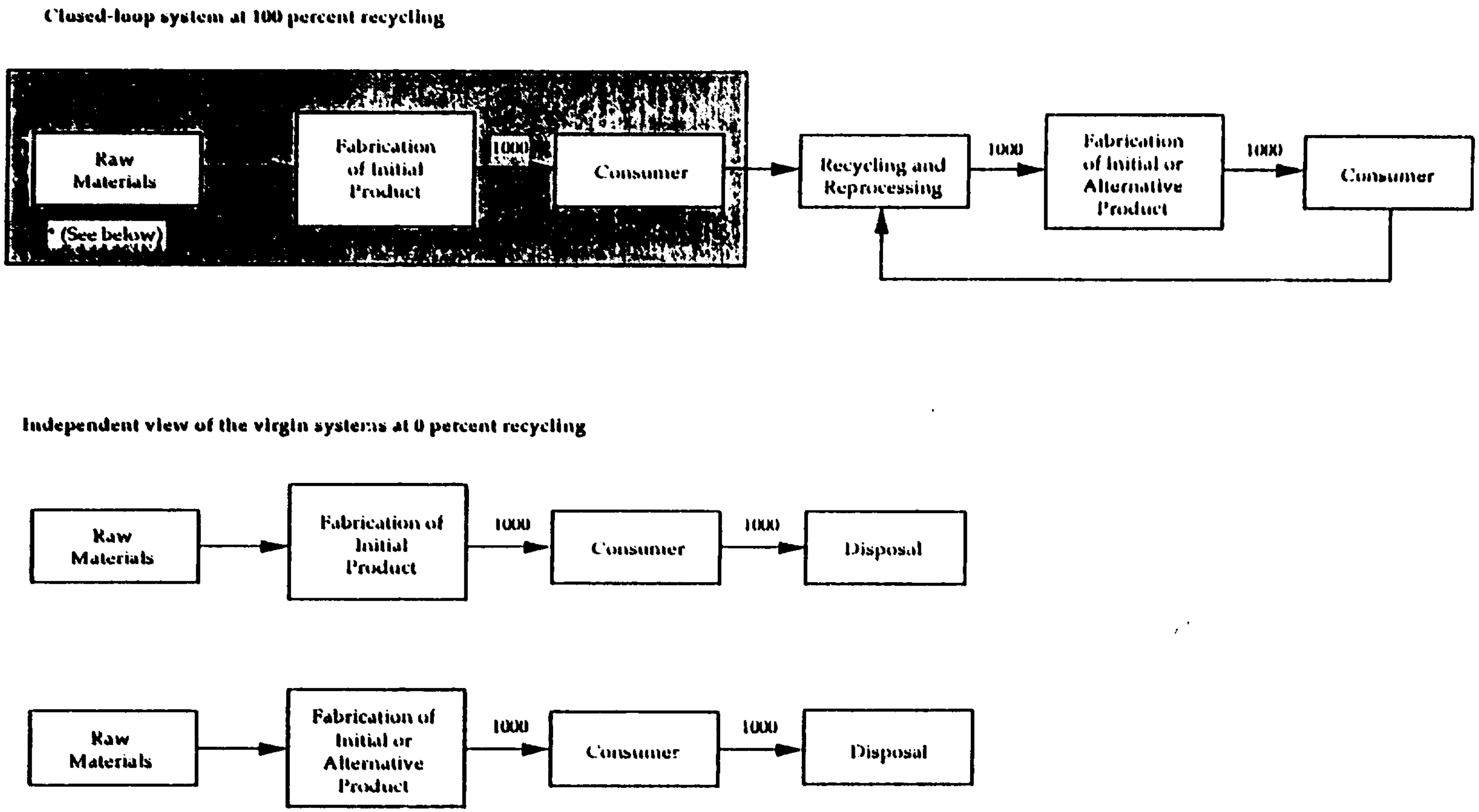

Figure 1-3. Illustration of closed-loop recycling system in comparison to each system independently

* Note: In a closed-loop system, since the material is recycled many times, the impacts of the initial virgin system manufacturing steps are divided between all of the many products made from that original material. Consequently, these initial impacts become negligible, and the only impacts associated with closed-loop recycled material are those which result form the recycling process and any subsequent processes such as fabrication.

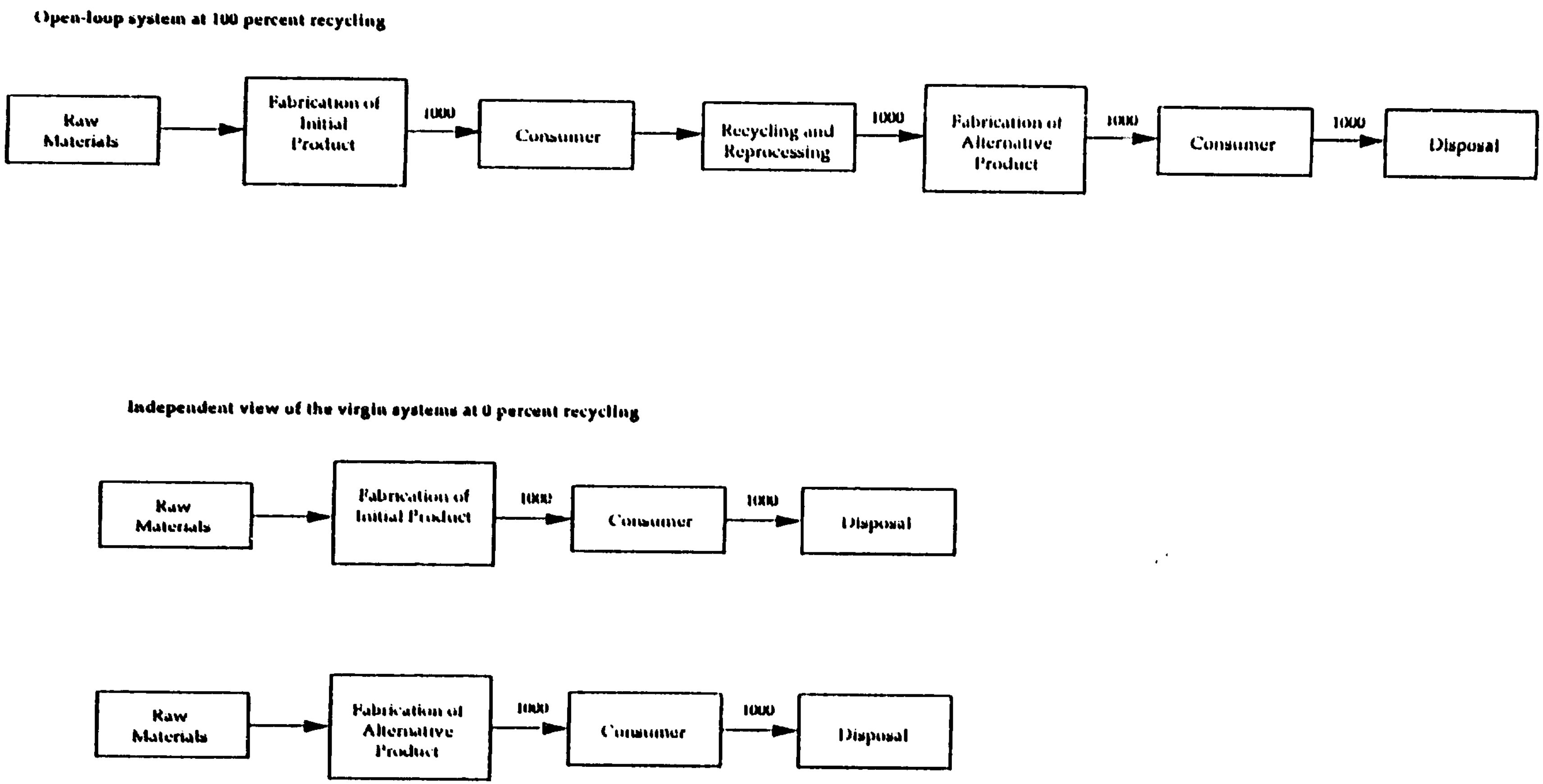

Figure 1-4. Illustration of open-loop recycling system in comparison to each system independently

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

The recycling method assumed for each of the systems that include recycling is outlined in the pertinent chapters of this report.

The refillable glass and PETG bottles are analyzed in this study at rates of 25 trips (or uses) and 6 trips per bottle, respectively. The number of trips per bottle can be converted to a trippage rate, somewhat analogous to a recycling rate, using the following formula.

$$\text{Trippage rate} = ((\text{trips} - 1)/\text{trips}) \times 100\%$$

For example, where the bottle on average is used for 25 trips, the trippage rate is obtained as follows:

$$\text{Trippage rate} = ((25 - 1)/25) \times 100\% = 96\%$$

This rate is roughly comparable to a 96 percent closed-loop recycling system, where 96 percent of the bottles are recovered for reuse in new bottles. In this case, only 40 kilograms of virgin material are needed to make enough bottles to deliver the same amount of product which would require 1,000 kilograms of bottles in a non-refillable system. Those 40 kilograms make 25 "trips" through the refilling loop to deliver the comparable amount of product. The practice of re-use also introduces the necessity of collection and washing operations to complete the system for these bottles.

System Components Not Included

The following components of each system are not included in this study. Neglecting such factors helps keep the scope of the study focused and manageable within practical budget and time constraints.

Capital Equipment. The energy and wastes associated with the manufacture of capital equipment are not included. This includes equipment to manufacture buildings, motor vehicles, and industrial machinery. The energy and emissions associated with such capital equipment generally become negligible with respect to a 1,000-kilogram system analysis.

Space Conditioning. The fuels and electricity consumed to heat, cool, and light manufacturing establishments are omitted from the calculations in most cases. For most industries, space conditioning energy is quite low compared to process energy. Energy consumed for space conditioning is usually less than one percent of the total energy consumption for the manufacturing process.

Support Personnel Requirements. The energy and wastes associated with research and development, sales, and administrative personnel or activities are not included in this inventory.

Miscellaneous Materials and Additives. Materials such as catalysts, pigments, or other additives which total only a small percentage of the net process inputs are often excluded from the inventory if their contributions are estimated to be negligible.

Consumer Effects. Effects related to consumer activities such as transporting a product home from the retail store are not included in this analysis. It is assumed that trips to retail stores are necessary for other reasons, and are not attributed solely to the products. Similarly, the energy required to refrigerate products in the home are not included, because a number of various food products are also stored in home refrigerators.

Consumer recycling practices and resulting effects on recycling are another area not included in this analysis. Certain highly variable and unpredictable household practices, along with variable practices in collecting and transporting recyclables can have a major effect on results. These household practices vary from country to country, and depend on the industrial stage of the given country as well as education and culture.

To illustrate this point, an example is provided here of the effect of varying consumer practices in the U.S. If glass containers are rinsed with hot water before being recycled, the energy to heat hot water may be as much as 1 to 3.5 Gigajoules per tonne of glass bottles. While this is not required for some containers, our surveys show that many households do in fact use hot water in some cases. Other household practices include dedicated trips by car to a recycling or buy back center, requiring from 1.7 to 3.5 Gigajoules per tonne of recyclables. Another important variable is the efficiency of routing the vehicles that pick up materials. In the case of buy back or drop off centers, our data show that the energy to pick up the recyclables and take them to a Materials Recovery Facility (MRF) or other processing site can be as high as 8 Gigajoules per tonne of material. One other possible occurrence which is certainly relevant today is that recovered materials may be exported to foreign markets, adding as much as 2.3 Gigajoules per tonne to the recycling energy requirements.

All of these factors taken together can add perhaps as much as 12 Gigajoules per tonne to the ordinary recycled product manufacturing energy. The inclusion of these variables is quite complex. They are all a function of recycling rate, but not in any simple way. For low recovery rates, fewer inefficient household practices may occur, but inefficiencies in the collection and processing system may result in anomalous high energy requirements. On the other hand, high recovery rates may create inefficiency by increasing transportation requirements and by bringing more inefficient participants into the system.

GEOGRAPHICAL SCOPE

The calculations of process energy requirements and emissions, fuel energy values and emissions, transportation requirements, method of manufacture and a number of other important details are dependent on the country in which a material is manufactured. Many of the materials used to produce the packaging systems examined in this analysis are produced in Mexico from imported or domestically produced raw materials. Other materials are imported in a semi-finished form from several different countries. It is not possible to examine the production of raw materials in every country that exports to Mexico. Therefore, a number of assumptions were made about the country of origin for the raw materials used in the packaging configurations examined in this study. These assumptions are presented in Table 1-2. Unless a material is further broken down by raw material requirement in the table, all of the raw materials used to produce it are also assumed to originate in the specified country.

The countries indicated as raw material suppliers in Table 1-2 are not necessarily the sole or primary suppliers of these materials to Mexico. Raw materials were assumed to originate in these countries for two reasons:

1) life cycle data were available for production in these countries and

2) data supplied by producers in Mexico indicated that at least a portion of the raw materials used in their manufacturing operations were produced in these countries.

Precise import statistics were not available for this study; therefore, it is not known what percent of imported raw materials are represented by those examined in this study.

Table 1-2

COUNTRY OF ORIGIN FOR RAW MATERIALS

Raw Material	Country of Origin
Three-piece tin-coated steel can	
Tin-coated steel sheet	U.S.A.
Finished can body and ends	Mexico
Aluminum beer can	
Aluminum sheet	U.S.A.
Aluminum ingots	U.S.A., Canada
Bauxite	U.S.A., Australia, Jamaica
Alumina	Australia, Jamaica, Guinea
Converted can body and top	Mexico
Non-refillable glass soft drink bottle	
Glass	Mexico
Steel crown	Mexico
Steel sheet	U.S.A.
Refillable glass soft drink bottle	
Glass	Mexico
Steel crown	Mexico
Steel sheet	U.S.A.
Refillable PETG soft drink bottle	
PETG bottle	Mexico
PETG resin	U.S.A.
Polypropylene closure	Mexico
Polypropylene resin	U.S.A.
Non-refillable PET edible oil bottle	
PET bottle	Mexico
PET resin	U.S.A.
HDPE closure	Mexico
HDPE shampoo bottle	
HDPE bottle	Mexico
Polypropylene closure	Mexico
Polypropylene resin	U.S.A.

(continued)

Table 1-2
(continued)

COUNTRY OF ORIGIN FOR RAW MATERIALS

Raw Material	Country of Origin
PVC water bottle	
PVC bottle	Mexico
HDPE closure	Mexico
LDPE bread bag	
LDPE bag	Mexico
Woven polypropylene sugar bag	
Woven bag	Mexico
Polypropylene resin	U.S.A.
Polypropylene syrup bottle	
Polypropylene bottle	U.S.A.
HDPE closure	U.S.A.
HDPE cap for closure	U.S.A.
Polystyrene yogurt container	
Polystyrene container	Mexico
Foil seal	Mexico
Aluminum foil	Mexico
Aluminum sheet	U.S.A.
Expanded polystyrene grape crate	
Polystyrene crate	Mexico
Paper sack for corn flour	
Paper sack	Mexico
Bleached semi-kraft paper	Mexico
Post-industrial paper	Mexico, U.S.A.
Paper sack for cement	
Paper sack	Mexico
Unbleached semi-kraft paper	Mexico
Post-industrial paper	Mexico, U.S.A.

(continued)

Table 1-2
(continued)

COUNTRY OF ORIGIN FOR RAW MATERIALS

Raw Material	Country of Origin
Folding carton cereal box	
Cereal box	Mexico
Boxboard	Mexico
Double kraft liner	U.S.A.
Old corrugated containers	Mexico
Clay coating	U.S.A.
Corrugated box for egg trays	
Corrugated box	Mexico
Corrugated boxboard	Mexico
Old corrugated containers	Mexico, U.S.A.
Preconsumer box clippings	Mexico
Starch adhesive	Mexico
Corn	U.S.A.
Metallized snack pack	
Metallized BOPP film	Mexico
Aluminum wire	Germany, U.S.A.
BOPP film	Mexico
Polypropylene resin	U.S.A.
Gable top milk carton	
Milk carton	Mexico
LDPE coated paperboard	U.S.A.
Aseptic brick for milk	
Aseptic brick	Mexico
Laminated aseptic board stock	Mexico
Aluminum foil	U.S.A.
LDPE resin	U.S.A.
Paperboard	Brazil, Sweden
Wooden fruit crate	
Fruit crate	Mexico

Source: Franklin Associates, Ltd.

DATA

The accuracy of the study is only as good as the quality of input data. The development of methodology for the collection of data is essential to obtaining quality data. Careful adherence to that methodology determines not only data quality but also objectivity. However, methods for quantifying and communicating data quality have not yet been established. Documentation of the methodology for data collection is currently the only method for communicating data quality.

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

Process Data

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

Each process identified during the construction of the flow diagram is then researched to identify potential industry sources for data. Each source for process data is contacted and provided with worksheets to assist in gathering the necessary process data for their product. Figure 1-5 presents a sample of the worksheet used to collect data for this study. M.R. Servicios de Fomento Industrial S.A. de C.V., a consulting firm in Mexico City, organized and conducted data collection from producers in Mexico. The completed data sheets were first checked in Mexico for reasonableness of data, then comprehensively checked by Franklin Associates.

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

After each data set has been completed and verified, the data sets for each process are aggregated together into a single set of data for that process. The method of aggregation for each process is determined on a case-by-case basis. Process technologies and assumptions are then documented and returned with the aggregated data to each data supplier for their review. The data and documentation may also be provided to other industry and academic experts for comment. This provides an opportunity for experts in each process to review the completed data for accuracy, reasonableness of assumptions, and representativeness.

Análisis del Ciclo de Vida y Normatividad de Envases y Embalajes Usados en México

O.N.U.D.I. SF/MEX/94/001

Data Worksheet

Date:
Interviewer:

1) General Information

Product:
Base Quantity:
Production Period Begining: | Production Period Ending:
Company Name:
Adress:
General Phone Number:

Prepared by:
Position:
Phone Number:

System [illegible]

Prepared by:
Position:
Phone Number:

2) Raw Material [illegible]

	Material	Weight	Units	Country of Origin	Comments
1)			kg		
2)			kg		
3)			kg		
4)			kg		
5)			kg		
6)			kg		
7)			kg		
8)			kg		

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(Franklin Associates, Ltd., Tellus Institute, Inc. (USA) / Instituo Internacional del Reciclaje, M.R. Servicios de Fomento Industrial (MEX))

Figure 1-5. Data collection worksheet.

System Inputs (continued)

Product:
Prepared by:
Position:
Phone Number:

3) Other Inputs

Material	Amount	Units	Comments
Process Water		liters	
Atmospheric Air		m3	
Oxygen From Air		kg	
Nitrogen From Air		kg	
Other:			
1)			
2)			
3)			
4)			
5)			

System Outputs

Prepared by:
Position:
Phone Number:

4) Main Output

Material	Weight	Units	Comments
1)		kg	

5) Coproduct/Byproduct/Recycled Material Outputs

Material	Weight	Units	Comments
Recovered heat		kJ	
Steam		kg@ bar	
Other:			
1)			
2)			
3)			
4)			
5)			

Hoja ② de ⑪

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Figure 1-5. Data collection worksheet (continued).

System Outputs (continued)

Product:	
Prepared by:	
Position:	
Phone Number:	

6) Solid Waste (discarded material only; list recycled materials above)

Material	Weight	Units	Comments
Wastewater Sludge		kg	
Process Waste		kg	Percent moisture %
Off-spec. Product		kg	
Trim or Scrap		kg	
Packaging Material		kg	
Other:			
1)			
2)			
3)			
4)			
5)			
6)			

Prepared by:	
Position:	
Phone Number:	

7) Atmospheric Emissions

Material	Weight	Units	Measured	Norm	Calculated	Estimate	Comments
Particulates		kg					
Sulfur Oxides		kg					
Nitrogen Oxides		kg					
Carbon Monoxide		kg					
Carbon Dioxide (fossil)		kg					
Carbon Dioxide (non-fossil)		kg					
Aldehydes		kg					
Methane		kg					
Kerosene		kg					
Ethylene Oxide		kg					
Benzene		kg					

Hoja ③ de ⑤

Sp. Ver. & Tech. Rev. RHBC/SPI (ver 2) @ 24/01/1994 [Interno SPI: RSBB_FIV] File A:\RSBB_FIV\INVENTARIO\[Lotus 123]\II_DATOS.WK1

[Franklin Associates, Ltd., Tellus Institute, Inc. (USA) / Instituto Internacional del Reciclaje, M.R. Servicios de Fomento Industrial (MEX)]

Figure 1-5. Data collection worksheet (continued).

System Outline (continued)

Product: ____________________
Prepared by: ____________________
Position: ____________________
Phone Number: ____________________

7) Atmospheric Emissions (continued)

Material	Weight	Units	Measured	Norm	Calculated	Estimate	Comments
Ethylbenzene		kg					
Naphthalene		kg					
Vynil Chloride		kg					
Carbon Tetrachloride		kg					
Other Hydrocarbons (specify):							
1)		kg					
2)		kg					
3)		kg					
4)		kg					
5)		kg					
Chloroform		kg					
Fluoride		kg					
Hydrogen Sulfide		kg					
Ammonia		kg					
Chloride		kg					
Phosphorus		kg					
Mercury		kg					
Nitrogen		kg					
Lead		kg					
Zinc		kg					
Other Atmospheric Emissions (specify):							
1)		kg					
2)		kg					
3)		kg					
4)		kg					
5)		kg					

Prepared by: ____________________
Position: ____________________
Phone Number: ____________________

8) Waterborne Emissions

Material	Weight	Units	Measured	Norm	Calculated	Estimate	Comments
Dissolved Solids		kg					
Suspended Solids		kg					

Hoja ④ de ⑨

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Figure 1-5. Data collection worksheet (continued).

System Outputs (continued)

Product:
Prepared by:
Position:
Phone Number:

B) Waterborne Emissions (continued)

Material	Weight	Units	Measured	None	Calculated	Estimate	Comments
COD		kg					
BOD		kg					
Oil and Grease		kg					
Benzene		kg					
Vinyl Chloride		kg					
Ethylbenzene		kg					
Phenol		kg					
Naphthalene		kg					
Carbon Tetrachloride		kg					
1,2 Dichloroethane		kg					
Other Hydrocarbons (specify)							
1)		kg					
2)		kg					
3)		kg					
4)		kg					
5)		kg					
Sulfuric Acid		kg					
Hydrochloric Acid		kg					
Other Acids (specify)							
1)		kg					
2)		kg					
3)		kg					
4)		kg					
5)		kg					
Aluminum		kg					
Antimony		kg					
Arsenic		kg					
Cyanide		kg					
Chloride		kg					
Chromium		kg					
Phosphorus		kg					
Iron		kg					
Mercury		kg					
Nitrogen		kg					
Nickel		kg					

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[Franklin Associates, Ltd., Tellus Institute, Inc. (USA) / Instituto Internacional del Reciclaje, M.R. Servicios de Fomento Industrial (MEX)]

Figure 1-5. Data collection worksheet (continued).

System Outputs (continued)

Product:
Prepared by:
Position:
Phone Number:

8) Waterborne Emissions (continued)

Material	Weight	Units	Measured	Form	Calculated	Estimate	Comments
Lead		kg					
Thallium		kg					
Zinc		kg					
Metal Ions		kg					
Fluorides		kg					
Phosphates		kg					
Nitrates		kg					
Sulfides		kg					
Sulfates		kg					
Pesticides		kg					
Chloroform		kg					
Tin		kg					
Ferrous Sulfate		kg					
Other Waterborne Emissions (specify)							
1)		kg					
2)		kg					
3)		kg					
4)		kg					
5)		kg					
Alkalinity		pH					

Prepared by:
Position:
Phone Number:

9) Other Outputs

Material	Weight	Units	Measured	Form	Calculated	Estimate	Comments
Discharged Water		liters					
Evaporative Loss		kg					
Other (specify)							
1)							
2)							
3)							
4)							
5)							

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[Franklin Associates Ltd., Tellus Institute, Inc. (USA), Instituto Internacional del Reciclaje, M.R. Servicios de Fomento Industrial (MFX)]

Figure 1-5. Data collection worksheet (continued)

Energy Inputs

Product:	
Prepared by:	
Position:	
Phone Number:	

10) Purchased Energy

Energy Source	Amount	Units	Comments
Purchased Electricity		kWh	
Power Factor			
Natural Gas		m³	
LPG		kg	
Coal		kg	
Distillate Oil		litros	
Gasoline		litros	
Diesel		litros	
Wood		kg	
Other Fuel (specify):			
1)		kg	
2)		kg	
3)		kg	
4)		kg	
5)		kg	

Prepared by:	
Position:	
Phone Number:	

11) Self Generated Electricity

Energy Source	Amount	Units	Comments
Amount Used		kWh	
Fuels Used to Generate (specify):			
1)			
2)			
3)			
4)			
5)			

Hoja ⑦ de ⑧

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Sp. Ver. & Tech. Rev. RIIBC/SPI (ver. 2) @ 26/01/1994 (Intento SEI-RSUB PIV)

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Figure 1-5. Data collection worksheet (continued).

Energy Inputs (continued)

Product:
Prepared by:
Position:
Phone Number:

12) Transportation (average shipping distance to customer)

Transportation Mode	Distance	Units	Comments
Combination Truck – Diesel		km	
Combination Truck – Gasoline		km	
Single unit Truck – Diesel		km	
Single unit Truck – Gasoline		km	
Rail – Diesel		km	
Rail – Electricity		km	
Barge – Diesel		km	
Barge – Residual		km	
Ocean Freighter – Diesel		km	
Ocean Freighter – Residual		km	
Natural Gas Pipeline		km	
Petrochemical Pipeline		km	

Fuel-Related Emissions

Prepared by:
Position:
Phone Number:

Material	Weight	Units	Measured	Norm	Calculated	Estimate	Comments
Particulates		kg					
Sulfur Oxides		kg					
Nitrogen Oxides		kg					
Carbon Monoxide		kg					
Carbon Dioxide (fossil)		kg					
Carbon Dioxide (non – fossil)		kg					
Other Atmospheric Emissions (specify):							
1)		kg					
2)		kg					
3)		kg					
4)		kg					
5)		kg					

Sp. Ver. & Tech. Rev. HIIEC/SPI (ver. 3) @ 24/03/1991 [Interno SPI: RSUII_PIV]

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Figure 1-5. Data collection worksheet (continued).

Fuel Related Emissions (continued)

Product:	
Prepared by:	
Position:	
Phone Number:	

(4) Waterborne Emissions

Material	Weight	Units	Measured	Norm	Calculated	Estimate	Comments
Dissolved Solids		kg					
Suspended Solids		kg					
COD		kg					
BOD		kg					
Phenol		kg					
Oil and Grease		kg					
Other Hydrocarbons (specify)							
1)		kg					
2)		kg					
3)		kg					
4)		kg					
5)		kg					

Prepared by:	
Position:	
Phone Number:	

(5) Solid Waste

Material	Weight	Units	Measured	Norm	Calculated	Estimate	Comments
Air Pollution Control		kg					
Ash		kg					
Other Solid Waste (specify)							
1)		kg					
2)		kg					
3)		kg					
4)		kg					
5)		kg					

Hoja ① de ①

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Sp. Ver. & Tech. Rev. RIIRC/SPI (ver. 1) @ 26/03/1991 [Interno SPI: RSUR_PIV]

(Franklin Associates, Ltd., Tellus Institute, Inc. (USA) / Instituto Internacional del Reciclaje, M.R. Servicios de Fomento Industrial (MEX))

Figure 1-5. Data collection worksheet (continued).

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

Objectivity. Each process is researched independently of all other processes. No calculations are performed to link processes together with the production of their raw materials until after data gathering and review is complete. The procedure of providing the aggregated data and documentation to suppliers and other industry experts provides several opportunities to review the objectivity of the research. This process serves as an external expert review of each process. Also, because these data are reviewed individually, assumptions are reviewed based on their relevance to the process rather than on thei. effect on the overall outcome of the study.

Sources. Some data for this study were developed specifically for this project. The study also relies upon the existing FAL database of LCI data for products and processes. This database has been developed over a period of years through research for many LCI projects.

One advantage of this database is that FAL research has been conducted for many products and processes, so that the database reflects a broad range of expertise, rather than expertise on a single product type at the expense of other types of products. For example, if a producer of plastic products were to commission a study, the sponsor could supply high quality data for the production of those plastic products. However, it may be much more difficult to obtain the same quality data for a material not produced by the sponsor. Because of the large number and wide variety of studies which have contributed to the database, uniform data quality can be achieved.

Another advantage of the database is that it is continually updated. The primary sources used for the necessary revisions to the existing database are technical literature, government publications, published industry statistics and personal interviews with industry representatives. Franklin Associates continually improves its extensive database by pursuing industry input for all types of manufacturing processes.

Throughout this report, Franklin Associates, Ltd. is usually shown as the source of information for the summarized results. In most cases, a single summary table may have been developed from raw industrial data obtained from 100 or more specific sources. The comprehensive appendix to this report presents the basic industrial data and each specific source.

The source of data used for each packaging system is discussed in the pertinent chapter of this report.

Fuel Data

The energy and emissions released when fuels are burned are only one part of the energy and emissions associated with the use of a fuel. Before each fuel is usable, it must be mined, as in the case of coal or uranium, or extracted from the earth in some manner. Further processing is often necessary before the fuel is usable. Coal is crushed or pulverized and sometimes cleaned. Crude oil is refined to produce fuel oils and liquefied petroleum gases. Raw natural gas is desulfurized, cleansed, and adjusted in composition to meet pipeline standards.

To avoid confusion regarding environmental emissions from the combustion of fuels and emissions resulting from the fuel production process, it is necessary to define terms to describe the different emissions. The combustion products of fuels are defined as "combustion data." Emissions which result from the mining, refining, and transportation of fuels are defined as "precombustion data." Precombustion data and combustion data together are referred to as "fuel-related data."

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

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

For electricity production in Mexico, M.R. Servicios de Fomento Industrial S.A. de C.V. compiled data for energy sources and emissions from public data of Comisión Federal de Electricidad. These same data for emissions from utility boilers were used to estimate the emissions from industrial boilers. M.R. Servicios de Fomento Industrial S.A. de C.V. also collected the data for the combustion energy content of fuels in Mexico.

Data Accuracy

An important issue in considering the use of this study is the reliability of the calculations. In a complex study with literally thousands of numbers, the accuracy of the data and how it affects conclusions is truly a complex subject, and one that does not lend itself to standard error analysis techniques. However, it is possible to estimate the reliability of the study results in other ways.

One important aspect of data accuracy is the way each number affects the study results. In some cases, each number contributes very little to the total value, so a large error in one data point does not necessarily create a problem. It is assumed that with careful scrutiny of the data any errors will be random. That is, some numbers will be a little high due to errors, and some will be slightly low, but in the summing process these errors cancel out. For process steps that make a larger than average contribution to the total, special care is taken with the data quality.

Conversely, certain numbers do not stand alone, but rather affect several numbers in the system. An example is the amount of a raw material required for a process. This number will affect every step in the production sequence prior to the process. Errors such as this that propagate backward throughout the system are more significant in steps that are closest to the end of the production sequence.

This was the first attempt to gather national data for environmental life cycle studies in Mexico. The readers should be aware that, because of the complexity of a national data procurement effort, there are inevitable data quality problems which result from incomplete reporting in any first effort of this type. More time is required to correct those problems. For the systems studied in this project, most of the energy required and the emissions produced are from manufacturing operations. However, at best, for any manufacturing system producing goods in Mexico, data were received from only one or two producers with operations in Mexico. This may be very poor statistical coverage in some cases where there may be as many as dozens of producers in operation in Mexico. The number of producers responding is reported in each succeeding chapter of this report.

The data received from Mexican producers were compared to average U.S. values for validation, but further sources for verification of the reasonableness of data could not be found. In many cases, **no** data were obtained from operations in Mexico, so U.S. average data were used as a surrogate. This includes solid waste data for which there was no Mexican information available. While basic manufacturing processes in Mexico may be similar to processes in the U.S., there are no data suggesting that pollution controls are the same, which may lead to indeterminate errors incurred by using U.S. data as surrogates for manufacturing in Mexico. Therefore, validity of any conclusions drawn from analyses based upon these data need to be viewed with the data quality problems in mind.

PRESENTATION OF RESULTS

The geographical scope for this study includes the production of materials in more than one country. One of the objectives of this analysis is to inventory the resource usage and environmental emissions that occur in Mexico and countries that supply raw materials to Mexico. Therefore, results are reported according to country.

The energy requirements and environmental emissions for manufacturing operations and the amounts of postconsumer solid waste resulting from disposal of the packaging systems are presented separately from the energy requirements and fuel-related emissions for collecting and landfilling postconsumer solid waste. Data for postconsumer solid waste collection and landfilling are based solely on data for the solid waste disposal system in the United States. It is not known if this system is representative of the disposal system in Mexico. Due to the unknown applicability of these data, they are not combined with other life-cycle data.

Energy Requirements

The quantities of energy which result from the entire life cycle of the products examined in this study have been totaled by country. The various types of energy are converted to Gigajoules so that they may be summed in various categories. Energy requirements are presented as total energy values that include both combustion and precombustion energy requirements.

Energy usage for each system is categorized as "process energy," "transportation energy" or "energy of material resource." Process energy includes all fuel and energy requirements for production. This category includes all purchased fuels and electricity, and fuels used for self-generated electricity or purchased steam. Transportation energy includes all energy expended in transporting raw and intermediate materials to the next step in the production sequence. The energy of material resource was defined previously in this chapter.

The Gigajoule values for fuels and electricity consumed for each package are also summed and categorized into an energy profile according to the seven basic energy sources listed below:

- Natural gas
- Petroleum

- Coal
- Hydropower
- Nuclear
- Wood-derived (self-generated power and steam in pulp mills)
- Other (including geo-thermal, solar, wind, etc.)

Each system's energy profile includes the Gigajoule values for all transportation steps and all fossil fuel-derived feedstock materials, as well as the process energy.

Environmental Emissions

Environmental emissions include solid wastes, air emissions, and waterborne emissions. The scope of this analysis is to identify where and what emissions are generated through a cradle-to grave analysis of the systems being examined. No attempt has been made to determine the relative environmental effects of these pollutants.

The quantities of solid waste generated from the entire life cycle of the products examined in this study have been totaled. The individual categories of atmospheric and waterborne emissions have not been totaled because it is widely recognized that various substances emitted to the air and water differ greatly in their effect on the environment.

Solid Wastes. Solid waste is categorized as process waste, fuel waste or postconsumer waste. Process waste is industrial waste that is produced during the manufacture of the product. Process-related industrial solid wastes include: wastewater treatment sludges; trim scrap, off-spec product and unused raw materials that are not recycled; packaging used to deliver raw materials that is not re-used or recycled; and mineral extraction wastes. Postconsumer solid wastes are the packaging materials that are disposed by consumers after they have fulfilled their use. The packaging is adjusted to account for recycled content and recovery rate of the containers. Fuel-related solid wastes include: solids collected in air pollution control devices, fuel combustion residues such as the ash generated by burning coal or wood, and industrial waste generated during the production of the fuel (precombustion solid waste).

Solid wastes in each category are presented in both kilograms and cubic meters of waste and represent materials under landfill conditions. The volume data are important when considering land disposal because landfills are filled on a volume basis. Landfill densities were taken primarily from a study performed by Franklin Associates, Ltd. for the United States Environmental Protection Agency (EPA), **Characterization of Municipal Solid Waste in the United States: 1992 Update.** Landfill densities were also obtained from other landfill density studies performed by Franklin Associates in cooperation with The Garbage Project of the University of Arizona's Archeology Department, including **Estimate of the Volume of MSW and Selected Components in Trash Cans and Landfills, February 1990**. Landfill densities for the primary containers in this study are presented in Appendix Q.

Atmospheric Emissions. Atmospheric emissions are categorized as process or fuel-related emissions. Process emissions include all atmospheric pollutants produced during the manufacture of a product that are not the result of the combustion of a fuel. Fuel-related emissions include all emissions from the combustion of a fuel source. Included in the fuel-related emissions are emissions from the generation of electricity and all emission resulting from production of the fuel source (pre-combustion emissions).

Emissions include all substances classified as pollutants. Emissions are reported as kilograms of pollutant per 100,000 units of product output. Where control devices exist, the amounts reported represent actual discharges into the atmosphere after existing emission control devices. The emissions associated with the combustion of fuel for process or transportation energy as well as the process emissions are included in the analysis.

Waterborne Emissions. Waterborne emissions are categorized as process or fuel-related emissions. Process emissions include all waterborne pollutants produced during the manufacture of a product that are not the result of the combustion of a fuel. Fuel-related emissions include all emissions from the combustion of a fuel source. Included in the fuel-related emissions are emissions from the generation of electricity and all emission resulting from production of the fuel source (pre-combustion emissions).

As with atmospheric emissions, waterborne wastes include all substances classified as pollutants. Waterborne wastes are reported as kilograms of pollutant per unit of product output. The values reported are the average quantity of pollutants still present in the wastewater stream after wastewater treatment, and represent discharges into receiving waters.

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

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

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

6 **Product Life Cycle Assessment–Principles and Methodology.** Nord 1992:9. ISBN 92 9120 012 3.

Chapter 2

ENERGY AND ENVIRONMENTAL RESULTS FOR ALUMINUM BEVERAGE CONTAINERS

INTRODUCTION

This chapter provides a summary of the energy requirements and environmental emissions for the production, recycling and disposal of aluminum beverage containers in Mexico. The basis for the results presented in this chapter is 100,000 aluminum containers. Supporting data for this chapter are presented in Appendix C of the separately bound Appendix document.

The aluminum cans analyzed in this study are assumed to contain 51.6 percent postconsumer recycled aluminum. This aluminum is recycled in a closed-loop system. Therefore, the recovery rate is assumed to equal 51.6 percent. To complete this closed-loop system, containers are collected in Mexico and transported to the United States to be remelted, cast into ingots and rolled into aluminum sheet.

DATA SOURCES

Data for the production of primary and secondary aluminum sheet in the United States were taken from Franklin Associates' database. This information was reviewed by representatives of the aluminum industry in the United States for this study, and updated according to their suggestions.

Data for the production of aluminum cans were provided by two of the three aluminum can manufacturers in Mexico. These two aluminum can producers represent approximately 80 percent of the aluminum can market. Each producer supplied data that were averaged considering all the producer's facilities. The data were then aggregated for this analysis.

RESULTS AND DISCUSSION

Manufacturing Energy Requirements

Table 2-1 presents the energy requirements for the manufacture of 100,000 aluminum containers. The energy usage is categorized by country.

Process energy accounts for about 85 percent of the total energy for the system; 80 percent of this energy is used in the United States.

Table 2-1

ENERGY REQUIREMENTS FOR MANUFACTURE OF 100,000 ALUMINUM BEVERAGE CONTAINERS

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total
Aluminum Beverage Containers								
United States	164	86%	11.4	6%	15.0	8%	191	100%
Mexico	40.4	80%	10.3	20%			50.7	100%
Total Energy	205	85%	21.7	9%	15.0	6%	241	100%

Source: Franklin Associates, Ltd.

Transportation energy accounts for an additional nine percent of the total energy. Transportation energy is divided about equally between the United States and Mexico (transportation energy categorized under the United States also includes the transportation of raw materials used to make aluminum sheet from their country of origin, including Canada, Jamaica, Australia and Guinea).

Only six percent of the total energy for the container is classified as energy of material resource. This energy represents the coal and petroleum-based coke and pitch used during aluminum smelting.

Table 2-2 presents the energy profile for production of aluminum beverage containers. The energy profile for the United States is influenced the most by the fuel requirements for the production of electricity used for aluminum smelting.

Natural gas represents the largest energy source for can production in Mexico. About 55 percent of the energy used in Mexico for aluminum can production comes from this energy source.

Manufacturing Environmental Emissions

Solid Waste. Table 2-3 presents the solid waste for manufacturing 100,000 aluminum beverage containers. Included in this table is the postconsumer solid waste generated from disposal of containers that are not collected for recycling.

Process solid waste accounts for about 50 percent of the total solid waste weight and about 24 percent of the total solid waste volume. The process solid waste is produced in the United States and in countries supplying materials to the U.S. A large portion of this solid waste comes from refining bauxite to produce alumina.

Fuel-related solid waste makes up 27 percent of the solid waste weight and 13 percent of the solid waste volume.

Postconsumer solid waste accounts for 24 percent of the solid waste weight and about 63 percent of the solid waste volume.

Atmospheric and Waterborne Emissions. The total atmospheric and waterborne emissions for manufacturing aluminum beverage containers are presented in Table 2-4a and 2-4b, respectively.

Most of the atmospheric emissions for operations in Mexico are fuel related. These emissions are a result of production and combustion of fuels to produce energy for manufacturing operations and transportation of raw materials and finished products.

Table 2-2

ENERGY PROFILES FOR MANUFACTURE OF 100,000 ALUMINUM BEVERAGE CONTAINERS
(GJ per 100,000 Items)

	Energy Profile							
	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Total Energy
Aluminum Beverage Containers								
United States	49.3	30.8	65.1	28.7	16.1		0.38	191
Mexico	27.7	19.8	0.96	0.93	0.60		0.71	50.7
Total	77.0	50.6	66.1	29.7	16.7		1.09	241

Source: Franklin Associates, Ltd.

Table 2-3

SOLID WASTE BY WEIGHT AND VOLUME FOR MANUFACTURE OF 100,000 ALUMINUM BEVERAGE CONTAINERS

	Process Waste		Fuel Waste		Postconsumer Waste		Total Solid Waste	
	kg	cubic meter	kg	cubic meter	kg	cubic meter	kg	cubic meter
Aluminum Beverage Containers								
United States	1,511	1.89	836	1.04			2,347	2.93
Mexico	72.7	0.091	33.6	0.042	758	5.11	864	5.24
Total Solid Waste	1,584	1.98	870	1.09	758	5.11	3,212	8 17

Source: Franklin Associates, Ltd.

Table 2-4a

SUMMARY OF ATMOSPHERIC EMISSIONS FOR ALUMINUM BEVERAGE CONTAINERS
(Emissions per 100,000 items)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Atmospheric Emissions (kg)						
Particulates	31.0	12.7	43.7	0.069	2.54	2.61
Nitrogen Oxides	0.27	40.1	40.3		9.25	9.25
Hydrocarbons	2.27	33.0	35.3	11.7	13.3	25.0
Sulfur Oxides	12.5	63.6	76.1		26.7	26.7
Carbon Monoxide	76.5	15.4	91.9		14.1	14.1
Aldehydes	0.011	0.20	0.21		0.10	0.10
Methane		0.086	0.086		0.045	0.045
Other Organics		2.14	2.14		4.24	4.24
Kerosene		0.0015	0.0015		5.8E-05	5.8E-05
Ammonia	0.0077	0.0020	0.0097	0.013	0.0022	0.015
Lead	3.3E-07	0.0019	0.0019		0.0014	0.0014
Hydrogen Fluoride	1.68		1.68			
Fossil Carbon Dioxide	1,140	10,059	11,199		3,553	3,553
Hydrogen Chloride	4.1E-05	5.9E-05	9.9E-05		6.4E-05	6.4E-05
Mercury	3.3E-05	8.1E-05	1.1E-04		7.7E-05	7.7E-05
Chlorine	8.8E-05		8.8E-05		0.011	0.011
Chromium Compounds		0.0047	0.0047		0.0011	0.0011
Manganese Compounds		0.0076	0.0076		0.0014	0.0014
Nickel Compounds		0.0047	0.0047		0.0068	0.0068
Antimony					1.4E-04	1.4E-04
Arsenic		0.0023	0.0023		6.4E-04	6.4E-04
Beryllium		2.7E-04	2.7E-04		6.1E-05	6.1E-05
Cadmium					5.8E-04	5.8E-04
Cobalt		1.3E-04	1.3E-04		4.0E-04	4.0E-04
Selenium		5.0E-05	5.0E-05		1.5E-04	1.5E-04
Sulfuric Acid					1.03	1.03
Na_2O_2					9.2E-05	9.2E-05
KO_2					9.2E-05	9.2E-05
V_2O_5					9.2E-05	9.2E-05

Source: Franklin Associates, Ltd.

Table 2-4b

SUMMARY OF WATERBORNE EMISSIONS FOR ALUMINUM BEVERAGE CONTAINERS
(Emissions per 100,000 items)

	United States			Mexico		
Waterborne Emissions (kg)	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Acid	0.17	4.3E-07	0.17		4.7E-07	4.7E-07
Metal Ion	0.41	0.0091	0.42		0.0089	0.0089
Dissolved Solids	3.83	5.35	9.18	24.0	0.39	24.4
Suspended Solids	21.0	0.0049	21.0	0.13	0.032	0.16
BOD	1.19	0.0053	1.19		0.11	0.11
COD	14.1	0.025	14.1	0.98	0.18	1.16
Phenol	1.4E-04	3.0E-05	1.7E-04		0.0020	0.0020
Sulfides	9.3E-06		9.3E-06		0.0011	0.0011
Oil	7.59	0.099	7.69	0.34	0.12	0.46
Sulfuric Acid		5.17	5.17		0.10	0.10
Iron	0.044	1.29	1.34	6.7E-05	0.026	0.026
Ammonia	0.081	6.9E-04	0.082		0.018	0.018
Chromium	1.2E-06	1.7E-06	2.9E-06	0.0053	2.6E-04	0.0055
Lead	5.8E-07	7.6E-07	1.3E-06	0.0069	8.4E-07	0.0069
Zinc	7.3E-06	1.1E-05	1.9E-05	0.031	1.2E-05	0.031
Fluorides	0.24		0.24	0.037		0.037
Cyanide	2.7E-04		2.7E-04	0.0041		0.0041
Aluminum				0.10		0.10
Nickel	5.0E-08		5.0E-08	0.019		0.019
Mercury	9.1E-08		9.1E-08	6.2E-05		6.2E-05
Phosphates	1.61		1.61			
Arsenic				8.5E-04		8.5E-04

Source: Franklin Associates, Ltd.

Atmospheric hydrocarbon emissions are produced during the can production step. Presumably, these emissions are a result of solvent evaporation from varnish application and can painting. These emissions may not be typical for can production operations that do not use solvent-based varnishes and paints. However, it is not known what percentage of the can producers in Mexico use solvent-based varnishes and paints.

Many of the waterborne emissions in Mexico are process related. Data supplied by producers in Mexico reported these emissions for the can body production step.

Disposal Energy and Environmental Emissions

Table 2-5 presents the energy requirements for the operation of packer trucks and landfill equipment to dispose of postconsumer aluminum beverage cans that become solid waste (cans that are not collected for recycling). This equipment is assumed to use diesel as a fuel source; therefore, this energy is derived from petroleum.

The fuel-related environmental emissions for the operation of packer trucks and landfill equipment to dispose of postconsumer aluminum beverage cans that become solid waste are presented in Table 2-6.

Table 2-5

ENERGY REQUIREMENTS FOR DISPOSAL OF ALUMINUM BEVERAGE CONTAINERS
(gigajoules for units disposed per 100,000 items)

	Packer Truck Energy	Landfill Equipment Energy	Total Disposal Energy
Aluminum Beverage Containers	0.29	0.18	0.47

Source: Franklin Associates, Ltd.

Table 2-6

SUMMARY OF FUEL-RELATED ENVIRONMENTAL EMISSIONS FOR DISPOSAL OF ALUMINUM BEVERAGE CONTAINERS
(Emissions for units disposed per 100,000 items)

	Packer Truck Emissions	Landfill Equipment Emissions	Total Disposal Emissions
Atmospheric Emissions (kg)			
Particulates	0.027	0.017	0.044
Nitrogen Oxides	0.37	0.22	0.59
Hydrocarbons	0.093	0.057	0.15
Sulfur Oxides	0.087	0.052	0.14
Carbon Monoxide	0.12	0.071	0.19
Aldehydes	0.0056	0.0034	0.0091
Methane	4.03E-05	2.44E-05	6.47E-05
Other Organics	6.13E-07	3.71E-07	9.84E-07
Kerosene	1.99E-08	1.20E-08	3.19E-08
Ammonia	3.05E-05	1.85E-05	4.89E-05
Lead	2.05E-06	1.24E-06	3.29E-06
Fossil Carbon Dioxide	21.1	12.8	33.9
Hydrogen Chloride	8.98E-07	5.44E-07	1.44E-06
Mercury	6.67E-08	4.04E-08	1.07E-07
Chlorine	1.58E-05	9.57E-06	2.54E-05
Chromium Compounds	5.56E-07	3.37E-07	8.92E-07
Manganese Compounds	6.16E-07	3.73E-07	9.90E-07
Nickel Compounds	6.09E-06	3.69E-06	9.79E-06
Antimony	1.31E-07	7.95E-08	2.11E-07
Arsenic	3.79E-07	2.29E-07	6.08E-07
Beryllium	3.15E-08	1.91E-08	5.07E-08
Cadmium	4.69E-07	2.84E-07	7.53E-07
Cobalt	3.71E-07	2.25E-07	5.96E-07
Selenium	1.43E-07	8.64E-08	2.29E-07
Sulfuric Acid	9.89E-04	5.99E-04	0.0016
Na_2O_2	6.05E-07	3.67E-07	9.72E-07
KO_2	6.05E-07	3.67E-07	9.72E-07
V_2O_5	6.05E-07	3.67E-07	9.72E-07
Solid Waste (kg)	0.035	0.021	0.056
Solid Waste (cu m)	4.36E-05	2.64E-05	7.00E-05
Waterborne Emissions (kg)			
Acid	6.61E-09	4.01E-09	1.06E-08
Metal Ion	1.24E-04	7.53E-05	2.00E-04
Dissolved Solids	0.0054	0.0033	0.0087
Suspended Solids	4.47E-04	2.71E-04	7.18E-04
BOD	0.0015	9.00E-04	0.0024
COD	0.0025	0.0015	0.0040
Phenol	2.79E-05	1.69E-05	4.47E-05
Sulfides	1.51E-05	9.14E-06	2.42E-05
Oil	0.0015	9.15E-04	0.0024
Sulfuric Acid	3.54E-05	2.14E-05	5.68E-05
Iron	1.13E-05	6.83E-06	1.81E-05
Ammonia	2.55E-04	1.55E-04	4.10E-04
Chromium	3.60E-06	2.18E-06	5.78E-06
Lead	1.17E-08	7.10E-09	1.88E-08
Zinc	1.72E-07	1.04E-07	2.76E-07

Source: Franklin Associates, Ltd.

Chapter 3

ENERGY AND ENVIRONMENTAL RESULTS FOR PAPER PACKAGING

INTRODUCTION

This chapter provides a summary of the energy requirements and environmental emissions for the production, recycling and disposal of the following packaging materials in Mexico:

- Bleached semi-kraft paper sacks for corn flour
- Multi-layered unbleached semi-kraft paper sacks for cement
- Clay-coated paperboard folding-carton cereal boxes
- Corrugated paperboard boxes and separators for eggs

The basis for the results presented in this chapter is 100,000 packaging units. Supporting data for the paper sacks for corn flour and cement are presented in Appendix D of the separately bound Appendix document. Supporting data for the folding-carton cereal box and corrugated egg box are presented in Appendix G.

The paper packaging products examined in this study are produced in Mexico from recycled paper (both postindustrial and postconsumer) produced in the United States and Mexico. The recovery rate for bleached paper sacks is assumed to equal the estimated recovery rate for bleached paper products (15 percent). Postconsumer bleached paper flour sacks that are recovered for recycling are assumed to be recycled back into bleached paper sacks, thus establishing a closed-loop system. However, the raw material requirement for postconsumer recycled paper into bleached paper production in Mexico is greater than the quantity of bleached paper sacks recovered at this rate. Therefore, the remaining postconsumer inputs to bleached paper production are assumed to be obtained from virgin postconsumer material (virgin paper that has seen one use), thus establishing an open-loop recycling system for the remaining postconsumer paper requirements.

The recovery rate for the clay-coated paperboard box is assumed to equal the estimated recovery rate for paperboard products (13 percent). Recovered cereal boxes are assumed to be recycled back into cereal boxes, thus establishing a closed-loop system. The remaining postconsumer material needed to produced clay-coated paperboard is supplied by recovered old corrugated containers. This portion of the cereal box is not recovered; thus, it is assumed to be in an open-loop recycling system. Old corrugated containers used to produce clay-coated paperboard are assumed to be produced in Mexico.

The recovery rate for the cement sack is assumed to be zero due to potential problems with re-pulping equipment caused by residual product in the sack.

The recovery rate for corrugated containers is assumed to be as high as the postconsumer recycled content of the corrugated material collected in Mexico that is used to make the containers. Therefore, this material is assumed to be in a closed-loop system.

DATA SOURCES

Data for the production of postindustrial material imported into Mexico from the United States were take from Franklin Associates' database. Data for the production of corn in the United States were also taken from this database (corn is used to make starch adhesive in Mexico).

Data for the production of bleached and unbleached semi-kraft paper were derived from data provided by one producer in Mexico. Data for the production of clay-coated paperboard and cereal box converting were also derived from data provided by one producer in Mexico. Data for the production of recycled medium and liner used for the production of corrugated boxes were derived from data supplied by two producers in Mexico.

Data for the production of corn flour sacks, cement sacks and starch adhesive in Mexico were estimated from data in Franklin Associates' database. These data were collected from production operations in the United States. Data for the production of corrugated paperboard were also taken from this database; however, the amounts of liner and medium used to manufacture the paperboard were estimated from information supplied by sources in Mexico.

Data for the collection of postconsumer paper and paperboard used to manufacture recycled paper and paperboard in Mexico were estimated from information supplied by producers in Mexico.

RESULTS AND DISCUSSION

Bleached Semi-Kraft Paper Flour Sacks

Manufacturing Energy Requirements. Table 3-1 presents the energy requirements for the manufacture of 100,000 bleached semi-kraft paper flour sacks. The energy usage is categorized by country.

Process energy accounts for about 90 percent of the total energy for the system. About 63 percent of the process energy is used in the United States to produce postindustrial recycled paper scrap. This postindustrial material is used as a raw material for bleached semi-kraft paper production in Mexico.

Table 3-1

ENERGY REQUIREMENTS FOR MANUFACTURE OF 100,000 BLEACHED SEMI-KRAFT PAPER FLOUR SACKS

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total
Flour Sacks								
United States	67.9	94%	4.58	6%			72.5	100%
Mexico	38.7	85%	7.03	15%			45.7	100%
Total Energy	107	90%	11.6	10%			118	100%

Source: Franklin Associates, Ltd.

Transportation energy accounts for the remaining ten percent of the total energy. About 61 percent of the transportation energy is used in Mexico to transport raw materials and finished products.

The energy of material resource for wood-derived materials is not included in this analysis because wood is not used as a commercial fuel source in most industrial countries. Therefore, the energy of material resource for this system is reported as zero.

Table 3-2 presents the energy profile for production of bleached semi-kraft paper flour sacks. About 40 percent of the energy used in the United States is categorized as wood energy. This energy is used during the production of virgin paper products. Postindustrial recycled materials from these operations are used as raw materials for bleached semi-kraft paper production in Mexico.

Natural gas and petroleum represent the largest energy sources for bleached semi-kraft paper sack production in Mexico. About 89 percent of the energy used in Mexico for this system comes from these energy sources.

Manufacturing Environmental Emissions

Solid Waste. Table 3-3 presents the solid waste for manufacturing 100,000 bleached semi-kraft paper flour sacks. Included in this table is the postconsumer solid waste generated from disposal of packaging that is not collected for recycling.

Process solid waste accounts for about 16 percent of the total solid waste weight and about 10 percent of the total solid waste volume. About 55 percent of the process solid waste is produced in the United States.

Fuel-related solid waste makes up 15 percent of the solid waste weight and nine percent of the solid waste volume.

Postconsumer solid waste accounts for 69 percent of the total solid waste weight and about 81 percent of the total solid waste volume.

Atmospheric and Waterborne Emissions. The total atmospheric and waterborne emissions for manufacturing bleached semi-kraft paper flour sacks are presented in Table 3-4a and 3-4b, respectively.

Most of the atmospheric emissions for operations in Mexico are fuel related. These emissions are a result of production and combustion of fuels to produce energy for manufacturing operations and transportation of raw materials and finished products.

Table 3-2

ENERGY PROFILES FOR MANUFACTURE OF 100,000 BLEACHED SEMI-KRAFT PAPER FLOUR SACKS
(GJ per 100,000 Items)

	Energy Profile							
	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Total Energy
Flour Sacks								
United States	9.01	18.7	13.6	0.22	1.72	29.1	0.15	72.5
Mexico	18.6	22.0	1.52	1.48	0.95		1.12	45.7
Total	27.7	40.7	15.1	1.70	2.67	29.1	1.26	118

Source: Franklin Associates, Ltd.

Table 3-3

SOLID WASTE BY WEIGHT AND VOLUME FOR MANUFACTURE OF 100,000 BLEACHED SEMI-KRAFT PAPER FLOUR SACKS

	Process Waste		Fuel Waste		Postconsumer Waste		Total Solid Waste	
	kg	cubic meter	kg	cubic meter	kg	cubic meter	kg	cubic meter
Flour Sacks								
United States	165	0.21	239	0.30			404	0.50
Mexico	133	0.17	51.0	0.064	1,335	3.04	1,519	3.27
Total Solid Waste	298	0.37	290	0.36	1,335	3.04	1,922	3.77

Source: Franklin Associates, Ltd.

Table 3-4a

SUMMARY OF ATMOSPHERIC EMISSIONS FOR BLEACHED SEMI-KRAFT PAPER FLOUR SACKS
(Emissions per 100,000 items)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Atmospheric Emissions (kg)						
Particulates	0.31	6.16	6.47		2.52	2.52
Nitrogen Oxides		12.6	12.6		10.5	10.5
Hydrocarbons	0.25	9.23	9.48		19.7	19.7
Sulfur Oxides	1.12	16.3	17.5		39.3	39.3
Carbon Monoxide		24.8	24.8		8.69	8.69
Aldehydes	5.23E-04	1.41	1.41		0.12	0.12
Methane		0.022	0.022		0.039	0.039
Other Organics		1.38	1.38	28.3	2.85	31.1
Kerosene		1.69E-04	1.69E-04		9.01E-05	9.01E-05
Ammonia	2.61E-04	0.0019	0.0022		0.0024	0.0024
Lead		5.99E-04	5.99E-04		0.0013	0.0013
Fossil Carbon Dioxide		3,072	3,072		3,542	3,542
Non-Fossil Carbon Dioxide	10.3	2,581	2,592			
Hydrogen Chloride		5.70E-05	5.70E-05		6.94E-05	6.94E-05
Mercury	6.31E-05	4.94E-05	1.18E-04		1.14E-04	1.14E-04
Chlorine	4.01E-05		4.01E-05		0.017	0.017
Odorous Sulfur	1.15		1.15			
Chromium Compounds		0.0012	0.0012		0.0016	0.0016
Manganese Compounds		0.0017	0.0017		0.0022	0.0022
Nickel Compounds		0.0039	0.0039		0.010	0.010
Antimony					2.07E-04	2.07E-04
Arsenic		6.14E-04	6.14E-04		9.68E-04	9.68E-04
Beryllium		6.59E-05	6.59E-05		9.30E-05	9.30E-05
Cadmium					8.53E-04	8.53E-04
Cobalt		2.11E-04	2.11E-04		5.85E-04	5.85E-04
Selenium		8.09E-05	8.09E-05		2.25E-04	2.25E-04
Sulfuric Acid					1.51	1.51
Na2O2					7.69E-05	7.69E-05
KO2					7.69E-05	7.69E-05
V2O5					7.69E-05	7.69E-05

Source: Franklin Associates, Ltd.

Table 3-4b

SUMMARY OF WATERBORNE EMISSIONS FOR BLEACHED SEMI-KRAFT PAPER FLOUR SACKS
(Emissions per 100,000 items)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Waterborne Emissions (kg)						
Acid	0.39	4.19E-07	0.39		5.11E-07	5.11E-07
Metal Ion		0.0089	0.0089		0.0096	0.0096
Dissolved Solids	0.60	5.08	5.68	0.15	0.42	0.57
Suspended Solids	6.32	0.0047	6.33	6.00	0.035	6.03
BOD	4.09	0.0052	4.09	0.022	0.11	0.14
COD	4.09	0.024	4.11	0.093	0.19	0.28
Phenol	9.85E-07	2.88E-05	2.98E-05		0.0022	0.0022
Sulfides	1.39E-05		1.39E-05		0.0012	0.0012
Oil	0.0016	0.067	0.069	0.015	0.13	0.15
Sulfuric Acid		1.08	1.08		0.16	0.16
Iron		0.27	0.27		0.040	0.040
Ammonia		6.74E-04	6.74E-04		0.020	0.020
Chromium		1.67E-06	1.67E-06		2.78E-04	2.78E-04
Lead	1.02E-07	7.43E-07	8.45E-07		9.06E-07	9.06E-07
Zinc	1.02E-07	1.09E-05	1.10E-05		1.33E-05	1.33E-05
Cyanide	1.29E-05		1.29E-05			
Alkalinity	1.99E-06		1.99E-06			
Nickel	1.02E-07		1.02E-07			
Mercury	1.36E-07		1.36E-07			

Source: Franklin Associates, Ltd.

Emissions classified as "other organics" are produced during the sack production step. Data for this step were estimated from data provided by sack producers in the United States; however, the source of these emissions is not evident from available information. If these data are not representative of operations in Mexico, the emissions classified as "other organics" will not be accurate.

The majority of the process waterborne emissions in Mexico are released during the production of bleached semi-kraft paper used to manufacture the flour sacks.

Unbleached Semi-Kraft Paper Cement Sacks

Manufacturing Energy Requirements. Table 3-5 presents the energy requirements for the manufacture of 100,000 unbleached semi-kraft paper cement sacks. The energy usage is categorized by country. Process energy accounts for about 87 percent of the total energy for the system. About 33 percent of the process energy is used in the United States to produce postindustrial recycled paper. This postindustrial material is used as a raw material for unbleached semi-kraft paper production in Mexico.

Transportation energy accounts for the remaining 13 percent of the total energy. About 74 percent of the transportation energy is used in Mexico to transport raw materials and finished products.

The energy of material resource for wood-derived material is not included in this analysis because wood is not used as a commercial fuel source in most industrial countries. Therefore, the energy of material resource for this system is reported as zero.

Table 3-6 presents the energy profile for production of unbleached semi-kraft paper cement sacks. About 50 percent of the energy used in the United States is categorized as wood energy. This energy is used during the production of virgin paper products in the United States. Postindustrial recycled materials from these operations are used as raw materials for unbleached semi-kraft paper production in Mexico.

Natural gas and petroleum represent the largest energy sources for bleached semi-kraft paper sack production in Mexico. About 39 percent of the energy used in Mexico for unbleached paper sack production comes from natural gas and about 49 percent comes from petroleum.

Table 3-5

ENERGY REQUIREMENTS FOR MANUFACTURE OF 100,000 MULTI-LAYERED UNBLEACHED SEMI-KRAFT PAPER CEMENT SACKS

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total
Paper Cement Sacks								
United States	396	90%	45.9	10%			442	100%
Mexico	793	86%	130	14%			923	100%
Total Energy	1,189	87%	176	13%			1,365	100%

Source: Franklin Associates, Ltd.

Table 3-6

ENERGY PROFILES FOR MANUFACTURE OF 100,000 MULTI-LAYERED UNBLEACHED SEMI-KRAFT PAPER CEMENT SACKS
(GJ per 100,000 Items)

	Energy Profile							
	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Total Energy
Paper Cement Sacks								
United States	56.6	61.0	86.8	1.87	14.6	220	1.24	442
Mexico	361	455	32.0	31.1	20.0		23.6	923
Total	418	516	119	33.0	34.6	220	24.8	1,365

Source: Franklin Associates, Ltd.

Manufacturing Environmental Emissions

Solid Waste. Table 3-7 presents the solid waste for manufacturing 100,000 unbleached semi-kraft paper cement sacks. Included in this table is the postconsumer solid waste generated from disposal of the packaging.

Process solid waste accounts for about 10 percent of the total solid waste weight and about six percent of the total solid waste volume. About 83 percent of the process solid waste is produced in Mexico.

Fuel-related solid waste makes up eight percent of the solid waste weight and three percent of the solid waste volume.

Postconsumer solid waste accounts for 82 percent of the total solid waste weight and about 91 percent of the total solid waste volume.

Atmospheric and Waterborne Emissions. The total atmospheric and waterborne emissions for manufacturing unbleached paper cement sacks are presented in Table 3-8a and 3-8b, respectively.

Most of the atmospheric emissions for operations in Mexico are fuel related. These emissions are a result of production and combustion of fuels to produce energy for manufacturing operations and transportation of raw materials and finished products.

Emissions classified as "other organics" are produced during the cement sack production step. Data for this step were estimated from data provided by sack producers in the United States; however, the source of these emissions is not evident from available information. If these data are not representative of operations in Mexico, the emissions classified as "other organics" will not be accurate.

The majority of the process waterborne emissions in Mexico are released during the production of unbleached semi-kraft paper used to manufacture the cement sacks.

Clay-Coated Paperboard Folding Carton Cereal Boxes

Manufacturing Energy Requirements. Table 3-9 presents the energy requirements for the manufacture of 100,000 clay-coated paperboard cereal boxes. The energy usage is categorized by country.

Table 3-7

SOLID WASTE BY WEIGHT AND VOLUME FOR MANUFACTURE OF 100,000 MULTI-LAYERED UNBLEACHED SEMI-KRAFT PAPER CEMENT SACKS

	Process Waste		Fuel Waste		Postconsumer Waste		Total Solid Waste	
	kg	cubic meter	kg	cubic meter	kg	cubic meter	kg	cubic meter
Paper Cement Sacks								
United States	570	0.71	1,611	0.84			2,181	1.55
Mexico	2,844	3.55	1,073	1.34	28,500	64.9	32,417	69.8
Total Solid Waste	3,414	4.26	2,684	2.18	28,500	64.9	34,598	71.4

Source: Franklin Associates, Ltd.

Table 3-8a

SUMMARY OF ATMOSPHERIC EMISSIONS FOR
MULTI-LAYERED UNBLEACHED SEMI-KRAFT PAPER CEMENT SACKS
(Emissions per 100,000 items)

	United States			Mexico		
	Process Emissions	**Fuel Emissions**	**Total Emissions**	**Process Emissions**	**Fuel Emissions**	**Total Emissions**
Atmospheric Emissions (kg)						
Particulates	7.82	43.6	51.5	7.96	52.9	60.9
Nitrogen Oxides	5.72E-04	90.1	90.1		211	211
Hydrocarbons	0.48	50.5	51.0		389	389
Sulfur Oxides	2.16	96.2	98.4		533	533
Carbon Monoxide		187	187		171	171
Aldehydes	0.0010	10.8	10.8		2.28	2.28
Methane		0.12	0.12		0.79	0.79
Other Organics	4.09E-04	13.2	13.2	513	54.0	567
Kerosene		0.0014	0.0014		0.0019	0.0019
Ammonia	0.0023	0.0063	0.0087		0.049	0.049
Lead		0.0025	0.0025		0.027	0.027
Fossil Carbon Dioxide		15,481	15,481		70,933	70,933
Non-Fossil Carbon Dioxide	77.5	19,502	19,580			
Hydrogen Chloride		1.87E-04	1.87E-04		0.0014	0.0014
Mercury	4.79E-05	1.15E-04	1.63E-04		0.0025	0.0025
Chlorine	0.0046		0.0046		0.35	0.35
Odorous Sulfur	0.56		0.56			
Chromium Compounds		0.0063	0.0063		0.034	0.034
Manganese Compounds		0.010	0.010		0.047	0.047
Nickel Compounds		0.0069	0.0069		0.22	0.22
Antimony					0.0045	0.0045
Arsenic		0.0031	0.0031		0.021	0.021
Beryllium		3.65E-04	3.65E-04		0.0020	0.0020
Cadmium					0.018	0.018
Cobalt		2.16E-04	2.16E-04		0.013	0.013
Selenium		8.31E-05	8.31E-05		0.0049	0.0049
Sulfuric Acid					32.6	32.6
Na2O2					0.0016	0.0016
KO2					0.0016	0.0016
V2O5					0.0016	0.0016

Source: Franklin Associates, Ltd.

Table 3-8b

SUMMARY OF WATERBORNE EMISSIONS FOR MULTI-LAYERED UNBLEACHED SEMI-KRAFT PAPER CEMENT SACKS

(Emissions per 100,000 items)

	United States			Mexico		
Waterborne Emissions (kg)	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Acid	0.75	1.37E-06	0.75		1.06E-05	1.06E-05
Metal Ion		0.029	0.029		0.20	0.20
Dissolved Solids	0.58	16.7	17.3	56.6	3.73	60.3
Suspended Solids	23.4	0.015	23.4	169	0.71	170
BOD	15.4	0.017	15.4	20.4	2.37	22.8
COD	13.7	0.080	13.8	46.9	3.94	50.8
Phenol	1.90E-06	9.43E-05	9.62E-05		0.044	0.044
Sulfides	1.33E-05		1.33E-05		0.024	0.024
Oil	0.0033	0.24	0.24	2.60	2.69	5.29
Sulfuric Acid		6.91	6.91		3.39	3.39
Iron		1.73	1.73		0.85	0.85
Ammonia		0.0022	0.0022		0.41	0.41
Chromium		5.46E-06	5.46E-06		0.0057	0.0057
Lead	7.15E-08	2.44E-06	2.51E-06		1.37E-05	1.37E-05
Zinc	7.15E-08	3.57E-05	3.58E-05		2.74E-04	2.74E-04
Cyanide	2.48E-05		2.48E-05			
Alkalinity	3.84E-06		3.84E-06			
Nickel	7.15E-08		7.15E-08			
Mercury	1.31E-07		1.31E-07			
Phosphates	0.039		0.039			
Nitrogen	0.11		0.11			
Pesticides	4.62E-04		4.62E-04			

Source: Franklin Associates, Ltd.

Table 3-9

ENERGY REQUIREMENTS FOR MANUFACTURE OF 100,000 CLAY-COATED PAPERBOARD CEREAL BOXES

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total
Folding Carton Cereal Box								
United States	64.2	92%	5.84	8%			70.1	100%
Mexico	139	96%	5.47	4%			145	100%
Total Energy	204	95%	11.31	5%			215	100%

Source: Franklin Associates, Ltd.

Process energy accounts for about 95 percent of the total energy for the system. About 31 percent of the process energy is used in the United States to produce postindustrial recycled paper. This postindustrial material is used as a raw material for paperboard production in Mexico.

Transportation energy accounts for the remaining five percent of the total energy. About 48 percent of the transportation energy is used in Mexico to transport raw materials and finished products.

The energy of material resource for wood-derived material is not included in this analysis because wood is not used as a commercial fuel source in most industrial countries. Therefore, the energy of material resource for this system is reported as zero.

Table 3-10 presents the energy profile for production of clay-coated paperboard cereal boxes. About 51 percent of the energy used in the United States is categorized as wood energy. This energy is used during the production of virgin paper products in the United States. Postindustrial recycled materials from these operations are used as raw materials for clay-coated paperboard production in Mexico.

Natural gas represents the largest energy source for clay-coated paperboard cereal box production in Mexico. About 94 percent of the energy used in Mexico for cereal box production comes from natural gas.

Manufacturing Environmental Emissions

Solid Waste. Table 3-11 presents the solid waste for manufacturing 100,000 clay-coated paperboard cereal boxes. Included in this table is the postconsumer solid waste generated from disposal of the packaging.

Process solid waste accounts for about 15 percent of the total solid waste weight and about 10 percent of the total solid waste volume. About 75 percent of the process solid waste is produced in Mexico.

Fuel-related solid waste makes up three percent of the solid waste weight and one percent of the solid waste volume.

Postconsumer solid waste accounts for 82 percent of the solid waste weight and about 89 percent of the solid waste volume.

Atmospheric and Waterborne Emissions. The total atmospheric and waterborne emissions for manufacturing clay-coated paperboard cereal boxes are presented in Table 3-12a and 3-12b, respectively.

Table 3-10

ENERGY PROFILES FOR 100,000 CLAY-COATED PAPERBOARD CEREAL BOXES
(GJ per 100,000 Items)

	Energy Profile							
	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Total Energy
Folding Carton Cereal Box								
United States	9.71	8.30	13.4	0.27	2.08	36.1	0.18	70.1
Mexico	137	7.62	0.22	0.21	0.14		0.16	145
Total	146	15.9	13.6	0.48	2.22	36.1	0.34	215

Source: Franklin Associates, Ltd.

Table 3-11

SOLID WASTE BY WEIGHT AND VOLUME FOR MANUFACTURE OF 100,000 CLAY-COATED PAPERBOARD CEREAL BOXES

	Process Waste		Fuel Waste		Postconsumer Waste		Total Solid Waste	
	kg	cubic meter	kg	cubic meter	kg	cubic meter	kg	cubic meter
Clay-Coated Paperboard Cereal Boxes								
United States	319	0.40	253	0.17			572	0.57
Mexico	976	1.22	10.8	0.013	6,960	14.3	7,946	15.6
Total Solid Waste	1,295	1.62	264	0.19	6,960	14.3	8,519	16.1

Source: Franklin Associates, Ltd.

Table 3-12a

SUMMARY OF ATMOSPHERIC EMISSIONS FOR CLAY-COATED PAPERBOARD CEREAL BOXES
(Emissions per 100,000 items)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Atmospheric Emissions (kg)						
Particulates	1.08	6.93	8.01		1.31	1.31
Nitrogen Oxides	0.063	13.5	13.6		14.7	14.7
Hydrocarbons	0.083	8.13	8.21		104	104
Sulfur Oxides	0.38	14.8	15.2		49.4	49.4
Carbon Monoxide		29.5	29.5		7.96	7.96
Aldehydes	1.74E-04	1.74	1.74		0.089	0.089
Methane		0.020	0.020		0.18	0.18
Other Organics	5.47E-08	1.51	1.51		1.76	1.76
Kerosene		1.99E-04	1.99E-04		1.31E-05	1.31E-05
Ammonia	8.72E-05	8.64E-04	9.51E-04		9.60E-04	9.60E-04
Lead		3.90E-04	3.90E-04		3.70E-04	3.70E-04
Fossil Carbon Dioxide		2,366	2,366		13,783	13,783
Non-Fossil Carbon Dioxide	13.4	3,198	3,212			
Hydrogen Chloride		2.55E-05	2.55E-05		2.83E-05	2.83E-05
Mercury	7.81E-06	1.78E-05	2.56E-05		2.57E-05	2.57E-05
Chlorine	4.56E-06		4.56E-06		0.0036	0.0036
Odorous Sulfur	0.097		0.097			
Chromium Compounds		9.73E-04	9.73E-04		3.43E-04	3.43E-04
Manganese Compounds		0.0016	0.0016		4.56E-04	4.56E-04
Nickel Compounds		0.0011	0.0011		0.0023	0.0023
Antimony		5.15E-07	5.15E-07		4.69E-05	4.69E-05
Arsenic		4.86E-04	4.86E-04		2.06E-04	2.06E-04
Beryllium		5.63E-05	5.63E-05		1.96E-05	1.96E-05
Cadmium		8.28E-06	8.28E-06		1.90E-04	1.90E-04
Cobalt		3.36E-05	3.36E-05		1.33E-04	1.33E-04
Selenium		1.29E-05	1.29E-05		5.09E-05	5.09E-05
Sulfuric Acid					0.48	0.48
Na2O2					2.43E-04	2.43E-04
KO2					2.43E-04	2.43E-04
V2O5					2.43E-04	2.43E-04
Isopropyl Acetate				7.60		7.60

Source: Franklin Associates, Ltd.

Table 3-12b

SUMMARY OF WATERBORNE EMISSIONS FOR CLAY-COATED PAPERBOARD CEREAL BOXES
(Emissions per 100,000 items)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Waterborne Emissions (kg)						
Acid	0.13	1.38E-07	0.13		2.08E-07	2.08E-07
Metal Ion		0.0040	0.0040		0.0039	0.0039
Dissolved Solids	0.097	2.29	2.38	170	0.17	171
Suspended Solids	2.31	0.0021	2.31	1.68	0.014	1.69
BOD	1.46	0.0023	1.46	32.7	0.047	32.8
COD	1.40	0.011	1.41	71.2	0.078	71.3
Phenol	3.29E-07	1.29E-05	1.32E-05		3.77E-04	3.77E-04
Sulfides	2.17E-06		2.17E-06	0.12	4.75E-04	0.12
Oil	5.50E-04	0.034	0.035	1.04	0.15	1.19
Sulfuric Acid		1.07	1.07		0.032	0.032
Iron	0.0016	0.27	0.27		0.0082	0.0082
Ammonia		3.02E-04	3.02E-04		0.0080	0.0080
Chromium		7.46E-07	7.46E-07		1.13E-04	1.13E-04
Lead	1.17E-08	3.32E-07	3.44E-07		3.69E-07	3.69E-07
Zinc	1.17E-08	4.87E-06	4.88E-06		5.41E-06	5.41E-06
Cyanide	4.29E-06		4.29E-06			
Alkalinity	6.64E-07		6.64E-07			
Aluminum				0.23		0.23
Nickel	1.17E-08		1.17E-08			
Mercury	2.13E-08		2.13E-08			
Phosphates	5.44E-04		5.44E-04			
Sulfates				34.1		34.1

Source: Franklin Associates, Ltd.

Most of the atmospheric emissions for operations in Mexico are fuel related. These emissions are a result of production and combustion of fuels to produce energy for manufacturing operations and transportation of raw materials and finished products.

The majority of the process waterborne emissions in Mexico are produced during the production of clay-coated paperboard used to manufacture the cereal box.

Corrugated Boxes and Separators for Eggs

Manufacturing Energy Requirements. Table 3-13 presents the energy requirements for the manufacture of 100,000 corrugated boxes and separators for eggs. The energy usage is categorized by country.

Process energy accounts for about 76 percent of the total energy for the system. About 85 percent of the process energy is used to make the corrugated box. Almost all of the total process energy (about 99 percent) is used in Mexico to manufacture the boxes and separators. Processes energy in the United States is used to produce corn (used for starch production) and to process the postconsumer recycled paper products exported to Mexico.

Transportation energy accounts for the remaining 24 percent of the total energy. A large portion of this energy is used to collect and transport postconsumer corrugated material used to make the recycled medium and liner.

The energy of material resource for wood-derived materials is not included in this analysis because wood is not used as a commercial fuel source in most industrial countries. Therefore, the energy of material resource for this system is reported as zero.

Table 3-14 presents the energy profile for production of paperboard cereal boxes. No energy is categorized as wood-derived because the corrugated materials examined in this analysis are produced from postconsumer recycled material.

Petroleum represents the largest energy source for production of corrugated boxes and separators in Mexico. About 68 percent of the energy used in Mexico for corrugated packaging production comes from petroleum.

Manufacturing Environmental Emissions

Solid Waste. Table 3-15 presents the solid waste for manufacturing 100,000 corrugated boxes and separators for eggs. Included in this table is the postconsumer solid waste generated from disposal of the packaging.

Table 3-13

ENERGY REQUIREMENTS FOR MANUFACTURE OF 100,000 CORRUGATED BOXES AND SEPARATORS FOR EGGS

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total
Corrugated Box								
United States	10.0	25%	29.4	75%			39.4	100%
Mexico	1,003	77%	292	23%			1,296	100%
Total Energy	1,013	76%	322	24%			1,335	100%
Corrugated Separator								
United States	1.69	26%	4.87	74%			6.56	100%
Mexico	179	78%	51.6	22%			231	100%
Total Energy	181	76%	56.5	24%			237	100%
Package Total								
United States	11.7	25%	34.3	75%			46.0	100%
Mexico	1,182	77%	344	23%			1,526	100%
Total Energy	1,194	76%	378	24%			1,572	100%

Source: Franklin Associates, Ltd.

Table 3-14

ENERGY PROFILES FOR MANUFACTURE OF 100,000 CORRUGATED BOXES AND SEPARATORS FOR EGGS
(GJ per 100,000 Items)

	Energy Profile							
	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Total Energy
Corrugated Box								
United States	1.48	31.2	4.60	0.22	1.71		0.15	39.4
Mexico	249	876	55.5	47.6	30.8		36.1	1,296
Total	251	908	60.1	47.8	32.6		36.2	1,335
Corrugated Separator								
United States	0.25	5.20	0.76	0.036	0.28		0.024	6.55
Mexico	44.3	156	9.9	8.50	5.51		6.44	231
Total	44.5	161	10.7	8.54	5.79		6.47	237
Package Total								
United States	1.74	36.4	5.36	0.26	2.00		0.17	46.0
Mexico	294	1,032	65.5	56.1	36.4		42.5	1,526
Total	295	1,069	70.8	56.4	38.3		42.7	1,572

Source: Franklin Associates, Ltd.

Table 3-15

SOLID WASTE BY WEIGHT AND VOLUME FOR MANUFACTURE OF 100,000 CORRUGATED BOXES AND SEPARATORS FOR EGGS

	Process Waste		Fuel Waste		Postconsumer Waste		Total Solid Waste	
	kg	cubic meter	kg	cubic meter	kg	cubic meter	kg	cubic meter
Corrugated Boxes and Separators								
United States	47.6	0.059	80.5	0.0065			128	0.066
Mexico	5,476	6.84	2,185	2.72	65,818	148	73,479	157
Total Solid Waste	5,524	6.90	2,266	2.73	65,818	148	73,608	158

Source: Franklin Associates, Ltd.

Process solid waste accounts for about eight percent of the total solid waste weight and about four percent of the total solid waste volume. Over 99 percent of the process solid waste is produced in Mexico.

Fuel-related solid waste makes up three percent of the solid waste weight and two percent of the solid waste volume.

Postconsumer solid waste accounts for 89 percent of the total solid waste weight and about 94 percent of the total solid waste volume.

Atmospheric and Waterborne Emissions. The total atmospheric and waterborne emissions for manufacturing corrugated boxes and separators for eggs are presented in Table 3-16a and 3-16b, respectively.

Most of the atmospheric emissions for operations in Mexico are fuel related. These emissions are a result of production and combustion of fuels to produce energy for manufacturing operations and transportation of raw materials and finished products.

Process particulate emissions in Mexico result mainly from box converting operations. The remaining process atmospheric emissions are mainly from starch adhesive production.

A large portion of the process dissolved solids, suspended solids, BOD, COD and oil waterborne emissions in Mexico are a result of the corrugated paperboard production step. The remaining process emissions in Mexico result mainly from starch adhesive production.

Disposal Energy and Environmental Emissions

Table 3-17 presents the energy requirements for the operation of packer trucks and landfill equipment to dispose of postconsumer paper packaging that becomes solid waste (packaging that is not collected for recycling). This equipment is assumed to use diesel as a fuel source; therefore, this energy is derived from petroleum.

The fuel-related environmental emissions for the operation of packer trucks and landfill equipment to dispose of postconsumer solid waste from the bleached semi-kraft paper flour sacks, unbleached semi-kraft paper cement sacks, clay-coated paperboard cereal boxes and corrugated boxes and separators are presented in Tables 3-18, 3-19, 3-20 and 3-21, respectively.

Table 3-16a

SUMMARY OF ATMOSPHERIC EMISSIONS FOR CORRUGATED BOXES AND SEPARATORS FOR EGGS
(Emissions per 100,000 items)

	United States			Mexico		
Atmospheric Emissions (kg)	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Particulates	3.94	4.89	8.83	105	125	230
Nitrogen Oxides		25.6	25.6		451	451
Hydrocarbons	0.047	12.1	12.1	0.18	504	504
Sulfur Oxides		9.51	9.51	0.011	1,631	1,631
Carbon Monoxide		19.0	19.0		399	399
Aldehydes		0.57	0.57	3.82E-04	5.39	5.39
Methane		0.0092	0.0092		1.00	1.00
Other Organics	0.0094	8.29	8.30		131	131
Kerosene		1.98E-04	1.98E-04		0.0034	0.0034
Ammonia	0.047	0.0037	0.051	1.91E-04	0.11	0.11
Lead		1.83E-04	1.83E-04		0.056	0.056
Fossil Carbon Dioxide		3,138	3,138		109,393	109,393
Hydrogen Chloride		1.10E-04	1.10E-04		0.0032	0.0032
Mercury		9.34E-06	9.34E-06	9.15E-06	0.0052	0.0052
Chlorine				5.35E-06	0.72	0.72
Chromium Compounds		4.37E-04	4.37E-04		0.071	0.071
Manganese Compounds		7.00E-04	7.00E-04		0.096	0.096
Nickel Compounds		6.13E-04	6.13E-04		0.46	0.46
Antimony					0.0094	0.0094
Arsenic		2.20E-04	2.20E-04		0.043	0.043
Beryllium		2.53E-05	2.53E-05		0.0041	0.0041
Cadmium					0.038	0.038
Cobalt		2.35E-05	2.35E-05		0.027	0.027
Selenium		9.01E-06	9.01E-06		0.010	0.010
Sulfuric Acid					68.3	68.3
Na2O2					0.0029	0.0029
KO2					0.0029	0.0029
V2O5					0.0029	0.0029

Source: Franklin Associates, Ltd.

Table 3-16b

SUMMARY OF WATERBORNE EMISSIONS FOR CORRUGATED BOXES AND SEPARATORS FOR EGGS
(Emissions per 100,000 items)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Waterborne Emissions (kg)						
Acid		3.09E-07	3.09E-07		2.38E-05	2.38E-05
Metal Ion		0.017	0.017		0.45	0.45
Dissolved Solids		9.74	9.74	685	19.8	705
Suspended Solids	9.37	0.0091	9.38	771	1.61	773
BOD	0.0023	0.010	0.012	257	5.35	262
COD	0.011	0.047	0.058	577	8.88	586
Phenol		5.55E-05	5.55E-05	7.19E-07	0.10	0.10
Sulfides				2.55E-06	0.054	0.054
Oil	0.0023	0.12	0.12	29.7	5.67	35.4
Sulfuric Acid		0.47	0.47		6.91	6.91
Iron		0.12	0.12		1.74	1.74
Ammonia	0.0028	0.0013	0.0041	9.39E-06	0.92	0.92
Chromium		3.21E-06	3.21E-06	1.45E-06	0.013	0.013
Lead		1.43E-06	1.43E-06	1.37E-08	4.22E-05	4.22E-05
Zinc		2.10E-05	2.10E-05	1.37E-08	6.19E-04	6.19E-04
Nickel				1.37E 08		1.37E-08
Mercury				2.50E-08		2.50E-08
Phosphates	0.64		0.64			
Nitrogen	2.78		2.78			
Pesticides	0.035		0.035			

Source: Franklin Associates, Ltd.

Table 3-17

ENERGY REQUIREMENTS FOR DISPOSAL OF PAPER PACKAGING
(gigajoules for units disposed per 100,000 items)

	Packer Truck Energy	Landfill Equipment Energy	Total Disposal Energy
Bleached Semi-Kraft Paper Flour Sacks	0.18	0.10	0.28
Unbleached Semi-Kraft Paper Cement Sacks	3.84	2.23	6.07
Clay-Coated Paperboard Cereal Box	0.85	0.49	1.34
Corrugated Egg Containers			
Corrugated Box	7.42	4.30	11.7
Corrugated Separator	1.35	0.78	2.13
Package Total	8.77	5.08	13.9

Source: Franklin Associates, Ltd.

Table 3-18

SUMMARY OF FUEL-RELATED ENVIRONMENTAL EMISSIONS FOR DISPOSAL OF BLEACHED SEMI-KRAFT PAPER FLOUR SACKS
(Emissions for units disposed per 100,000 items)

	Packer Truck Emissions	Landfill Equipment Emissions	Total Disposal Emissions
Atmospheric Emissions (kg)			
Particulates	0.017	0.010	0.027
Nitrogen Oxides	0.23	0.13	0.36
Hydrocarbons	0.058	0.034	0.092
Sulfur Oxides	0.054	0.031	0.085
Carbon Monoxide	0.073	0.042	0.11
Aldehydes	0.0035	0.0020	0.0055
Methane	2.50E-05	1.45E-05	3.95E-05
Other Organics	3.80E-07	2.21E-07	6.01E-07
Kerosene	1.23E-08	7.16E-09	1.95E-08
Ammonia	1.89E-05	1.10E-05	2.99E-05
Lead	1.27E-06	7.37E-07	2.01E-06
Fossil Carbon Dioxide	13.1	7.52	20.7
Hydrogen Chloride	5.57E-07	3.24E-07	8.81E-07
Mercury	4.14E-08	2.40E-08	6.55E-08
Chlorine	9.81E-06	5.69E-06	1.55E-05
Chromium Compounds	3.45E-07	2.00E-07	5.45E-07
Manganese Compounds	3.82E-07	2.22E-07	6.04E-07
Nickel Compounds	3.78E-06	2.20E-06	5.98E-06
Antimony	8.15E-08	4.73E-08	1.29E-07
Arsenic	2.35E-07	1.36E-07	3.71E-07
Beryllium	1.96E-08	1.14E-08	3.09E-08
Cadmium	2.91E-07	1.69E-07	4.60E-07
Cobalt	2.30E-07	1.34E-07	3.64E-07
Selenium	8.85E-08	5.14E-08	1.40E-07
Sulfuric Acid	6.13E-04	3.56E-04	9.70E-04
Na2O2	3.75E-07	2.18E-07	5.93E-07
KO2	3.75E-07	2.18E-07	5.93E-07
V2O5	3.75E-07	2.18E-07	5.93E-07
Solid Waste (kg)	0.022	0.013	0.034
Solid Waste (cu m)	2.70E-05	1.57E-05	4.27E-05
Waterborne Emissions (kg)			
Acid	6.61E-09	4.01E-09	1.06E-08
Metal Ion	1.24E-04	7.53E-05	2.00E-04
Dissolved Solids	0.0054	0.0033	0.0087
Suspended Solids	4.47E-04	2.71E-04	7.18E-04
BOD	0.0015	9.00E-04	0.0024
COD	0.0025	0.0015	0.0040
Phenol	2.79E-05	1.69E-05	4.47E-05
Sulfides	1.51E-05	9.14E-06	2.42E-05
Oil	0.0015	9.15E-04	0.0024
Sulfuric Acid	3.54E-05	2.14E-05	5.68E-05
Iron	1.13E-05	6.83E-06	1.81E-05
Ammonia	2.55E-04	1.55E-04	4.10E-04
Chromium	3.60E-06	2.18E-06	5.78E-06
Lead	1.17E-08	7.10E-09	1.88E-08
Zinc	1.72E-07	1.04E-07	2.76E-07

Source: Franklin Associates, Ltd.

Table 3-19

SUMMARY OF FUEL-RELATED ENVIRONMENTAL EMISSIONS FOR DISPOSAL OF UNBLEACHED SEMI-KRAFT PAPER CEMENT SACKS
(Emissions for units disposed per 100,000 items)

	Packer Truck Emissions	Landfill Equipment Emissions	Total Disposal Emissions
Atmospheric Emissions (kg)			
Particulates	0.36	0.21	0.58
Nitrogen Oxides	4.85	2.81	7.66
Hydrocarbons	1.24	0.72	1.96
Sulfur Oxides	1.15	0.67	1.81
Carbon Monoxide	1.55	0.90	2.45
Aldehydes	0.075	0.043	0.12
Methane	5.34E-04	3.10E-04	8.43E-04
Other Organics	8.12E-06	4.72E-06	1.28E-05
Kerosene	2.63E-07	1.53E-07	4.16E-07
Ammonia	4.04E-04	2.34E-04	6.38E-04
Lead	2.71E-05	1.57E-05	4.29E-05
Fossil Carbon Dioxide	280	163	443
Hydrogen Chloride	1.19E-05	6.91E-06	1.88E-05
Mercury	8.84E-07	5.14E-07	1.40E-06
Chlorine	2.09E-04	1.22E-04	3.31E-04
Chromium Compounds	7.36E-06	4.28E-06	1.16E-05
Manganese Compounds	8.17E-06	4.74E-06	1.29E-05
Nickel Compounds	8.08E-05	4.69E-05	1.28E-04
Antimony	1.74E-06	1.01E-06	2.75E-06
Arsenic	5.02E-06	2.91E-06	7.93E-06
Beryllium	4.18E-07	2.43E-07	6.61E-07
Cadmium	6.22E-06	3.61E-06	9.83E-06
Cobalt	4.92E-06	2.86E-06	7.78E-06
Selenium	1.89E-06	1.10E-06	2.99E-06
Sulfuric Acid	0.013	0.0076	0.021
Na_2O_2	8.02E-06	4.66E-06	1.27E-05
KO_2	8.02E-06	4.66E-06	1.27E-05
V_2O_5	8.02E-06	4.66E-06	1.27E-05
Solid Waste (kg)	0.46	0.27	0.73
Solid Waste (cu m)	5.77E-04	3.35E-04	9.13E-04
Waterborne Emissions (kg)			
Acid	6.61E-09	4.01E-09	1.06E-08
Metal Ion	1.24E-04	7.53E-05	2.00E-04
Dissolved Solids	0.0054	0.0033	0.0087
Suspended Solids	4.47E-04	2.71E-04	7.18E-04
BOD	0.0015	9.00E-04	0.0024
COD	0.0025	0.0015	0.0040
Phenol	2.79E-05	1.69E-05	4.47E-05
Sulfides	1.51E-05	9.14E-06	2.42E-05
Oil	0.0015	9.15E-04	0.0024
Sulfuric Acid	3.54E-05	2.14E-05	5.68E-05
Iron	1.13E-05	6.83E-06	1.81E-05
Ammonia	2.55E-04	1.55E-04	4.10E-04
Chromium	3.60E-06	2.18E-06	5.78E-06
Lead	1.17E-08	7.10E-09	1.88E-08
Zinc	1.72E-07	1.04E-07	2.76E-07

Source: Franklin Associates, Ltd.

Table 3-20

SUMMARY OF FUEL-RELATED ENVIRONMENTAL EMISSIONS FOR DISPOSAL OF CLAY-COATED PAPERBOARD CEREAL BOXES
(Emissions for units disposed per 100,000 items)

	Packer Truck Emissions	Landfill Equipment Emissions	Total Disposal Emissions
Atmospheric Emissions (kg)			
Particulates	0.081	0.047	0.13
Nitrogen Oxides	1.07	0.62	1.69
Hydrocarbons	0.27	0.16	0.43
Sulfur Oxides	0.25	0.15	0.40
Carbon Monoxide	0.34	0.20	0.54
Aldehydes	0.017	0.0096	0.026
Methane	1.18E-04	6.54E-05	1.86E-04
Other Organics	1.30E-06	1.04E-06	2.34E-06
Kerosene	5.83E-08	3.37E-08	9.20E-08
Ammonia	8.94E-05	5.17E-05	1.41E-04
Lead	6.00E-06	3.47E-06	9.47E-06
Fossil Carbon Dioxide	62.0	35.9	97.9
Hydrogen Chloride	2.64E-06	1.53E-06	4.16E-06
Mercury	1.96E-07	1.13E-07	3.09E-07
Chlorine	4.64E-05	2.68E-05	7.32E-05
Chromium Compounds	1.63E-06	9.43E-07	2.57E-06
Manganese Compounds	1.31E-06	1.05E-06	2.35E-06
Nickel Compounds	1.79E-05	1.03E-05	2.82E-05
Antimony	3.85E-07	2.23E-07	6.08E-07
Arsenic	1.11E-06	6.43E-07	1.75E-06
Beryllium	9.25E-08	5.36E-08	1.46E-07
Cadmium	1.38E-06	7.97E-07	2.17E-06
Cobalt	1.09E-06	6.31E-07	1.72E-06
Selenium	4.18E-07	2.42E-07	6.60E-07
Sulfuric Acid	0.0029	0.0017	0.0046
Na2O2	1.78E-06	1.03E-06	2.80E-06
KO2	1.78E-06	1.03E-06	2.80E-06
V2O5	1.78E-06	1.03E-06	2.80E-06
Solid Waste (kg)	0.10	0.059	0.16
Solid Waste (cu m)	1.28E-04	7.40E-05	2.02E-04
Waterborne Emissions (kg)			
Acid	6.61E-09	4.01E-09	1.06E-08
Metal Ion	1.24E-04	7.53E-05	2.00E-04
Dissolved Solids	0.0054	0.0033	0.0087
Suspended Solids	4.47E-04	2.71E-04	7.18E-04
BOD	0.0015	9.00E-04	0.0024
COD	0.0025	0.0015	0.0040
Phenol	2.79E-05	1.69E-05	4.47E-05
Sulfides	1.51E-05	9.14E-06	2.42E-05
Oil	0.0015	9.15E-04	0.0024
Sulfuric Acid	3.54E-05	2.14E-05	5.68E-05
Iron	1.13E-05	6.83E-06	1.81E-05
Ammonia	2.55E-04	1.55E-04	4.10E-04
Chromium	3.60E-06	2.18E-06	5.78E-06
Lead	1.17E-08	7.10E-09	1.88E-08
Zinc	1.72E-07	1.04E-07	2.76E-07

Source: Franklin Associates, Ltd.

Table 3-21

SUMMARY OF FUEL-RELATED ENVIRONMENTAL EMISSIONS FOR DISPOSAL OF CORRUGATED BOXES AND SEPARATORS FOR EGGS
(Emissions for units disposed per 100,000 items)

	Packer Truck Emissions	Landfill Equipment Emissions	Total Disposal Emissions
Atmospheric Emissions (kg)			
Particulates	0.83	0.48	1.31
Nitrogen Oxides	11.1	6.41	17.5
Hydrocarbons	2.83	1.64	4.46
Sulfur Oxides	2.62	1.52	4.13
Carbon Monoxide	3.54	2.05	5.59
Aldehydes	0.17	0.099	0.27
Methane	0.0012	7.06E-04	0.0019
Other Organics	1.85E-05	1.07E-05	2.93E-05
Kerosene	6.01E-07	3.48E-07	9.50E-07
Ammonia	9.22E-04	5.34E-04	0.0015
Lead	6.19E-05	3.59E-05	9.77E-05
Fossil Carbon Dioxide	639	371	1,010
Hydrogen Chloride	2.72E-05	1.58E-05	4.29E-05
Mercury	2.02E-06	1.17E-06	3.19E-06
Chlorine	4.78E-04	2.77E-04	7.55E-04
Chromium Compounds	1.68E-05	9.74E-06	2.65E-05
Manganese Compounds	1.86E-05	1.08E-05	2.94E-05
Nickel Compounds	1.84E-04	1.07E-04	2.91E-04
Antimony	3.97E-06	2.30E-06	6.27E-06
Arsenic	1.15E-05	6.64E-06	1.81E-05
Beryllium	9.54E-07	5.53E-07	1.51E-06
Cadmium	1.42E-05	8.23E-06	2.24E-05
Cobalt	1.12E-05	6.51E-06	1.77E-05
Selenium	4.31E-06	2.50E-06	6.81E-06
Sulfuric Acid	0.030	0.017	0.047
Na_2O_2	1.83E-05	1.06E-05	2.89E-05
KO_2	1.83E-05	1.06E-05	2.89E-05
V_2O_5	1.83E-05	1.06E-05	2.89E-05
Solid Waste (kg)	1.06	0.61	1.67
Solid Waste (cu m)	0.0013	7.64E-04	0.0021
Waterborne Emissions (kg)			
Acid	6.61E-09	4.01E-09	1.06E-08
Metal Ion	1.24E-04	7.53E-05	2.00E-04
Dissolved Solids	0.0054	0.0033	0.0087
Suspended Solids	4.47E-04	2.71E-04	7.18E-04
BOD	0.0015	9.00E-04	0.0024
COD	0.0025	0.0015	0.0040
Phenol	2.79E-05	1.69E-05	4.47E-05
Sulfides	1.51E-05	9.14E-06	2.42E-05
Oil	0.0015	9.15E-04	0.0024
Sulfuric Acid	3.54E-05	2.14E-05	5.68E-05
Iron	1.13E-05	6.83E-06	1.81E-05
Ammonia	2.55E-04	1.55E-04	4.10E-04
Chromium	3.60E-06	2.18E-06	5.78E-06
Lead	1.17E-08	7.10E-09	1.88E-08
Zinc	1.72E-07	1.04E-07	2.76E-07

Source: Franklin Associates, Ltd.

Chapter 4

ENERGY AND ENVIRONMENTAL RESULTS FOR TIN-COATED STEEL CANS

INTRODUCTION

This chapter provides a summary of the energy requirements and environmental emissions for the production, recycling and disposal of tin-coated steel cans in Mexico. The basis for the results presented in this chapter is 100,000 steel cans. Supporting data for this chapter are presented in Appendix E of the separately bound Appendix document.

The steel cans analyzed in this study contain about 30 percent postconsumer recycled content. The postconsumer recovery rate for the steel cans in Mexico is assumed to be 47 percent. Therefore, 30 percent of the steel cans, by weight, is assumed to be recycled in a closed-loop system. The remaining 17 percent is assumed to be recycled in an open-loop system.

DATA SOURCES

Data for the production of tin-coated steel sheet in the United States were taken from Franklin Associates' database.

Data for the production of three-piece steel cans were provided by producers in Mexico. Information supplied by two can producers were aggregated for this analysis. Although these data seemed reasonable when compared to data collected for analogous operations in the United States, it is not known how well they represent the production of the "average" three-piece can in Mexico.

RESULTS AND DISCUSSION

Manufacturing Energy Requirements

Table 4-1 presents the energy requirements for the manufacture of 100,000 tin-coated steel cans. The energy usage is categorized by country.

Process energy accounts for about 43 percent of the total energy for the system; 86 percent of this energy is used in the United States.

Transportation energy accounts for an additional 22 percent of the total energy. Transportation energy is divided about equally between the United States and Mexico.

Table 4-1

ENERGY REQUIREMENTS FOR MANUFACTURE OF 100,000 TIN-COATED STEEL CANS

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total
Steel Cans								
United States	71.5	44%	23.7	14%	68.7	42%	164	100%
Mexico	11.7	37%	20.0	63%			31.7	100%
Total Energy	83.3	43%	43.7	22%	68.7	35%	196	100%

Source: Franklin Associates, Ltd.

Thirty-five percent of the total energy is classified as energy of material resource. All of this energy is used in the United States to manufacture tin-coated steel sheet. This energy represents the coal used to make metallurgical coke and coke oven gas which is used as a feedstock for steel production. While it is recognized that most of the energy content in the coke and coke oven gas is liberated during the production of steel, the methodology used in this study accounts for the energy derived from materials used as feedstocks on the basis of the energy content of the material that is extracted from the earth to produce the feedstocks (in this case coal).

Table 4-2 presents the energy profile for production of tin-coated steel cans. About 55 percent of the energy used in the United States is derived from coal. A large portion of this energy is coke and coke oven gas used during steel production.

About 63 percent of the energy used in Mexico is for transporting raw materials and finished goods (see Table 4-1). All of the energy used for this transportation is petroleum based. This is reflected in the energy profile for Mexico, with petroleum representing 72 percent of the energy used.

Manufacturing Environmental Emissions

Solid Waste. Table 4-3 presents the solid waste for manufacturing 100,000 tin-coated steel cans. Included in this table is the postconsumer solid waste generated from disposal of containers that are not collected for recycling.

Process solid waste accounts for about 86 percent of the total solid waste weight and about 73 percent of the total solid waste volume. About 99 percent of the process solid waste is produced in the United States. A large portion of this process solid waste, about 89 percent, comes from mining and beneficiating iron ore.

Fuel-related solid waste makes up two percent of the solid waste weight and volume.

Postconsumer solid waste accounts for 12 percent of the solid waste weight and about 25 percent of the solid waste volume.

Atmospheric and Waterborne Emissions. The total atmospheric and waterborne emissions for manufacturing tin-coated steel cans are presented in Table 4-4a and 4-4b, respectively.

All of the atmospheric emissions for operations in Mexico are fuel related. These emissions are a result of production and combustion of fuels to produce energy for manufacturing operations and transportation of raw materials and finished products.

Table 4-2

ENERGY PROFILES FOR MANUFACTURE OF 100,000 TIN-COATED STEEL CANS
(GJ per 100,000 Items)

	Energy Profile							
	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Total Energy
Steel Cans								
United States	33.2	32.1	89.4	0.98	7.68		0.65	164
Mexico	8.13	22.7	0.27	0.26	0.17		0.20	31.7
Total	41.3	54.8	89.7	1.25	7.85		0.85	196

Source: Franklin Associates, Ltd.

Table 4-3

SOLID WASTE BY WEIGHT AND VOLUME FOR MANUFACTURE OF 100,000 TIN-COATED STEEL CANS

	Process Waste		Fuel Waste		Postconsumer Waste		Total Solid Waste	
	kg	cubic meter	kg	cubic meter	kg	cubic meter	kg	cubic meter
Tin-Coated Steel Can								
United States	13,024	16.3	289	0.36			13,314	16.6
Mexico	99.6	0.12	11.5	0.014	1,874	5.67	1,985	5.81
Total Solid Waste	13,124	16.4	301	0.38	1,874	5.67	15,299	22.4

Source: Franklin Associates, Ltd.

Table 4-4a

SUMMARY OF ATMOSPHERIC EMISSIONS FOR TIN-COATED STEEL CANS (Emissions per 100,000 items)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Atmospheric Emissions (kg)						
Particulates	61.9	6.04	67.9		2.87	2.87
Nitrogen Oxides	3.03	26.5	29.5		14.9	14.9
Hydrocarbons	11.0	26.8	37.8		13.6	13.6
Sulfur Oxides	14.7	25.1	39.8		14.1	14.1
Carbon Monoxide	105	17.9	123		15.8	15.8
Aldehydes		0.38	0.38		0.31	0.31
Methane		0.055	0.055		0.016	0.016
Other Organics		6.83	6.83		7.06	7.06
Kerosene		7.3E-04	7.3E-04		1.8E-05	1.8E-05
Ammonia	0.16	0.0033	0.16		0.0024	0.0024
Lead	6.0E-05	6.4E-04	7.0E-04		3.9E-04	3.9E-04
Fossil Carbon Dioxide	7,246	6,013	13,259		2,453	2,453
Hydrogen Chloride		9.8E-05	9.8E-05		7.1E-05	7.1E-05
Mercury		3.2E-05	3.2E-05		2.5E-05	2.5E-05
Chlorine					0.0041	0.0041
Chromium Compounds	3.5E-05	0.0017	0.0017		3.3E-04	3.3E-04
Manganese Compounds	7.7E-04	0.0026	0.0034		4.4E-04	4.4E-04
Nickel Compounds	9.7E-06	0.0017	0.0017		0.0022	0.0022
Zinc Compounds	6.4E-04		6.4E-04			
Copper Compounds	6.7E-05		6.7E-05			
Antimony					4.6E-05	4.6E-05
Arsenic		8.0E-04	8.0E-04		2.0E-04	2.0E-04
Beryllium		9.5E-05	9.5E-05		1.9E-05	1.9E-05
Cadmium					1.9E-04	1.9E-04
Cobalt		5.1E-05	5.1E-05		1.3E-04	1.3E-04
Selenium		1.9E-05	1.9E-05		5.0E-05	5.0E-05
Sulfuric Acid					0.34	0.34
Na2O2					6.1E-05	6.1E-05
KO2					6.1E-05	6.1E-05
V2O5					6.1E-05	6.1E-05

Source: Franklin Associates, Ltd.

Table 4-4b

SUMMARY OF WATERBORNE EMISSIONS FOR TIN-COATED STEEL CANS
(Emissions per 100,000 items)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Waterborne Emissions (kg)						
Acid	4.41	7.2E-07	4.41		5.2E-07	5.2E-07
Metal Ion		0.015	0.015		0.0098	0.0098
Dissolved Solids	0.18	8.76	8.93		0.43	0.43
Suspended Solids	0.26	0.0081	0.27		0.035	0.035
BOD		0.0088	0.0088		0.12	0.12
COD		0.042	0.042		0.19	0.19
Phenol	0.0030	4.9E-05	0.0030		0.0022	0.0022
Sulfides					0.0012	0.0012
Oil	0.025	0.13	0.15		0.13	0.13
Sulfuric Acid		1.74	1.74		0.031	0.031
Iron	1.10	0.44	1.54		0.0080	0.0080
Ammonia	0.014	0.0012	0.015		0.020	0.020
Chromium		2.9E-06	2.9E-06		2.3E-04	2.3E-04
Lead	1.3E-05	1.3E-06	1.4E-05		9.2E-07	9.2E-07
Zinc	2.3E-04	1.9E-05	2.5E-04		1.4E-05	1.4E-05
Cyanide	0.0068		0.0068			

Source: Franklin Associates, Ltd.

No atmospheric hydrocarbon emissions were reported by steel can producers in Mexico; however, hydrocarbon emissions were reported by **aluminum** can producers for the can production step. Presumably, these emissions are a result of solvent evaporation from varnish application and can painting. It is not known if similar emissions will result from varnish application during steel can production, and if so, what the level of these emissions will be for steel can production. This aspect of the study results needs further investigation.

All of the waterborne emissions in Mexico are fuel-related. These emissions result from the production and processing of fuels.

Disposal Energy and Environmental Emissions

Table 4-5 presents the energy requirements for the operation of packer trucks and landfill equipment to dispose of postconsumer tin-coated steel cans that become solid waste (cans that are not collected for recycling). This equipment is assumed to use diesel as a fuel source; therefore, this energy is derived from petroleum.

The fuel-related environmental emissions for the operation of packer trucks and landfill equipment to dispose of postconsumer tin-coated steel cans that become solid waste are presented in Table 4-6.

Table 4-5

ENERGY REQUIREMENTS FOR DISPOSAL OF TIN-COATED STEEL CANS
(gigajoules for units disposed per 100,000 items)

	Packer Truck Energy	Landfill Equipment Energy	Total Disposal Energy
Steel Cans	0.31	0.19	0.51

Source: Franklin Associates, Ltd.

Table 4-6

SUMMARY OF FUEL-RELATED ENVIRONMENTAL EMISSIONS FOR DISPOSAL OF TIN-COATED STEEL CANS
(Emissions for units disposed per 100,000 items)

	Packer Truck Emissions	Landfill Equipment Emissions	Total Disposal Emissions
Atmospheric Emissions (kg)			
Particulates	0.030	0.018	0.048
Nitrogen Oxides	0.39	0.25	0.64
Hydrocarbons	0.10	0.063	0.16
Sulfur Oxides	0.093	0.058	0.15
Carbon Monoxide	0.13	0.079	0.20
Aldehydes	0.0061	0.0038	0.0099
Methane	4.35E-05	2.71E-05	7.05E-05
Other Organics	6.62E-07	4.12E-07	1.07E-06
Kerosene	2.15E-08	1.34E-08	3.48E-08
Ammonia	3.29E-05	2.05E-05	5.34E-05
Lead	2.21E-06	1.38E-06	3.58E-06
Fossil Carbon Dioxide	22.8	14.2	37.0
Hydrogen Chloride	9.70E-07	6.04E-07	1.57E-06
Mercury	7.20E-08	4.49E-08	1.17E-07
Chlorine	1.71E-05	1.06E-05	2.77E-05
Chromium Compounds	6.00E-07	3.73E-07	9.73E-07
Manganese Compounds	6.65E-07	4.14E-07	1.08E-06
Nickel Compounds	6.58E-06	4.10E-06	1.07E-05
Antimony	1.42E-07	8.83E-08	2.30E-07
Arsenic	4.09E-07	2.55E-07	6.63E-07
Beryllium	3.41E-08	2.12E-08	5.53E-08
Cadmium	5.06E-07	3.15E-07	8.22E-07
Cobalt	4.01E-07	2.50E-07	6.51E-07
Selenium	1.54E-07	9.58E-08	2.50E-07
Sulfuric Acid	0.0011	6.65E-04	0.0017
Na2O2	6.53E-07	4.07E-07	1.06E-06
KO2	6.53E-07	4.07E-07	1.06E-06
V2O5	6.53E-07	4.07E-07	1.06E-06
Solid Waste (kg)	0.038	0.023	0.061
Solid Waste (cu m)	4.70E-05	2.93E-05	7.63E-05
Waterborne Emissions (kg)			
Acid	6.61E-09	4.01E-09	1.06E-08
Metal Ion	1.24E-04	7.53E-05	2.00E-04
Dissolved Solids	0.0054	0.0033	0.0087
Suspended Solids	4.47E-04	2.71E-04	7.18E-04
BOD	0.0015	9.00E-04	0.0024
COD	0.0025	0.0015	0.0040
Phenol	2.79E-05	1.69E-05	4.47E-05
Sulfides	1.51E-05	9.14E-06	2.42E-05
Oil	0.0015	9.15E-04	0.0024
Sulfuric Acid	3.54E-05	2.14E-05	5.68E-05
Iron	1.13E-05	6.83E-06	1.81E-05
Ammonia	2.55E-04	1.55E-04	4.10E-04
Chromium	3.60E-06	2.18E-06	5.78E-06
Lead	1.17E-08	7.10E-09	1.88E-08
Zinc	1.72E-07	1.04E-07	2.76E-07

Source: Franklin Associates, Ltd.

Chapter 5

ENERGY AND ENVIRONMENTAL RESULTS FOR WOODEN FRUIT CRATES

INTRODUCTION

This chapter provides a summary of the energy requirements and environmental emissions for the production, recycling and disposal of wooden fruit crates in Mexico. The basis for the results presented in this chapter is 100,000 wooden crates. Supporting data for this chapter are presented in Appendix F of the separately bound Appendix document.

The wooden fruit crates analyzed in this study are produced from wood obtained by cutting trees (no recycled content). Wooden crates are not recycled in Mexico. There is some reuse of the product; however, the reuse rate is unknown and thus was not included in this analysis.

DATA SOURCES

Data for the production of wood products used to manufacture the wooden fruit crates and transportation requirements were provided by one producer in Mexico. Data for the fabrication of wooden fruit crates in Mexico were estimated from data obtained from Franklin Associates' database for similar operations in the United States.

RESULTS AND DISCUSSION

Manufacturing Energy Requirements

Table 5-1 presents the energy requirements for the manufacture of 100,000 wooden fruit crates. All of the steps in the production of wooden fruit crates take place in Mexico.

Process energy accounts for about 80 percent of the total energy for the system.

Transportation energy accounts for the remaining 20 percent of the total energy. This energy is used to transport raw materials and finished goods within Mexico.

The energy of material resource for wood-derived materials is not included in this analysis because wood is not used as a commercial fuel source in most industrial countries nor in Mexico. Therefore, the energy of material resource for this system is reported as zero.

Table 5-1

ENERGY REQUIREMENTS FOR MANUFACTURE OF 100,000 WOODEN FRUIT CRATES

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total
Fruit Crates								
Mexico	435	80%	108	20%			543	100%
Total Energy	435	80%	108	20%			543	100%

Source: Franklin Associates, Ltd.

Table 5-2 presents the energy profile for production of wooden fruit crates. Petroleum-derived energy makes up about 75 percent of the total energy. Petroleum supplies all of the energy used for chain saws and transportation modes. It also make up a large portion (about 54 percent) of the energy used to produce electricity. These are the only energy requirements for production of the wooden crates.

Manufacturing Environmental Emissions

Solid Waste. Table 5-3 presents the solid waste for manufacturing 100,000 wooden fruit crates. Included in this table is the postconsumer solid waste generated from disposal of containers that are not collected for recycling.

Together, process and fuel-related solid waste only account for about one percent of the total solid waste weight and less than one percent of the total solid waste volume.

Postconsumer solid waste from disposal of the wooden fruit crates accounts for 99 percent of the solid waste weight and greater than 99 percent of the solid waste volume.

Atmospheric and Waterborne Emissions. The total atmospheric and waterborne emissions for manufacturing wooden fruit crates are presented in Table 5-4a and 5-4b, respectively.

All of the atmospheric emissions for operations in Mexico are fuel related. These emissions are a result of production and combustion of fuels to produce energy for manufacturing operations and transportation of raw materials and finished products.

All of the waterborne emissions in Mexico are fuel-related. These emissions also result from the production and processing of fuels.

Disposal Energy and Environmental Emissions

Table 5-5 presents the energy requirements for the operation of packer trucks and landfill equipment to dispose of postconsumer wooden fruit crates that become solid waste (crates that are not collected for recycling). This equipment is assumed to use diesel as a fuel source; therefore, this energy is derived from petroleum.

The fuel-related environmental emissions for the operation of packer trucks and landfill equipment to dispose of postconsumer wooden fruit crates that become solid waste are presented in Table 5-6.

Table 5-2

ENERGY PROFILES FOR MANUFACTURE OF 100,000 WOODEN FRUIT CRATES
(GJ per 100,000 Items)

	Energy Profile							
	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Total Energy
Fruit Crates								
Mexico	55.2	409	23.7	23.1	14.8		17.5	543
Total	55.2	409	23.7	23.1	14.8		17.5	543

Source: Franklin Associates, Ltd.

Table 5-3

SOLID WASTE BY WEIGHT AND VOLUME FOR MANUFACTURE OF 100,000 WOODEN FRUIT CRATES

	Process Waste		Fuel Waste		Postconsumer Waste		Total Solid Waste	
	kg	cubic meter	kg	cubic meter	kg	cubic meter	kg	cubic meter
Fruit Crate								
Mexico	110	0.14	800	1.00	85,845	181	86,754	182
Total Solid Waste	110	0.14	800	1.00	85,845	181	86,754	182

Source: Franklin Associates, Ltd.

Table 5-4a

SUMMARY OF ATMOSPHERIC EMISSIONS FOR WOODEN FRUIT CRATES
(Emissions per 100,000 items)

	Mexico		
	Process Emissions	Fuel Emissions	Total Emissions
Atmospheric Emissions (kg)			
Particulates		37.5	37.5
Nitrogen Oxides		164	164
Hydrocarbons		170	170
Sulfur Oxides		551	551
Carbon Monoxide		851	851
Aldehydes		2.81	2.81
Methane		0.31	0.31
Other Organics		38.7	38.7
Kerosene		0.0014	0.0014
Ammonia		0.043	0.043
Lead		0.11	0.11
Fossil Carbon Dioxide		35,810	35,810
Hydrogen Chloride		0.0013	0.0013
Mercury		0.0018	0.0018
Chlorine		0.26	0.26
Chromium Compounds		0.025	0.025
Manganese Compounds		0.035	0.035
Nickel Compounds		0.16	0.16
Antimony		0.0032	0.0032
Arsenic		0.015	0.015
Beryllium		0.0015	0.0015
Cadmium		0.013	0.013
Cobalt		0.0092	0.0092
Selenium		0.0035	0.0035
Sulfuric Acid		23.4	23.4
Na2O2		9.39E-04	9.39E-04
KO2		9.39E-04	9.39E-04
V2O5		9.39E-04	9.39E-04

Source: Franklin Associates, Ltd.

Table 5-4b

SUMMARY OF WATERBORNE EMISSIONS FOR WOODEN FRUIT CRATES
(Emissions per 100,000 items)

	Mexico		
	Process Emissions	Fuel Emissions	Total Emissions
Waterborne Emissions (kg)			
Acid		9.35E-06	9.35E-06
Metal Ion		0.18	0.18
Dissolved Solids		7.75	7.75
Suspended Solids		0.63	0.63
BOD		2.10	2.10
COD		3.48	3.48
Phenol		0.039	0.039
Sulfides		0.021	0.021
Oil		2.18	2.18
Sulfuric Acid		2.51	2.51
Iron		0.63	0.63
Ammonia		0.36	0.36
Chromium		0.0051	0.0051
Lead		1.66E-05	1.66E-05
Zinc		2.43E-04	2.43E-04

Source: Franklin Associates, Ltd.

Table 5-5

ENERGY REQUIREMENTS FOR DISPOSAL OF WOODEN FRUIT CRATES
(gigajoules for units disposed per 100,000 items)

	Packer Truck Energy	Landfill Equipment Energy	Total Disposal Energy
Fruit Crates	9.16	6.22	15.4

Source: Franklin Associates, Ltd.

Table 5-6

SUMMARY OF FUEL-RELATED ENVIRONMENTAL EMISSIONS FOR DISPOSAL OF WOODEN FRUIT CRATES
(Emissions for units disposed per 100,000 items)

	Packer Truck Emissions	Landfill Equipment Emissions	Total Disposal Emissions
Atmospheric Emissions (kg)			
Particulates	0.87	0.59	1.46
Nitrogen Oxides	11.6	7.84	19.4
Hydrocarbons	2.95	2.00	4.96
Sulfur Oxides	2.73	1.86	4.59
Carbon Monoxide	3.70	2.51	6.20
Aldehydes	0.18	0.12	0.30
Methane	0.0013	8.63E-04	0.0021
Other Organics	1.94E-05	1.31E-05	3.25E-05
Kerosene	6.28E-07	4.26E-07	1.05E-06
Ammonia	9.63E-04	6.53E-04	0.0016
Lead	6.46E-05	4.39E-05	1.08E-04
Fossil Carbon Dioxide	668	453	1,121
Hydrogen Chloride	2.84E-05	1.93E-05	4.76E-05
Mercury	2.11E-06	1.43E-06	3.54E-06
Chlorine	4.99E-04	3.39E-04	8.38E-04
Chromium Compounds	1.76E-05	1.19E-05	2.95E-05
Manganese Compounds	1.95E-05	1.32E-05	3.27E-05
Nickel Compounds	1.93E-04	1.31E-04	3.23E-04
Antimony	4.15E-06	2.82E-06	6.96E-06
Arsenic	1.20E-05	8.12E-06	2.01E-05
Beryllium	9.97E-07	6.76E-07	1.67E-06
Cadmium	1.48E-05	1.01E-05	2.49E-05
Cobalt	1.17E-05	7.96E-06	1.97E-05
Selenium	4.50E-06	3.06E-06	7.56E-06
Sulfuric Acid	0.031	0.021	0.052
Na2O2	1.91E-05	1.30E-05	3.21E-05
KO2	1.91E-05	1.30E-05	3.21E-05
V2O5	1.91E-05	1.30E-05	3.21E-05
Solid Waste (kg)	1.10	0.75	1.85
Solid Waste (cu m)	0.0014	9.34E-04	0.0023
Waterborne Emissions (kg)			
Acid	6.61E-09	4.01E-09	1.06E-08
Metal Ion	1.24E-04	7.53E-05	2.00E-04
Dissolved Solids	0.0054	0.0033	0.0087
Suspended Solids	4.47E-04	2.71E-04	7.18E-04
BOD	0.0015	9.00E-04	0.0024
COD	0.0025	0.0015	0.0040
Phenol	2.79E-05	1.69E-05	4.47E-05
Sulfides	1.51E-05	9.14E-06	2.42E-05
Oil	0.0015	9.15E-04	0.0024
Sulfuric Acid	3.54E-05	2.14E-05	5.68E-05
Iron	1.13E-05	6.83E-06	1.81E-05
Ammonia	2.55E-04	1.55E-04	4.10E-04
Chromium	3.60E-06	2.18E-06	5.78E-06
Lead	1.17E-08	7.10E-09	1.88E-08
Zinc	1.72E-07	1.04E-07	2.76E-07

Source: Franklin Associates, Ltd.

Chapter 6

ENERGY AND ENVIRONMENTAL RESULTS FOR PET AND PETG PACKAGING

INTRODUCTION

This chapter provides a summary of the energy requirements and environmental emissions for the production, recycling and disposal of the following packaging materials in Mexico:

- 1.5 liter refillable PETG bottle for soft drinks
- 1 liter non-refillable PET bottle for edible oil

The basis for the results presented in this chapter is 100,000 packaging units. Supporting data for the PET and PETG packaging systems are presented in Appendix H of the separately bound Appendix document. Data for production of the polypropylene closures used on the PETG bottles can be found in Appendix K. Data for the production of the HDPE closure used on the PET bottle can be found in Appendix I.

The postconsumer recovery rate for the PET bottle examined in this study is assumed to be zero. The refillable PETG bottle is assumed to have an average usage of six trips before it is discarded. The postconsumer recovery rate for the bottle after its useful lifetime is assumed to be zero. The recovery rate for polypropylene closures used on the bottles is assumed to be zero.

DATA SOURCES

Data supplied by PET and PETG bottle producers in Mexico indicated the use of PET and PETG resin produced in the United States; therefore, all of the resin used to manufacturer the containers examined in this study is assumed to come from manufacturers in the United States. Polypropylene resin used to manufacture the closures for the PETG bottle is also assumed to come from the United States. Data for the production of PET, PETG and polypropylene resin in the United States are taken from Franklin Associates' database.

Data for the production of non-refillable PET bottles were derived from information supplied by one container manufacturer in Mexico. Data for refillable PETG bottle production were also derived from information supplied by one container manufacturer in Mexico (a different manufacturer than the one supplying information for PET bottles). Data for washing refillable bottles were derived from information for washing and filling supplied by one bottler in Mexico. Data for the average distance traveled and method used to collect refillable bottles were estimated from information supplied by M.R. Servicios de

Fomento Industrial S.A. de C.V., Mexico City. Data for the production of HDPE resin (used for the PET bottle closures), closures and caustic soda (used to clean the refillable bottles) in Mexico were estimated from data taken from Franklin Associates' database for similar production operations in the United States.

RESULTS AND DISCUSSION

Refillable PETG Soft Drink Bottles

Manufacturing Energy Requirements. Table 6-1 presents the energy requirements for the manufacture of 100,000 PETG soft drink bottles, assuming six trips per bottle. The energy usage is categorized by country and grouped by bottle and closure.

Process energy accounts for about 62 percent of the total energy for the system. The PETG bottle uses about 92 percent of the process energy. About 63 percent of the process energy for the bottle is used in the United States to manufacture PETG resin. About 60 percent of the process energy for the closure is used in the United States to manufacture polypropylene resin.

Transportation energy accounts for about four percent of the total energy. About 92 percent of the transportation energy is allocated to the bottle. Sixty-four percent of the transportation energy for the bottle is used in the United States for PETG resin production. Less than nine percent of the bottle transportation energy in Mexico is for collecting refillable bottles.

The energy of material resource accounts for 34 percent of the total energy for the system. All of this energy represents the crude oil and natural gas that are used as a raw materials for PETG and polypropylene production in the United States.

Table 6-2 presents the energy profile for production of PETG soft drink bottles. Together, natural gas and petroleum account for about 80 percent of the total energy for the system.

Electricity supplies over 75 percent of the energy used to manufacture the PETG bottles and all of the energy used to manufacture the polypropylene closures in Mexico. Consequently, the energy profile for Mexico is indicative of the energy sources used to generate electricity.

Table 6-1

ENERGY REQUIREMENTS FOR MANUFACTURE OF 100,000 REFILLABLE PETG SOFT DRINK BOTTLES
(assuming 6 trips per bottle)

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total
PETG Soft Drink Bottle								
United States	102	54%	6.50	3%	80.5	43%	189	100%
Mexico	60.4	94%	3.60	6%			64.0	100%
Total Energy	162	64%	10.1	4%	80.5	32%	253	100%
Polypropylene Closure								
United States	8.29	34%	0.41	2%	15.3	64%	24.0	100%
Mexico	5.59	91%	0.53	9%			6.12	100%
Total Energy	13.9	46%	0.93	3%	15.3	51%	30.1	100%
Package Total								
United States	110	52%	6.91	3%	95.8	45%	213	100%
Mexico	66.0	94%	4.13	6%			70.1	100%
Total Energy	176	62%	11.0	4%	95.8	34%	283	100%

Source: Franklin Associates, Ltd.

Table 6-2

ENERGY PROFILES FOR MANUFACTURE OF 100,000 REFILLABLE PETG SOFT DRINK BOTTLES
(GJ per 100,000 bottles assuming 6 trips per bottle)

	Energy Profile							
	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Total Energy
PETG Soft Drink Bottle								
United States	61.0	84.2	37.8	0.58	4.52		0.38	189
Mexico	9.24	44.9	3.02	2.85	1.83		2.16	64.0
Total	70.3	129	40.9	3.43	6.35		2.54	253
Polypropylene Closure								
United States	18.5	3.83	1.13	0.055	0.43		0.036	24.0
Mexico	0.84	4.08	0.36	0.35	0.22		0.27	6.12
Total	19.4	7.91	1.49	0.40	0.65		0.30	30.1
Package Total								
United States	79.6	88.0	39.0	0.63	4.95		0.42	212.6
Mexico	10.08	49.0	3.38	3.20	2.06		2.42	70.1
Total	89.7	137.0	42.3	3.83	7.00		2.84	283

Source: Franklin Associates, Ltd.

Manufacturing Environmental Emissions

Solid Waste. Table 6-3 presents the solid waste for manufacturing 100,000 PETG soft drink bottles. Included in this table is the postconsumer solid waste generated from disposal of PETG bottles after their last trip and disposal of the closures.

Process solid waste accounts for about five percent of the total solid waste weight and about two percent of the total solid waste volume. About 88 percent of the process solid waste is produced in Mexico. Most of the process solid waste produced in Mexico is packaging and other solid waste produced during the PETG bottle manufacturing step.

Fuel-related solid waste makes up 21 percent of the solid waste weight and six percent of the solid waste volume.

Postconsumer solid waste accounts for 73 percent of the total solid waste weight and about 93 percent of the total solid waste volume.

Atmospheric and Waterborne Emissions. The total atmospheric and waterborne emissions for manufacturing PETG soft drink bottles are presented in Table 6-4a and 6-4b, respectively.

Most of the atmospheric emissions for operations in Mexico are fuel related. These emissions are a result of production and combustion of fuels to produce energy for manufacturing operations and transportation of raw materials and finished products.

Process atmospheric emissions classified as "other organics" that are released in Mexico are produced during production of the PETG bottle. All other process atmospheric emissions released in Mexico are from the production of caustic soda used to clean the refillable bottles.

Most of the waterborne dissolved solids process emissions released in Mexico are from bottle washing. All other process waterborne emissions released in Mexico are from the production of caustic soda.

Table 6-3

SOLID WASTE BY WEIGHT AND VOLUME FOR MANUFACTURE OF 100,000 REFILLABLE PETG SOFT DRINK BOTTLES
(assuming 6 trips per bottle)

	Process Waste		Fuel Waste		Postconsumer Waste		Total Solid Waste	
	kg	cubic meter	kg	cubic meter	kg	cubic meter	kg	cubic meter
PETG Soft Drink Bottle								
United States	18.1	0.023	475	0.59			493	0.61
Mexico	134	0.17	106	0.13	1,767	8.39	2,007	8.69
Total Solid Waste	153	0.19	581	0.72	1,767	8.39	2,500	9.30
Polypropylene Closure								
United States	0.45	5.59E-04	7.21	0.0033			7.66	0.0038
Mexico			5.38	0.0067	273	2.79	278	2.80
Total Solid Waste	0.45	5.59E-04	12.6	0.010	273	2.79	286	2.80
Package Total								
United States	18.6	0.023	482	0.59			501	0.61
Mexico	134	0.17	112	0.14	2,040	11.2	2,286	11.5
Total Solid Waste	153	0.19	594	0.73	2,040	11.2	2,786	12.1

Source: Franklin Associates, Ltd.

Table 6-4a

SUMMARY OF ATMOSPHERIC EMISSIONS FOR REFILLABLE PETG SOFT DRINK BOTTLES
(Emissions per 100,000 bottles assuming 6 trips per bottle)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Atmospheric Emissions (kg)						
Particulates	1.42	3.21	9.62	3.12E-05	4.64	4.64
Nitrogen Oxides	1.76	23.4	25.1		27.0	27.0
Hydrocarbons	54.5	31.6	86.1		19.4	19.4
Sulfur Oxides	5.05	42.4	47.5	6.02E-04	71.9	71.9
Carbon Monoxide	28.3	12.3	40.7		13.0	13.0
Aldehydes	0.057	0.12	0.17		0.32	0.32
Methane		0.084	0.084		0.043	0.043
Other Organics		1.50	1.50	0.17	1.17	1.34
Kerosene		4.56E-04	4.56E-04		1.83E-04	1.83E-04
Ammonia	0.0075	0.0020	0.0095		0.0050	0.0050
Lead	2.06E-06	0.0013	0.0013		0.0025	0.0025
Fossil Carbon Dioxide		7,558	7,558		4,624	4,624
Hydrogen Chloride	2.21E-04	5.94E-05	2.81E-04		1.46E-04	1.46E-04
Mercury		7.57E-05	7.57E-05	3.69E-05	2.32E-04	2.68E-04
Chlorine	2.94E-04		2.94E-04	2.16E-05	0.035	0.035
Chromium Compounds		0.0029	0.0029		0.0033	0.0033
Manganese Compounds		0.0045	0.0045		0.0046	0.0046
Nickel Compounds		0.0054	0.0054		0.020	0.020
Antimony		8.60E-05	8.60E-05		4.20E-04	4.20E-04
Arsenic		0.0015	0.0015		0.0020	0.0020
Beryllium		1.66E-04	1.66E-04		1.93E-04	1.93E-04
Cadmium		6.91E-04	6.91E-04		0.0017	0.0017
Cobalt		2.45E-04	2.45E-04		0.0012	0.0012
Selenium		9.40E-05	9.40E-05		4.56E-04	4.56E-04
Sulfuric Acid					3.04	3.04
Na2O2					1.14E-04	1.14E-04
KO2					1.14E-04	1.14E-04
V2O5					1.14E-04	1.14E-04

Source: Franklin Associates, Ltd.

Table 6-4b

SUMMARY OF WATERBORNE EMISSIONS FOR REFILLABLE PETG SOFT DRINK BOTTLES
(Emissions per 100,000 bottles assuming 6 trips per bottle)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Waterborne Emissions (kg)						
Acid	0.052	4.37E-07	0.052		1.08E-06	1.08E-06
Metal Ion	0.031	0.0093	0.040		0.020	0.020
Dissolved Solids	19.6	5.41	25.0	33.4	0.89	34.3
Suspended Solids	0.90	0.0049	0.91		0.073	0.073
BOD	1.05	0.0054	1.05	1.10E-06	0.24	0.24
COD	2.79	0.025	2.81	1.10E-06	0.40	0.40
Phenol	2.42E-04	3.00E-05	2.72E-04		0.0045	0.0045
Sulfides	0.024		0.024	1.03E-05	0.0025	0.0025
Oil	0.26	0.099	0.36		0.25	0.25
Sulfuric Acid		3.03	3.03		0.34	0.34
Iron	5.97E-04	0.76	0.76		0.084	0.084
Ammonia	0.42	7.03E-04	0.42		0.042	0.042
Chromium	6.55E-04	1.74E-06	6.57E-04		5.86E-04	5.86E-04
Lead	2.89E-06	7.75E-07	3.66E-06	5.51E-08	1.91E-06	1.96E-06
Zinc	4.81E-04	1.14E-05	4.92E-04	5.51E-08	2.30E-05	2.30E-05
Nickel				5.51E-08		5.51E-08
Mercury				1.01E-07		1.01E-07
Phosphates	0.0026		0.0026			
Other Chem.	0.047		0.047			

Source: Franklin Associates, Ltd.

Non-Refillable PET Soft Drink Bottles

Manufacturing Energy Requirements. Table 6-5 presents the energy requirements for the manufacture of 100,000 PET edible oil bottles. The energy usage is categorized by country and grouped by bottle and closure.

Process energy accounts for about 55 percent of the total energy for the system. The PET bottle uses about 95 percent of the process energy. About 68 percent of the process energy for the bottle is used in the United States to manufacture PET resin.

Transportation energy accounts for about six percent of the total energy. About 98 percent of the transportation energy is allocated to the bottle. Sixty-two percent of the transportation energy for the bottle is used in the United States for PET resin production.

The energy of material resource accounts for 40 percent of the total energy for the system. Ninety-two percent of this energy is used in the United States to manufacture PET resin. The remaining eight percent is used in Mexico to make HDPE resin for the closure.

Table 6-6 presents the energy profile for production of PET bottles. Together, natural gas and petroleum account for about 84 percent of the total energy for the system.

Electricity supplies all of the energy used to manufacture the PET bottles and HDPE closures in Mexico. Consequently, the energy profile for Mexico is indicative of the energy sources used to generate electricity.

Manufacturing Environmental Emissions

Solid Waste. Table 6-7 presents the solid waste for manufacturing 100,000 PET edible oil bottles. Included in this table is the postconsumer solid waste generated from disposal of the bottles and closures.

Process solid waste accounts for about eight percent of the total solid waste weight and about two percent of the total solid waste volume. About 89 percent of the process solid waste is produced in Mexico. This solid waste is produced during PET bottle manufacture and consists of packaging material used to deliver resin and other process waste.

Fuel-related solid waste makes up less than one percent of the solid waste weight and volume.

Postconsumer solid waste accounts for 92 percent of the total solid waste weight and about 98 percent of the total solid waste volume.

Table 6-5

ENERGY REQUIREMENTS FOR MANUFACTURE OF 100,000 NON-REFILLABLE PET BOTTLES FOR EDIBLE OIL

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total
PET Edible Oil Bottle								
United States	172	47%	16.2	4%	179	49%	368	100%
Mexico	80.8	89%	9.92	11%			90.7	100%
Total Energy	253	55%	26.2	6%	179	39%	458	100%
HDPE Closure								
Mexico	12.0	44%	0.69	3%	14.4	53%	27.0	100%
Total Energy	12.0	44%	0.69	3%	14.4	53%	27.0	100%
Package Total								
United States	172	47%	16.2	4%	179	49%	368	100%
Mexico	92.7	79%	10.6	9%	14.4	12%	118	100%
Total Energy	265	55%	26.8	6%	194	40%	485	100%

Source: Franklin Associates, Ltd.

Table 6-6

ENERGY PROFILES FOR MANUFACTURE OF 100,000 NON-REFILLABLE PET BOTTLES FOR EDIBLE OIL
(GJ per 100,000 Items)

	Energy Profile							
	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Total Energy
PET Edible Oil Bottle								
United States	111	200	43.5	1.40	11.0		0.93	368
Mexico	12.1	61.3	5.20	5.06	3.25		3.83	90.7
Total	123	261	48.7	6.46	14.2		4.76	458
HDPE Closure								
Mexico	20.4	5.10	0.46	0.45	0.29		0.34	27.0
Total	20.4	5.10	0.46	0.45	0.29		0.34	27.0
Package Total								
United States	111	200	43.5	1.40	11.0		0.93	368
Mexico	32.5	66.4	5.66	5.51	3.54		4.17	118
Total	143	267	49.2	6.91	14.5		5.11	485

Source: Franklin Associates, Ltd.

Table 6-7

SOLID WASTE BY WEIGHT AND VOLUME FOR MANUFACTURE OF 100,000 NON-REFILLABLE PET BOTTLES FOR EDIBLE OIL

	Process Waste		Fuel Waste		Postconsumer Waste		Total Solid Waste	
	kg	cubic meter	kg	cubic meter	kg	cubic meter	kg	cubic meter
PET Edible Oil Bottle								
United States	37.2	0.046	7.21	0.0033			44.4	0.050
Mexico	307	0.38	5.38	0.0067	3,850	18.3	4,162	18.7
Total Solid Waste	344	0.43	12.6	0.010	3,850	18.3	4,206	18.7
HDPE Closure								
Mexico	0.58	7.27E-04	15.4	0.019	254	2.59	270	2.61
Total Solid Waste	0.58	7.27E-04	15.4	0.019	254	2.59	270	2.61
Package Total								
United States	37.2	0.046	7.21	0.0033			44.4	0.050
Mexico	307	0.38	20.8	0.026	4,104	20.9	4,432	21.3
Total Solid Waste	344	0.43	28.0	0.029	4,104	20.9	4,476	21.3

Source: Franklin Associates, Ltd.

Atmospheric and Waterborne Emissions. The total atmospheric and waterborne emissions for manufacturing PET edible oil bottles are presented in Table 6-8a and 6-8b, respectively.

Most of the atmospheric emissions for operations in Mexico are fuel related. These emissions are a result of production and combustion of fuels to produce energy for manufacturing operations and transportation of raw materials and finished products.

Process atmospheric emissions classified as "other organics" that are released in Mexico are produced during production of the PET bottle. All other process atmospheric emissions released in Mexico are from the production of HDPE resin and fabrication of the closures.

All of the process waterborne emissions released in Mexico are from the production of HDPE resin and fabrication of the closures.

Disposal Energy and Environmental Emissions

Table 6-9 presents the energy requirements for the operation of packer trucks and landfill equipment to dispose of postconsumer solid waste from refillable PETG soft drink bottle systems (after the last filling) and PET edible oil bottle systems. This equipment is assumed to use diesel as a fuel source; therefore, this energy is derived from petroleum.

The fuel-related environmental emissions for the operation of packer trucks and landfill equipment to dispose of postconsumer solid waste from the refillable PETG soft drink bottle systems and the PET edible oil bottle systems are presented in Tables 6-10 and 6-11, respectively.

Table 6-8a

SUMMARY OF ATMOSPHERIC EMISSIONS FOR NON-REFILLABLE PET BOTTLES FOR EDIBLE OIL
(Emissions per 100,000 items)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Atmospheric Emissions (kg)						
Particulates	3.38	10.3	13.7	0.20	6.80	7.00
Nitrogen Oxides	1.78	35.7	37.5	0.28	23.6	23.9
Hydrocarbons	105	47.6	153	14.3	29.8	44.1
Sulfur Oxides	3.11	54.1	57.2	3.81	126	130
Carbon Monoxide	44.3	18.8	63.1	0.059	17.7	17.8
Aldehydes	2.43	0.31	2.74		0.21	0.21
Methane		0.11	0.11		0.076	0.076
Other Organics	28.5	3.73	32.3	0.78	3.79	4.57
Kerosene		0.0011	0.0011		3.33E-04	3.33E-04
Ammonia	0.014	0.0075	0.022		0.0071	0.0071
Lead	3.92E-06	0.0021	0.0021		0.0045	0.0045
Fossil Carbon Dioxide	0.056	12,423	12,423		7,086	7,086
Hydrogen Chloride	4.22E-04	2.22E-04	6.44E-04		2.08E-04	2.08E-04
Mercury		1.38E-04	1.38E-04		4.18E-04	4.18E-04
Chlorine	5.61E-04		5.61E-04		0.061	0.061
Chromium Compounds		0.0040	0.0040		0.0060	0.0060
Manganese Compounds		0.0057	0.0057		0.0082	0.0082
Nickel Compounds		0.015	0.015		0.037	0.037
Antimony		2.91E-04	2.91E-04		7.59E-04	7.59E-04
Arsenic		0.0021	0.0021		0.0036	0.0036
Beryllium		2.26E-04	2.26E-04		5.43E-04	5.43E-04
Cadmium		0.0015	0.0015		0.0031	0.0031
Cobalt		9.23E-04	9.23E-04		0.0021	0.0021
Selenium		3.16E-04	3.16E-04		3.24E-04	3.24E-04
Sulfuric Acid					5.49	5.49
Na2O2					1.37E-04	1.37E-04
KO2					1.37E-04	1.37E-04
V2O5					1.37E-04	1.37E-04
Ethylene Glycol	0.60		0.60			

Source: Franklin Associates, Ltd.

Table 6-8b

SUMMARY OF WATERBORNE EMISSIONS FOR NON-REFILLABLE PET BOTTLES FOR EDIBLE OIL
(Emissions per 100,000 items)

	United States			Mexico		
Waterborne Emissions (kg)	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Acid	0.14	1.63E-06	0.14	0.033	1.53E-06	0.033
Metal Ion	0.059	0.035	0.093		0.029	0.029
Dissolved Solids	39.0	19.9	58.8		1.28	1.28
Suspended Solids	1.73	0.018	1.74	0.026	0.10	0.13
BOD	2.29	0.020	2.31	0.017	0.34	0.36
COD	7.96	0.095	8.05	0.082	0.57	0.65
Phenol	6.84E-04	1.12E-04	7.97E-04		0.0065	0.0065
Sulfides	0.062		0.062	0.015	0.0035	0.019
Oil	0.50	0.28	0.78	0.012	0.36	0.38
Sulfuric Acid		3.57	3.57		0.60	0.60
Iron	0.0011	0.89	0.90		0.15	0.15
Ammonia	3.54	0.0026	3.55		0.059	0.059
Chromium	0.0012	6.50E-06	0.0012		8.34E-04	8.34E-04
Lead	5.50E-06	2.90E-06	8.40E-06		2.72E-06	2.72E-06
Zinc	0.0013	4.25E-05	0.0013	2.82E-04	3.99E-05	3.22E-04
Phosphates	0.0069		0.0069	0.0017		0.0017
Other Chem.	0.34		0.34			

Source: Franklin Associates, Ltd.

Table 6-9

ENERGY REQUIREMENTS FOR DISPOSAL OF PET AND PETG PACKAGING
(gigajoules for units disposed per 100,000 items)

	Packer Truck Energy	Landfill Equipment Energy	Total Disposal Energy
PETG Soft Drink Bottle*			
PETG Bottle	0.49	0.29	0.77
Polypropylene Closure	0.16	0.096	0.26
Package Total	0.65	0.38	1.03
PET Edible Oil Bottle			
PET Bottle	1.06	0.63	1.69
HDPE Closure	0.15	0.089	0.24
Package Total	1.21	0.72	1.93

* Allocated over six trips per bottle before disposal.

Source: Franklin Associates, Ltd.

Table 6-10

SUMMARY OF FUEL-RELATED ENVIRONMENTAL EMISSIONS FOR DISPOSAL OF REFILLABLE PETG SOFT DRINK BOTTLES
(Emissions for units disposed per 100,000 items)*

	Packer Truck Emissions	Landfill Equipment Emissions	Total Disposal Emissions
Atmospheric Emissions (kg)			
Particulates	0.061	0.036	0.098
Nitrogen Oxides	0.82	0.48	1.30
Hydrocarbons	0.21	0.12	0.33
Sulfur Oxides	0.19	0.11	0.31
Carbon Monoxide	0.26	0.15	0.42
Aldehydes	0.013	0.0075	0.020
Methane	8.99E-05	5.33E-05	1.43E-04
Other Organics	1.37E-06	8.12E-07	2.18E-06
Kerosene	4.44E-08	2.63E-08	7.07E-08
Ammonia	6.80E-05	4.04E-05	1.08E-04
Lead	4.57E-06	2.71E-06	7.28E-06
Fossil Carbon Dioxide	47.2	28.0	75.2
Hydrogen Chloride	2.01E-06	1.19E-06	3.20E-06
Mercury	1.49E-07	8.84E-08	2.37E-07
Chlorine	3.53E-05	2.09E-05	5.62E-05
Chromium Compounds	1.24E-06	7.36E-07	1.96E-06
Manganese Compounds	1.38E-06	8.17E-07	2.19E-06
Nickel Compounds	1.36E-05	8.07E-06	2.17E-05
Antimony	2.93E-07	1.74E-07	4.67E-07
Arsenic	8.45E-07	5.02E-07	1.35E-06
Beryllium	7.04E-08	4.18E-08	1.12E-07
Cadmium	1.05E-06	6.22E-07	1.67E-06
Cobalt	8.29E-07	4.92E-07	1.32E-06
Selenium	3.18E-07	1.89E-07	5.07E-07
Sulfuric Acid	0.0022	0.0013	0.0035
Na2O2	1.35E-06	8.02E-07	2.15E-06
KO2	1.35E-06	8.02E-07	2.15E-06
V2O5	1.35E-06	8.02E-07	2.15E-06
Solid Waste (kg)	0.078	0.046	0.12
Solid Waste (cu m)	9.73E-05	5.77E-05	1.55E-04
Waterborne Emissions (kg)			
Acid	6.61E-09	4.01E-09	1.06E-08
Metal Ion	1.24E-04	7.53E-05	2.00E-04
Dissolved Solids	0.0054	0.0033	0.0067
Suspended Solids	4.47E-04	2.71E-04	7.18E-04
BOD	0.0015	9.00E-04	0.0024
COD	0.0025	0.0015	0.0040
Phenol	2.79E-05	1.69E-05	4.47E-05
Sulfides	1.51E-05	9.14E-06	2.42E-05
Oil	0.0015	9.15E-04	0.0024
Sulfuric Acid	3.54E-05	2.14E-05	5.68E-05
Iron	1.13E-05	6.83E-06	1.31E-05
Ammonia	2.55E-04	1.55E-04	4.10E-04
Chromium	3.60E-06	2.18E-06	5.78E-06
Lead	1.17E-08	7.10E-09	1.88E-08
Zinc	1.72E-07	1.04E-07	2.76E-07

* Allocated over six trips per bottle before disposal.

Source: Franklin Associates, Ltd.

Table 6-11

SUMMARY OF FUEL-RELATED ENVIRONMENTAL EMISSIONS FOR DISPOSAL OF NON-REFILLABLE PET BOTTLES FOR EDIBLE OIL
(Emissions for units disposed per 100,000 items)

	Packer Truck Emissions	Landfill Equipment Emissions	Total Disposal Emissions
Atmospheric Emissions (kg)			
Particulates	0.11	0.068	0.18
Nitrogen Oxides	1.53	0.91	2.43
Hydrocarbons	0.39	0.23	0.62
Sulfur Oxides	0.36	0.21	0.58
Carbon Monoxide	0.49	0.29	0.78
Aldehydes	0.024	0.014	0.037
Methane	1.68E-04	9.96E-05	2.68E-04
Other Organics	2.56E-06	1.52E-06	4.07E-06
Kerosene	8.29E-08	4.92E-08	1.32E-07
Ammonia	1.27E-04	7.54E-05	2.02E-04
Lead	8.53E-06	5.06E-06	1.36E-05
Fossil Carbon Dioxide	88.2	52.3	140
Hydrogen Chloride	3.75E-06	2.22E-06	5.97E-06
Mercury	2.78E-07	1.65E-07	4.44E-07
Chlorine	6.59E-05	3.91E-05	1.05E-04
Chromium Compounds	2.32E-06	1.37E-06	3.69E-06
Manganese Compounds	2.57E-06	1.52E-06	4.10E-06
Nickel Compounds	2.54E-05	1.51E-05	4.05E-05
Antimony	5.48E-07	3.25E-07	8.73E-07
Arsenic	1.58E-06	9.37E-07	2.52E-06
Beryllium	1.32E-07	7.81E-08	2.10E-07
Cadmium	1.96E-06	1.16E-06	3.12E-06
Cobalt	1.55E-06	9.19E-07	2.47E-06
Selenium	5.95E-07	3.53E-07	9.48E-07
Sulfuric Acid	0.0041	0.0024	0.0066
Na2O2	2.52E-06	1.50E-06	4.02E-06
KO2	2.52E-06	1.50E-06	4.02E-06
V2O5	2.52E-06	1.50E-06	4.02E-06
Solid Waste (kg)	0.15	0.086	0.23
Solid Waste (cu m)	1.32E-04	1.08E-04	2.90E-04
Waterborne Emissions (kg)			
Acid	6.61E-09	4.01E-09	1.06E-08
Metal Ion	1.24E-04	7.53E-05	2.00E-04
Dissolved Solids	0.0054	0.0033	0.0087
Suspended Solids	4.47E-04	2.71E-04	7.18E-04
BOD	0.0015	9.00E-04	0.0024
COD	0.0025	0.0015	0.0040
Phenol	2.79E-05	1.69E-05	4.47E-05
Sulfides	1.51E-05	9.14E-06	2.42E-05
Oil	0.0015	9.15E-04	0.0024
Sulfuric Acid	3.54E-05	2.14E-05	5.68E-05
Iron	1.13E-05	6.83E-06	1.81E-05
Ammonia	2.55E-04	1.55E-04	4.10E-04
Chromium	3.60E-06	2.18E-06	5.78E-06
Lead	1.17E-08	7.10E-09	1.88E-08
Zinc	1.72E-07	1.04E-07	2.76E-07

Source: Franklin Associates, Ltd.

Chapter 7

ENERGY AND ENVIRONMENTAL RESULTS FOR POLYETHYLENE PACKAGING

INTRODUCTION

This chapter provides a summary of the energy requirements and environmental emissions for the production, recycling and disposal of the following packaging materials in Mexico:

- 400 ml HDPE shampoo bottles
- LDPE-film bread bags

The basis for the results presented in this chapter is 100,000 packaging units. Supporting data for the HDPE and LDPE packaging systems are presented in Appendix I of the separately bound Appendix document. Data for production of the polypropylene closure used on the shampoo bottle can be found in Appendix K.

The postconsumer recovery rates for the HDPE bottles and LDPE-film bread bags examined in this study are assumed to be zero.

DATA SOURCES

Data supplied by producers in Mexico that use HDPE and LDPE resin to produce packaging material indicated that the resin was obtained from manufacturers in Mexico. Data for HDPE and LDPE production in Mexico were not available for this study. Therefore, information from Franklin Associates' database for resin production in the United States were used to estimate resin production in Mexico. Likewise, data for the production of LDPE-film bread bags in Mexico were estimated from information from Franklin Associates' database. Data for the production of HDPE bottles were supplied by one producer in Mexico.

The polypropylene closure used on the HDPE shampoo bottle is assumed to be produced from resin manufactured in the United States. Data for polypropylene production in the United States were obtained from Franklin Associates' database.

RESULTS AND DISCUSSION

HDPE Shampoo Bottles

Manufacturing Energy Requirements. Table 7-1 presents the energy requirements for the manufacture of 100,000 HDPE shampoo bottles. The energy usage is categorized by country and grouped by bottle and closure.

Process energy accounts for about 48 percent of the total energy for the system. The HDPE bottle uses about 77 percent of the process energy, all of which is used in Mexico. About 60 percent of the process energy for the closure is used in the United States to manufacture polypropylene resin.

Transportation energy accounts for about two percent of the total energy. About 62 percent of the transportation energy is allocated to the bottle; the rest is used to produce the closure. About 56 percent of the transportation energy for the closure is used in Mexico.

The energy of material resource accounts for 51 percent of the total energy for the system. Seventy-six percent of this energy is used in Mexico for HDPE resin production.

Table 7-2 presents the energy profile for production of HDPE shampoo bottles. Natural gas accounts for about 70 percent of the total energy for the system. About 69 percent of the total natural gas energy used in Mexico is the energy of material resource for the HDPE resin (polyethylene resin manufactured in Mexico is assumed to be produced from a natural gas feedstock).

Manufacturing Environmental Emissions

Solid Waste. Table 7-3 presents the solid waste for manufacturing 100,000 HDPE shampoo bottles. Included in this table is the postconsumer solid waste generated from disposal of the bottles.

Process solid waste accounts for less than one percent of the total solid waste weight and volume for the system.

Fuel-related solid waste makes up eight percent of the solid waste weight and one percent of the solid waste volume.

Postconsumer solid waste accounts for 92 percent of the total solid waste weight and about 99 percent of the total solid waste volume.

Atmospheric and Waterborne Emissions. The total atmospheric and waterborne emissions for manufacturing HDPE shampoo bottles are presented in Table 7-4a and 7-4b, respectively.

Table 7-1

ENERGY REQUIREMENTS FOR MANUFACTURE OF 100,000 HDPE SHAMPOO BOTTLES

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total
HDPE Shampoo Bottles								
Mexico	243	48%	7.69	2%	255	50%	506	100%
Polypropylene Closure								
United States	42.5	34%	2.09	2%	78.6	64%	123	100%
Mexico	28.7	91%	2.70	9%			31.4	100%
Total Energy	71.2	46%	4.79	3%	78.6	51%	155	100%
Package Total								
United States	42.5	34%	2.09	2%	78.6	64%	123	100%
Mexico	272	51%	10.4	2%	255	47%	537	100%
Total Energy	314	48%	12.5	2%	334	51%	661	100%

Source: Franklin Associates, Ltd.

Table 7-2

ENERGY PROFILES FOR MANUFACTURE OF 100,000 HDPE SHAMPOO BOTTLES
(GJ per 100,000 Items)

	Energy Profile							
	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Total Energy
HDPE Shampoo Bottles								
Mexico	366	106	10.2	10.0	6.40		7.55	506
Polypropylene Closure								
United States	95.1	19.6	5.80	0.28	2.19		0.19	123
Mexico	4.29	20.9	1.85	1.79	1.15		1.36	31.4
Total	99.4	40.5	7.65	2.08	3.35		1.55	155
Package Total								
United States	95.1	19.6	5.80	0.28	2.19		0.19	123
Mexico	370	126.9	12.1	11.75	7.55		8.91	537
Total	465	146.5	17.9	12.03	9.75		9.09	661

Source: Franklin Associates, Ltd.

Table 7-3

SOLID WASTE BY WEIGHT AND VOLUME FOR MANUFACTURE OF 100,000 HDPE SHAMPOO BOTTLES

	Process Waste		Fuel Waste		Postconsumer Waste		Total Solid Waste	
	kg	cubic meter	kg	cubic meter	kg	cubic meter	kg	cubic meter
HDPE Shampoo Bottle								
Mexico	10.3	0.013	338	0.42	4,500	21.4	4,849	21.8
Total Solid Waste	10.3	0.013	338	0.42	4,500	21.4	4,849	21.8
Polypropylene Closure								
United States	5.06	0.0063	81.5	0.037			86.6	0.044
Mexico			60.9	0.076	1,400	14.3	1,461	14.4
Total Solid Waste	5.06	0.0063	142	0.11	1,400	14.3	1,547	14.4
Package Total								
United States	5.06	0.0063	81.5	0.037			86.6	0.044
Mexico	10.3	0.013	399	0.50	5,900	35.7	6,310	36.2
Total Solid Waste	15.4	0.019	481	0.54	5,900	35.7	6,396	36.2

Source: Franklin Associates, Ltd.

Table 7-4a

SUMMARY OF ATMOSPHERIC EMISSIONS FOR HDPE SHAMPOO BOTTLES (Emissions per 100,000 items)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Atmospheric Emissions (kg)						
Particulates	0.34	1.33	1.67	3.47	12.9	16.3
Nitrogen Oxides	1.59	6.22	7.31	4.95	48.3	53.3
Hydrocarbons	36.7	19.3	56.0	253	117	369
Sulfur Oxides	1.92	7.18	9.10	67.5	289	357
Carbon Monoxide	0.34	2.98	3.32	1.05	29.7	30.8
Aldehydes	0.015	0.028	0.043		0.20	0.20
Methane		0.044	0.044		0.26	0.26
Other Organics		0.36	0.36		2.15	2.15
Kerosene		2.10E-04	2.10E-04		7.12E-04	7.12E-04
Ammonia	0.0019	2.83E-04	0.0022		0.014	0.014
Lead	5.26E-07	1.83E-04	1.84E-04		0.0107	0.0107
Fossil Carbon Dioxide		2,533	2,533		21,333	21,333
Hydrogen Chloride	5.65E-05	8.34E-06	6.48E-05		4.02E-04	4.02E-04
Mercury		8.67E-06	8.67E-06		8.97E-04	8.97E-04
Chlorine	7.52E-05		7.52E-05		0.13	0.13
Chromium Compounds		4.53E-04	4.53E-04		0.013	0.013
Manganese Compounds		7.29E-04	7.29E-04		0.018	0.018
Nickel Compounds		5.32E-04	5.32E-04		0.079	0.079
Antimony					0.0016	0.0016
Arsenic		2.26E-04	2.26E-04		0.0076	0.0076
Beryllium		2.62E-05	2.62E-05		7.35E-04	7.35E-04
Cadmium					0.0067	0.0067
Cobalt		1.77E-05	1.77E-05		0.0046	0.0046
Selenium		6.79E-06	6.79E-06		0.0018	0.0018
Sulfuric Acid					11.9	11.9
Na2O2					7.88E-04	7.88E-04
KO2					7.88E-04	7.88E-04
V2O5					7.88E-04	7.88E-04

Source: Franklin Associates, Ltd.

Table 7-4b

SUMMARY OF WATERBORNE EMISSIONS FOR HDPE SHAMPOO BOTTLES
(Emissions per 100,000 items)

	United States			Mexico		
Waterborne Emissions (kg)	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Acid	0.19	6.14E-08	0.19	0.59	2.96E-06	0.59
Metal Ion	0.0078	0.0013	0.0091		0.056	0.056
Dissolved Solids	5.16	0.84	6.00		2.46	2.46
Suspended Solids	0.534	6.91E-04	0.534	0.47	0.20	0.67
BOD	0.305	7.54E-04	0.306	0.30	0.66	0.96
COD	0.64	0.0036	0.64	1.45	1.10	2.55
Phenol	2.85E-05	4.21E-06	3.28E-05		0.012	0.012
Sulfides	0.086		0.086	0.27	0.0067	0.27
Oil	0.12	0.033	0.15	0.22	0.76	0.98
Sulfuric Acid		0.49	0.49		1.27	1.27
Iron	1.52E-04	0.12	0.12		0.32	0.32
Ammonia	6.59E-04	9.87E-05	7.67E-04		0.114	0.114
Chromium	1.66E-06	2.44E-07	1.90E-06		0.0016	0.0016
Lead	7.37E-07	1.09E-07	8.46E-07		5.24E-06	5.24E-06
Zinc	0.0016	1.59E-06	0.0016	0.0050	7.68E-05	0.0051
Phosphates	0.0096		0.0096	0.030		0.030

Source: Franklin Associates, Ltd.

Most of the atmospheric emissions for operations in Mexico are fuel related. These emissions are a result of production and combustion of fuels to produce energy for manufacturing operations and transportation of raw materials and finished products.

All of the process atmospheric and waterborne emissions released in Mexico are produced during production of HDPE resin and fabrication of the bottle.

LDPE-Film Bread Bags

Manufacturing Energy Requirements. Table 7-5 presents the energy requirements for the manufacture of 100,000 LDPE-film bread bags. All of the processes necessary for the production of LDPE bread bags take place in Mexico.

Process energy accounts for about 39 percent of the total energy for the system. The ethylene and LDPE resin manufacturing steps account for about 41 and 40 percent of the process energy, respectively.

The energy of material resource accounts for 58 percent of the total energy for the system. This energy represents the natural gas that is used as a raw material for LDPE production.

Table 7-6 presents the energy profile for production of LDPE-film bread bags. Natural gas accounts for about 82 percent of the total energy for the system. About 72 percent of the natural gas energy is the energy of material resource for the natural gas feedstock used as a raw material for LDPE production.

Manufacturing Environmental Emissions

Solid Waste. Table 7-7 presents the solid waste for manufacturing 100,000 LDPE-film bread bags. Included in this table is the postconsumer solid waste generated from disposal of the bags.

Process solid waste accounts for less than one percent of the total solid waste weight and volume for the system.

Fuel-related solid waste makes up four percent of the solid waste weight and two percent of the solid waste volume.

Postconsumer solid waste makes up the remaining 96 percent of the solid waste weight and 98 percent of the total solid waste volume.

Table 7-5

ENERGY REQUIREMENTS FOR MANUFACTURE OF 100,000 LDPE BREAD BAGS

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total
LDPE Bread Bags								
Mexico	33.0	39%	2.36	3%	49.6	58%	85.0	100%
Total Energy	33.0	39%	2.36	3%	49.6	58%	85.0	100%

Source: Franklin Associates, Ltd.

Table 7-6

ENERGY PROFILES FOR MANUFACTURE OF 100,000 LDPE BREAD BAGS
(GJ per 100,000 Items)

	Energy Profile							
	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Total Energy
LDPE Bread Bags								
Mexico	69.6	12.0	1.03	1.00	0.64		0.76	85.0
Total	69.6	12.0	1.03	1.00	0.64		0.76	85.0

Source: Franklin Associates, Ltd.

Table 7-7

SOLID WASTE BY WEIGHT AND VOLUME FOR MANUFACTURE OF 100,000 LDPE BREAD BAGS

	Process Waste		Fuel Waste		Postconsumer Waste		Total Solid Waste	
	kg	cubic meter	kg	cubic meter	kg	cubic meter	kg	cubic meter
LDPE Bread Bags								
Mexico	2.00	0.0025	34.3	0.043	874	2.21	910	2.25
Total Solid Waste	2.00	0.0025	34.3	0.043	874	2.21	910	2.25

Source: Franklin Associates, Ltd.

Atmospheric and Waterborne Emissions. The total atmospheric and waterborne emissions for manufacturing LDPE-film bread bags are presented in Table 7-8a and 7-8b, respectively.

Most of the atmospheric emissions for operations in Mexico are fuel related. These emissions are a result of production and combustion of fuels to produce energy for manufacturing operations and transportation of raw materials and finished products.

Process emissions account for a large portion of the waterborne emissions. All of these emissions are a result of the LDPE resin manufacturing steps, including production and processing of raw materials needed to make LDPE resin.

Disposal Energy and Environmental Emissions

Table 7-9 presents the energy requirements for the operation of packer trucks and landfill equipment to dispose of postconsumer solid waste from the HDPE shampoo bottle systems and the LDPE-film bread bags. This equipment is assumed to use diesel as a fuel source; therefore, this energy is derived from petroleum.

The fuel-related environmental emissions for the operation of packer trucks and landfill equipment to dispose of postconsumer solid waste from the HDPE shampoo bottle systems and the LDPE-film bread bags are presented in Tables 7-10 and 7-11, respectively.

Table 7-8a

SUMMARY OF ATMOSPHERIC EMISSIONS FOR LDPE BREAD BAGS (Emissions per 100,000 items)

	Mexico		
	Process Emissions	Fuel Emissions	Total Emissions
Atmospheric Emissions (kg)			
Particulates	0.15	1.32	1.47
Nitrogen Oxides	0.96	6.08	7.04
Hydrocarbons	36.7	18.1	54.8
Sulfur Oxides	13.1	28.3	41.4
Carbon Monoxide	0.20	4.01	4.21
Aldehydes		0.034	0.034
Methane		0.035	0.035
Other Organics		0.69	0.69
Kerosene		6.11E-05	6.11E-05
Ammonia		0.0013	0.0013
Lead		0.0011	0.0011
Fossil Carbon Dioxide		2,870	2,870
Hydrogen Chloride		3.82E-05	3.82E-05
Mercury		7.77E-05	7.77E-05
Chlorine		0.011	0.011
Chromium Compounds		0.0011	0.0011
Manganese Compounds		0.0015	0.0015
Nickel Compounds		0.0068	0.0068
Antimony		1.41E-04	1.41E-04
Arsenic		6.59E-04	6.59E-04
Beryllium		6.33E-05	6.33E-05
Cadmium		5.83E-04	5.83E-04
Cobalt		4.00E-04	4.00E-04
Selenium		1.53E-04	1.53E-04
Sulfuric Acid		1.04	1.04
Na2O2		1.23E-04	1.23E-04
KO2		1.23E-04	1.23E-04
V2O5		1.23E-04	1.23E-04

Source: Franklin Associates, Ltd.

Table 7-8b

SUMMARY OF WATERBORNE EMISSIONS FOR LDPE BREAD BAGS (Emissions per 100,000 items)

	Mexico		
	Process Emissions	Fuel Emissions	Total Emissions
Waterborne Emissions (kg)			
Acid	0.11	2.81E-07	0.11
Metal Ion		0.0053	0.0053
Dissolved Solids		0.23	0.23
Suspended Solids	0.28	0.019	0.30
BOD	0.22	0.063	0.28
COD	0.71	0.10	0.81
Phenol		0.0012	0.0012
Sulfides	0.052	6.40E-04	0.053
Oil	0.043	0.080	0.12
Sulfuric Acid		0.11	0.11
Iron		0.027	0.027
Ammonia		0.011	0.011
Chromium		1.53E-04	1.53E-04
Lead		4.98E-07	4.98E-07
Zinc	9.71E-04	7.30E-06	9.78E-04
Phosphates	0.0058		0.0058

Source: Franklin Associates, Ltd.

Table 7-9

ENERGY REQUIREMENTS FOR DISPOSAL OF POLYETHYLENE PACKAGING
(gigajoules for units disposed per 100,000 items)

	Packer Truck Energy	Landfill Equipment Energy	Total Disposal Energy
HDPE Shampoo Bottle			
HDPE Bottle	1.24	0.73	1.97
Polypropylene Closure	0.83	0.49	1.32
Package Total	2.06	1.23	3.29
LDPE Bread Bags	0.13	0.076	0.20

Source: Franklin Associates, Ltd.

Table 7-10

SUMMARY OF FUEL-RELATED ENVIRONMENTAL EMISSIONS FOR DISPOSAL OF HDPE SHAMPOO BOTTLES
(Emissions for units disposed per 100,000 items)

	Packer Truck Emissions	Landfill Equipment Emissions	Total Disposal Emissions
Atmospheric Emissions (kg)			
Particulates	0.20	0.12	0.31
Nitrogen Oxides	2.60	1.55	4.15
Hydrocarbons	0.67	0.40	1.06
Sulfur Oxides	0.62	0.37	0.98
Carbon Monoxide	0.83	0.49	1.33
Aldehydes	0.040	0.024	0.064
Methane	2.87E-04	1.70E-04	4.57E-04
Other Organics	4.36E-06	2.59E-06	6.96E-06
Kerosene	1.41E-07	8.40E-08	2.25E-07
Ammonia	2.17E-04	1.29E-04	3.46E-04
Lead	1.46E-05	8.65E-06	2.32E-05
Fossil Carbon Dioxide	150	89.4	240
Hydrogen Chloride	6.40E-06	3.80E-06	1.02E-05
Mercury	4.75E-07	2.82E-07	7.57E-07
Chlorine	1.13E-04	6.68E-05	1.79E-04
Chromium Compounds	3.95E-06	2.35E-06	6.30E-06
Manganese Compounds	4.39E-06	2.61E-06	6.99E-06
Nickel Compounds	4.34E-05	2.58E-05	6.92E-05
Antimony	9.35E-07	5.55E-07	1.49E-06
Arsenic	2.70E-06	1.60E-06	4.30E-06
Beryllium	2.25E-07	1.33E-07	3.58E-07
Cadmium	3.34E-06	1.98E-06	5.32E-06
Cobalt	2.64E-06	1.57E-06	4.21E-06
Selenium	1.01E-06	6.03E-07	1.62E-06
Sulfuric Acid	0.0070	0.0042	0.011
Na2O2	4.31E-06	2.56E-06	6.87E-06
KO2	4.31E-06	2.56E-06	6.87E-06
V2O5	4.31E-06	2.56E-06	6.87E-06
Solid Waste (kg)	0.25	0.15	0.40
Solid Waste (cu m)	3.10E-04	1.84E-04	4.94E-04
Waterborne Emissions (kg)			
Acid	6.61E-09	4.01E-09	1.06E-08
Metal Ion	1.24E-04	7.53E-05	2.00E-04
Dissolved Solids	0.0054	0.0033	0.0087
Suspended Solids	4.47E-04	2.71E-04	7.18E-04
BOD	0.0015	9.00E-04	0.0024
COD	0.0025	0.0015	0.0040
Phenol	2.79E-05	1.69E-05	4.47E-05
Sulfides	1.51E-05	9.14E-06	2.42E-05
Oil	0.0015	9.15E-04	0.0024
Sulfuric Acid	3.54E-05	2.14E-05	5.68E-05
Iron	1.13E-05	6.83E-06	1.81E-05
Ammonia	2.55E-04	1.55E-04	4.10E-04
Chromium	3.60E-06	2.18E-06	5.78E-06
Lead	1.17E-08	7.10E-09	1.88E-08
Zinc	1.72E-07	1.04E-07	2.76E-07

Source: Franklin Associates, Ltd.

Table 7-11

SUMMARY OF FUEL-RELATED ENVIRONMENTAL EMISSIONS FOR DISPOSAL OF LDPE BREAD BAGS
(Emissions for units disposed per 100,000 items)

	Packer Truck Emissions	Landfill Equipment Emissions	Total Disposal Emissions
Atmospheric Emissions (kg)			
Particulates	0.012	0.0072	0.019
Nitrogen Oxides	0.16	0.096	0.26
Hydrocarbons	0.042	0.024	0.066
Sulfur Oxides	0.038	0.023	0.061
Carbon Monoxide	0.052	0.031	0.083
Aldehydes	0.0025	0.0015	0.0040
Methane	1.79E-05	1.05E-05	2.84E-05
Other Organics	2.72E-07	1.61E-07	4.33E-07
Kerosene	8.83E-09	5.20E-09	1.40E-08
Ammonia	1.35E-05	7.98E-06	2.15E-05
Lead	9.09E-07	5.36E-07	1.44E-06
Fossil Carbon Dioxide	9.39	5.53	14.9
Hydrogen Chloride	3.99E-07	2.35E-07	6.34E-07
Mercury	2.96E-08	1.75E-08	4.71E-08
Chlorine	7.02E-06	4.14E-06	1.12E-05
Chromium Compounds	2.47E-07	1.45E-07	3.92E-07
Manganese Compounds	2.74E-07	1.61E-07	4.35E-07
Nickel Compounds	2.71E-06	1.60E-06	4.30E-06
Antimony	5.83E-08	3.44E-08	9.27E-08
Arsenic	1.68E-07	9.92E-08	2.67E-07
Beryllium	1.40E-08	8.26E-09	2.23E-08
Cadmium	2.08E-07	1.23E-07	3.31E-07
Cobalt	1.65E-07	9.72E-08	2.62E-07
Selenium	6.33E-08	3.73E-08	1.01E-07
Sulfuric Acid	4.39E-04	2.59E-04	6.98E-04
Na2O2	2.69E-07	1.58E-07	4.27E-07
KO2	2.69E-07	1.58E-07	4.27E-07
V2O5	2.69E-07	1.58E-07	4.27E-07
Solid Waste (kg)	0.016	0.0091	0.025
Solid Waste (cu m)	1.94E-05	1.14E-05	3.08E-05
Waterborne Emissions (kg)			
Acid	6.61E-09	4.01E-09	1.06E-08
Metal Ion	1.24E-04	7.53E-05	2.00E-04
Dissolved Solids	0.0054	0.0033	0.0087
Suspended Solids	4.47E-04	2.71E-04	7.18E-04
BOD	0.0015	9.00E-04	0.0024
COD	0.0025	0.0015	0.0040
Phenol	2.79E-05	1.69E-05	4.47E-05
Sulfides	1.51E-05	9.14E-06	2.42E-05
Oil	0.0015	9.15E-04	0.0024
Sulfuric Acid	3.34E-05	2.14E-05	5.68E-05
Iron	1.13E-05	6.83E-06	1.81E-05
Ammonia	2.55E-04	1.55E-04	4.10E-04
Chromium	3.60E-06	2.18E-06	5.78E-06
Lead	1.17E-08	7.10E-09	1.88E-08
Zinc	1.72E-07	1.04E-07	2.76E-07

Source: Franklin Associates, Ltd.

Chapter 8

ENERGY AND ENVIRONMENTAL RESULTS FOR PVC WATER BOTTLES

INTRODUCTION

This chapter provides a summary of the energy requirements and environmental emissions for the production, recycling and disposal of PVC water bottles. The basis for the results presented in this chapter is 100,000 PVC water bottles. Supporting data for the PVC water bottle are presented in Appendix J of the separately bound Appendix document. Data for production of the HDPE closure used on the bottle can be found in Appendix H.

The postconsumer recovery rate for the PVC bottles examined in this study is assumed to be zero.

DATA SOURCES

The PVC resin examined in this study is assumed to be produced in Mexico from vinyl chloride monomer and resin modifiers produced in the United States. Data for production of vinyl chloride monomer and resin modifiers were taken from Franklin Associates' database. Data for the production of PVC resin from these raw materials were taken from information supplied by two resin producers in Mexico. Data for blowmolding PVC bottles were supplied by one producer in Mexico.

The HDPE closure used on the water bottle is assumed to be produced from resin manufactured in Mexico. Data for HDPE resin production in Mexico were not available for this study. Therefore, information from Franklin Associates' database for resin production in the United States were used to estimate resin production in Mexico.

RESULTS AND DISCUSSION

Manufacturing Energy Requirements. Table 8-1 presents the energy requirements for the manufacture of 100,000 PVC water bottles. The energy usage is categorized by country and grouped by bottle and closure.

Process energy accounts for about 59 percent of the total energy for the system. The PVC bottle uses about 97 percent of the process energy. About 59 percent of the process energy for the bottle is used in the United States to manufacture resin modifiers and vinyl chloride monomer.

Table 8-1

ENERGY REQUIREMENTS FOR MANUFACTURE OF 100,000 PVC WATER BOTTLES

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total
PVC Water Bottle								
United States	345	48%	18.0	2%	361	50%	724	100%
Mexico	243	90%	27.9	10%			270	100%
Total Energy	587	59%	45.8	5%	361	36%	994	100%
HDPE Closure								
Mexico	16.5	44%	0.95	3%	19.9	53%	37.3	100%
Total Energy	16.5	44%	0.95	3%	19.9	53%	37.3	100%
Package Total								
United States	345	48%	18.0	2%	361	50%	724	100%
Mexico	259	84%	28.8	9%	19.9	6%	308	100%
Total Energy	604	59%	46.8	5%	381	37%	1,032	100%

Source: Franklin Associates, Ltd.

Transportation energy accounts for five percent of the total energy. About 98 percent of the transportation energy is allocated to the bottle, the rest is used to produce the closure. About 61 percent of the transportation energy for the bottle is used in Mexico.

The energy of material resource accounts for 37 percent of the total energy for the system. Ninety-five percent of this energy is used in the United States for vinyl chloride monomer and resin modifier production.

Table 8-2 presents the energy profile for production of PVC water bottles. Natural gas account for about 59 percent of the total energy for the system. Petroleum accounts for another 27 percent of the total energy.

Manufacturing Environmental Emissions

Solid Waste. Table 8-3 presents the solid waste for manufacturing 100,000 PVC water bottles. Included in this table is the postconsumer solid waste generated from disposal of the bottles and closures.

Process solid waste accounts for about six percent of the total solid waste weight and about two percent of the total solid waste volume.

Fuel-related solid waste makes up 11 percent of the solid waste weight and three percent of the solid waste volume.

Postconsumer solid waste accounts for the remaining 83 percent of the total solid waste weight and 95 percent of the total solid waste volume.

Atmospheric and Waterborne Emissions. The total atmospheric and waterborne emissions for manufacturing PVC water bottles are presented in Table 8-4a and 8-4b, respectively.

Most of the atmospheric emissions for operations in Mexico are fuel related. These emissions are a result of production and combustion of fuels to produce energy for manufacturing operations and transportation of raw materials and finished products.

Vinyl chloride process-related atmospheric emissions released in Mexico are from the PVC resin production step. All of the other process emissions in Mexico are from production of HDPE resin and fabrication of the closure.

Table 8-2

ENERGY PROFILES FOR MANUFACTURE OF 100,000 PVC WATER BOTTLES
(GJ per 100,000 Items)

	Energy Profile							
	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Total Energy
PVC Water Bottle								
United States	520	101	72.9	3.22	25.2		2.14	724
Mexico	56.7	167	14.1	13.7	8.79		10.4	270
Total	577	268	86.9	16.9	34.0		12.5	994
HDPE Closure								
Mexico	28.1	7.03	0.64	0.62	0.40		0.47	37.3
Total	28.1	7.03	0.64	0.62	0.40		0.47	37.3
Package Total								
United States	520	101	72.9	3.22	25.2		2.14	724
Mexico	84.8	174	14.7	14.3	9.19		10.8	308
Total	605	275	87.6	17.5	34.4		13.0	1,032

Source: Franklin Associates, Ltd.

Table 8-3

SOLID WASTE BY WEIGHT AND VOLUME FOR MANUFACTURE OF 100,000 PVC WATER BOTTLES

	Process Waste		Fuel Waste		Postconsumer Waste		Total Solid Waste	
	kg	cubic meter	kg	cubic meter	kg	cubic meter	kg	cubic meter
PVC Water Bottle								
United States	273	0.34	997	1.24			1,270	1.59
Mexico	556	0.69	465	0.58	11,000	52.2	12,021	53.5
Total Solid Waste	829	1.03	1,462	1.83	11,000	52.2	13,291	55.1
HDPE Closure								
Mexico	0.80	0.0010	21.2	0.026	350	3.58	372	3.60
Total Solid Waste	0.80	0.0010	21.2	0.026	350	3.58	372	3.60
Package Total								
United States	273	0.34	997	1.24			1,270	1.59
Mexico	556	0.69	486	0.61	11,350	55.8	12,393	57.1
Total Solid Waste	830	1.04	1,483	1.85	11,350	55.8	13,663	58.7

Source: Franklin Associates, Ltd.

Table 8-4a

SUMMARY OF ATMOSPHERIC EMISSIONS FOR PVC WATER BOTTLES
(Emissions per 100,000 items)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Atmospheric Emissions (kg)						
Particulates	1.05	16.4	17.4	0.27	17.0	17.3
Nitrogen Oxides	8.17	61.5	69.6	0.39	61.4	61.7
Hydrocarbons	174	138	312	19.7	91.0	111
Sulfur Oxides	10.4	82.5	92.8	5.25	333	338
Carbon Monoxide	1.07	26.8	27.9	0.081	46.6	46.7
Aldehydes	0.086	0.27	0.36		0.56	0.56
Methane		0.32	0.32		0.22	0.22
Other Organics		2.77	2.77		3.90	3.90
Kerosene		0.0024	0.0024		3.65E-04	3.65E-04
Ammonia	0.033	0.0027	0.036		0.019	0.019
Lead	2.34E-06	0.0022	0.0022		0.012	0.012
Fossil Carbon Dioxide		21,316	21,316		20,268	20,268
Hydrogen Chloride	2.52E-04	8.02E-05	3.32E-04		5.46E-04	5.46E-04
Mercury	0.0018	1.00E-04	0.0019		0.0011	0.0011
Chlorine	0.0014		0.0014		0.16	0.16
Chromium Compounds		0.0055	0.0055		0.015	0.015
Manganese Compounds		0.0090	0.0090		0.021	0.021
Nickel Compounds		0.0060	0.0060		0.096	0.096
Antimony					0.0020	0.0020
Arsenic		0.0028	0.0028		0.0093	0.0093
Beryllium		3.20E-04	3.20E-04		3.91E-04	3.91E-04
Cadmium					0.0081	0.0081
Cobalt		1.32E-04	1.32E-04		0.0056	0.0056
Selenium		7.00E-05	7.00E-05		0.0021	0.0021
Sulfuric Acid					14.3	14.3
Na2O2					4.97E-04	4.97E-04
KO2					4.97E-04	4.97E-04
V2O5					4.97E-04	4.97E-04
Vinyl Chloride Monomer				18.3		18.3

Source: Franklin Associates, Ltd.

Table 8-4b

SUMMARY OF WATERBORNE EMISSIONS FOR PVC WATER BOTTLES
(Emissions per 100,000 items)

	United States			Mexico		
Waterborne Emissions (kg)	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Acid	0.61	5.91E-07	0.61	0.046	4.02E-06	0.046
Metal Ion	0.035	0.013	0.047		0.076	0.076
Dissolved Solids	35.6	7.84	43.4	5.39	3.35	8.74
Suspended Solids	5.54	0.0067	5.54	1.30	0.27	1.57
BOD	5.50	0.0073	5.50	8.81	0.90	9.71
COD	26.5	0.034	26.5	6.41	1.50	7.91
Phenol	0.0043	4.05E-05	0.0043		0.017	0.017
Sulfides	0.28		0.28	1.62	0.0092	1.63
Oil	0.62	0.25	0.87	0.065	0.97	1.03
Sulfuric Acid		6.07	6.07		1.55	1.55
Iron	6.79E-04	1.52	1.52		0.39	0.39
Ammonia	0.0030	9.49E-04	0.0039		0.16	0.16
Chromium	7.37E-06	2.35E-06	9.72E-06		0.0022	0.0022
Lead	6.00E-06	1.05E-06	7.05E-06		7.13E-06	7.13E-06
Zinc	0.0052	1.53E-05	0.0052	3.89E-04	1.04E-04	4.94E-04
Nickel	2.72E-06		2.72E-06			
Mercury	4.97E-06		4.97E-06			
Phosphates	0.031		0.031	0.0023		0.0023

Source: Franklin Associates, Ltd.

Disposal Energy and Environmental Emissions

Table 8-5 presents the energy requirements for the operation of packer trucks and landfill equipment to dispose of postconsumer solid waste from the PVC water bottle systems. This equipment is assumed to use diesel as a fuel source; therefore, this energy is derived from petroleum.

The fuel-related environmental emissions for the operation of packer trucks and landfill equipment to dispose of postconsumer solid waste from the PVC water bottle systems are presented in Table 8-6.

Table 8-5

ENERGY REQUIREMENTS FOR DISPOSAL OF PVC WATER BOTTLES
(gigajoules for units disposed per 100,000 items)

	Packer Truck Energy	Landfill Equipment Energy	Total Disposal Energy
PVC Water Bottles			
PVC Bottle	3.03	1.80	4.82
HDPE Closure	0.21	0.12	0.33
Package Total	3.24	1.92	5.15

Source: Franklin Associates, Ltd.

Table 8-6

SUMMARY OF FUEL-RELATED ENVIRONMENTAL EMISSIONS FOR DISPOSAL OF PVC WATER BOTTLES
(Emissions for units disposed per 100,000 items)

	Packer Truck Emissions	Landfill Equipment Emissions	Total Disposal Emissions
Atmospheric Emissions (kg)			
Particulates	0.31	0.18	0.49
Nitrogen Oxides	4.08	2.42	6.50
Hydrocarbons	1.04	0.62	1.66
Sulfur Oxides	0.97	0.57	1.54
Carbon Monoxide	1.31	0.77	2.08
Aldehydes	0.063	0.037	0.10
Methane	4.49E-04	2.66E-04	7.16E-04
Other Organics	6.84E-06	4.06E-06	1.09E-05
Kerosene	2.22E-07	1.31E-07	3.53E-07
Ammonia	3.40E-04	2.02E-04	5.41E-04
Lead	2.28E-05	1.35E-05	3.63E-05
Fossil Carbon Dioxide	236	140	376
Hydrogen Chloride	1.00E-05	5.94E-06	1.60E-05
Mercury	7.44E-07	4.41E-07	1.19E-06
Chlorine	1.76E-04	1.05E-04	2.81E-04
Chromium Compounds	6.20E-06	3.67E-06	9.87E-06
Manganese Compounds	6.88E-06	4.08E-06	1.10E-05
Nickel Compounds	6.80E-05	4.03E-05	1.08E-04
Antimony	1.46E-06	8.69E-07	2.33E-06
Arsenic	4.22E-06	2.51E-06	6.73E-06
Beryllium	3.52E-07	2.09E-07	5.61E-07
Cadmium	5.23E-06	3.10E-06	8.34E-06
Cobalt	4.14E-06	2.46E-06	6.60E-06
Selenium	1.59E-06	9.43E-07	2.53E-06
Sulfuric Acid	0.011	0.0065	0.018
Na_2O_2	6.75E-06	4.00E-06	1.08E-05
KO_2	6.75E-06	4.00E-06	1.08E-05
V_2O_5	6.75E-06	4.00E-06	1.08E-05
Solid Waste (kg)	0.39	0.23	0.62
Solid Waste (cu m)	4.86E-04	2.88E-04	7.74E-04
Waterborne Emissions (kg)			
Acid	6.61E-09	4.01E-09	1.06E-08
Metal Ion	1.24E-04	7.53E-05	2.00E-04
Dissolved Solids	0.0054	0.0033	0.0087
Suspended Solids	4.47E-04	2.71E-04	7.18E-04
BOD	0.0015	9.00E-04	0.0024
COD	0.0025	0.0015	0.0040
Phenol	2.79E-05	1.69E-05	4.47E-05
Sulfides	1.51E-05	9.14E-06	2.42E-05
Oil	0.0015	9.15E-04	0.0024
Sulfuric Acid	3.54E-05	2.14E-05	5.68E-05
Iron	1.13E-05	6.83E-06	1.81E-05
Ammonia	2.55E-04	1.55E-04	4.10E-04
Chromium	3.60E-06	2.18E-06	5.78E-06
Lead	1.17E-08	7.10E-09	1.88E-08
Zinc	1.72E-07	1.04E-07	2.76E-07

Source: Franklin Associates, Ltd.

Chapter 9

ENERGY AND ENVIRONMENTAL RESULTS FOR POLYPROPYLENE PACKAGING

INTRODUCTION

This chapter provides a summary of the energy requirements and environmental emissions for the production, recycling and disposal of the following packaging materials in Mexico:

- 354 ml polypropylene bottle for pancake syrup
- Woven polypropylene fabric sugar sack

The basis for the results presented in this chapter is 100,000 packaging units. Supporting data for the polypropylene packaging systems are presented in Appendix K of the separately bound Appendix document.

The postconsumer recovery rates for the polypropylene packaging systems examined in this study are assumed to be zero.

DATA SOURCES

It is assumed for this study that the polypropylene resin used to manufacture packaging in Mexico is produced in the United States. Data for polypropylene and HDPE resin production in the United States were taken from Franklin Associates' database. The polypropylene bottle for pancake syrup, and the HDPE closures used on the bottle, are also produced in the United States. Data for production of these components were taken from Franklin Associates' database.

The woven polypropylene fabric sugar sack is manufactured in Mexico. Data for production of this sack were supplied by one producer in Mexico.

RESULTS AND DISCUSSION

Polypropylene Bottle for Pancake Syrup

Manufacturing Energy Requirements. Table 9-1 presents the energy requirements for the manufacture of 100,000 polypropylene pancake syrup bottles. The energy usage is categorized by country and grouped by bottle and closure. All of the process energy for the system is used in the United States.

Process energy accounts for about 36 percent of the total energy for the system. The polypropylene bottle uses about 79 percent of the process energy.

Table 9-1

ENERGY REQUIREMENTS FOR MANUFACTURE OF 100,000 POLYPROPYLENE PANCAKE SYRUP CONTAINERS

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total
Polypropylene Pancake Syrup Bottles								
United States	109	35%	15.6	5%	186	60%	311	100%
Mexico			5.62	100%			5.62	100%
Total Energy	109	35%	21.2	7%	186	59%	317	100%
HDPE Closure and Cap								
United States	28.5	45%	2.34	4%	32.9	52%	63.7	100%
Mexico			0.96	100%			0.96	100%
Total Energy	28.5	44%	3.30	5%	32.9	51%	64.6	100%
Package Total								
United States	138	37%	17.9	5%	219	58%	375	100%
Mexico			6.59	100%			6.59	100%
Total Energy	138	36%	24.5	6%	219	57%	381	100%

Source: Franklin Associates, Ltd.

Transportation energy accounts for about six percent of the total energy. About 85 percent of the transportation energy is allocated to the bottle; the rest is used for the closure. Transportation energy is the only use of energy in Mexico for this system. Energy for transportation in Mexico accounts for about two percent of the total energy for the system.

The energy of material resource accounts for 57 percent of the total energy for the system. All of this energy is used in the United States to manufacture polypropylene and HDPE resin. Eighty-five percent of the energy of material resource is used for the polypropylene bottle.

Table 9-2 presents the energy profile for production of polypropylene pancake syrup bottles. Natural gas accounts for about 70 percent of the total energy for the system, and petroleum accounts for about 19 percent of the total energy. About 64 percent of the natural gas energy and petroleum energy used in the United States is the energy of material resource for polypropylene and HDPE resin production.

Manufacturing Environmental Emissions

Solid Waste. Table 9-3 presents the solid waste for manufacturing 100,000 polypropylene pancake syrup bottles and HDPE closures. Included in this table is the postconsumer solid waste generated from disposal of the bottles and closures.

Process solid waste accounts for less than one percent of the total solid waste weight and volume.

Fuel-related solid waste makes up nine percent of the solid waste weight and two percent of the solid waste volume.

Postconsumer solid waste accounts for 91 percent of the total solid waste weight and about 98 percent of the total solid waste volume.

Atmospheric and Waterborne Emissions. The total atmospheric and waterborne emissions for manufacturing pancake syrup bottles and closures are presented in Table 9-4a and 9-4b, respectively.

All of the atmospheric emissions and waterborne emissions for operations in Mexico are fuel related. These emissions are a result of production and combustion of fuels to transportation the bottle system components in Mexico.

Table 9-2

ENERGY PROFILES FOR MANUFACTURE OF 100,000 POLYPROPYLENE PANCAKE SYRUP CONTAINERS
(GJ per 100,000 Items)

	Energy Profile							
	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Total Energy
Polypropylene Pancake Syrup Bottles								
United States	227	57.4	18.6	0.90	7.04		0.60	311
Mexico		5.62						5.62
Total	227	63.0	18.6	0.90	7.04		0.60	317
HDPE Closure and Cap								
United States	40.0	10.1	9.30	0.45	3.51		0.30	63.7
Mexico		0.96						0.96
Total	40.0	11.1	9.30	0.45	3.51		0.30	64.6
Package Total								
United States	267	67.5	27.9	1.35	10.6		0.90	375
Mexico		6.59						6.59
Total	267	74.1	27.9	1.35	10.6		0.90	381

Source: Franklin Associates, Ltd.

Table 9-3

SOLID WASTE BY WEIGHT AND VOLUME FOR MANUFACTURE OF 100,000 POLYPROPYLENE SYRUP BOTTLES

	Process Waste		Fuel Waste		Postconsumer Waste		Total Solid Waste	
	kg	cubic meter	kg	cubic meter	kg	cubic meter	kg	cubic meter
Polypropylene Syrup Bottles								
United States	15.5	0.019	262	0.33			277	0.35
Mexico			0.68	8.5E-04	3,425	16.3	3,426	16.3
Total Solid Waste	15.5	0.019	263	0.33	3,425	16.3	3,703	16.6
HDPE Closure and Cap								
United States	1.99	7.6E-04	128	0.16			130	0.16
Mexico			0.12	1.4E-04	585	5.98	585	5.98
Total Solid Waste	1.99	7.6E-04	128	0.16	585	5.98	715	6.14
Package Total								
United States	17.5	0.020	390	0.49			407	0.51
Mexico			0.79	9.9E-04	4,010	22.2	4,011	22.2
Total Solid Waste	17.5	0.020	390	0.49	4,010	22.2	4,418	22.7

Source: Franklin Associates, Ltd.

Table 9-4a

SUMMARY OF ATMOSPHERIC EMISSIONS FOR POLYPROPYLENE PANCAKE SYRUP CONTAINERS
(Emissions per 100,000 items)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Atmospheric Emissions (kg)						
Particulates	1.29	7.12	8.41		0.56	0.56
Nitrogen Oxides	4.44	30.3	34.7		3.77	3.77
Hydrocarbons	102	58.6	161		2.13	2.13
Sulfur Oxides	5.36	32.9	38.3		1.97	1.97
Carbon Monoxide	0.94	16.5	17.5		4.52	4.52
Aldehydes	0.041	0.27	0.31		0.10	0.10
Methane		0.13	0.13		9.14E-04	9.14E-04
Other Organics		4.15	4.15		2.04	2.04
Kerosene		0.0010	0.0010		4.51E-07	4.51E-07
Ammonia	0.0053	0.0021	0.0075		6.92E-04	6.92E-04
Lead	1.46E-06	8.57E-04	8.58E-04		4.65E-05	4.65E-05
Fossil Carbon Dioxide		9,176	9,176		477	477
Hydrogen Chloride	1.57E-04	6.22E-05	2.20E-04		2.04E-05	2.04E-05
Mercury		3.87E-05	3.87E-05		1.52E-06	1.52E-06
Chlorine	2.10E-04		2.10E-04		3.59E-04	3.59E-04
Chromium Compounds		0.0021	0.0021		1.26E-05	1.26E-05
Manganese Compounds		0.0035	0.0035		1.40E-05	[illegible]
Nickel Compounds		0.0023	0.0023		1.38E-04	1.38E-04
Antimony					2.98E-06	2.98E-06
Arsenic		0.0011	0.0011		8.60E-06	8.60E-06
Beryllium		1.24E-04	1.24E-04		7.16E-07	7.16E-07
Cadmium					1.07E-05	1.07E-05
Cobalt		7.00E-05	7.00E-05		8.44E-06	8.44E-06
Selenium		2.69E-05	2.69E-05		3.24E-06	3.24E-06
Sulfuric Acid					0.022	0.022
Na_2O_2					1.37E-05	1.37E-05
KO_2					1.37E-05	1.37E-05
V_2O_5					1.37E-05	1.37E-05

Source: Franklin Associates, Ltd.

Table 9-4b

SUMMARY OF WATERBORNE EMISSIONS FOR POLYPROPYLENE PANCAKE SYRUP CONTAINERS
(Emissions per 100,000 items)

	United States			Mexico		
Waterborne Emissions (kg)	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Acid	0.53	4.58E-07	0.53		1.50E-07	1.50E-07
Metal Ion	0.022	0.0097	0.031		0.0028	0.0028
Dissolved Solids	14.4	5.81	20.2		0.12	0.12
Suspended Solids	1.33	0.0051	1.33		0.010	0.010
BOD	0.77	0.0056	0.77		0.034	0.034
COD	1.71	0.027	1.74		0.056	0.056
Phenol	7.96E-05	3.14E-05	1.11E-04		6.33E-04	6.33E-04
Sulfides	0.24		0.24		3.43E-04	3.43E-04
Oil	0.32	0.13	0.46		0.034	0.034
Sulfuric Acid		2.35	2.35		3.04E-04	3.04E-04
Iron	4.25E-04	0.59	0.59		2.56E-04	2.56E-04
Ammonia	0.0019	7.37E-04	0.0026		0.0058	0.0058
Chromium	4.61E-06	1.82E-06	6.43E-06		8.17E-05	8.17E-05
Lead	2.06E-06	3.12E-07	2.37E-06		2.66E-07	2.66E-07
Zinc	0.0045	1.19E-05	0.0045		3.90E-06	3.90E-06
Phosphates	0.027		0.027			

Source: Franklin Associates, Ltd.

Woven Polypropylene-Fabric Sugar Sacks

Manufacturing Energy Requirements. Table 9-5 presents the energy requirements for the manufacture of 100,000 woven polypropylene sugar sacks. The energy usage is categorized by country.

Process energy makes up 41 percent of the total energy for the system. About 71 percent of the process energy is used in the United States to produce polypropylene resin. The remaining process energy is used in Mexico to manufacture the sugar sack.

Transportation energy accounts for four percent of the total process energy for the system. Sixty-two percent of the transportation energy is used in Mexico to transport the resin and other materials.

The energy of material resource accounts for 55 percent of the total energy for the system. This energy represents the natural gas and petroleum raw materials used in the United States to produce the polypropylene resin.

Table 9-6 presents the energy profile for production of woven polypropylene sugar sacks. Natural gas accounts for about 68 percent of the total energy for the system, and petroleum accounts for another 24 percent of the total energy. The energy of material resource for the system makes up about 65 percent of the natural gas energy and 87 percent of the petroleum energy used in the United States.

Manufacturing Environmental Emissions

Solid Waste. Table 9-7 presents the solid waste for manufacturing 100,000 woven polypropylene sugar sacks. Included in this table is the postconsumer solid waste generated from disposal of the sacks.

Process solid waste accounts for less than one percent of the total solid waste weight and volume for the system.

Fuel related solid-waste makes up about seven percent of the total solid waste weight and two percent of the total solid waste volume.

Postconsumer solid waste makes up the remaining 92 percent of the solid waste weight and 97 percent of the total solid waste volume.

Atmospheric and Waterborne Emissions. The total atmospheric and waterborne emissions for manufacturing woven polypropylene sugar sacks are presented in Table 9-8a and 9-8b, respectively.

Table 9-5

ENERGY REQUIREMENTS FOR MANUFACTURE OF 100,000 WOVEN POLYPROPYLENE SUGAR SACKS

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total
Sugar Sacks								
United States	277	34%	13.6	2%	512	64%	803	100%
Mexico	112	83%	22.7	17%			135	100%
Total Energy	389	41%	36.3	4%	512	55%	938	100%

Source: Franklin Associates, Ltd.

Table 9-6

ENERGY PROFILES FOR MANUFACTURE OF 100,000 WOVEN POLYPROPYLENE SUGAR SACKS
(GJ per 100,000 Items)

	Energy Profile							
	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Total Energy
Sugar Sacks								
United States	620	128	37.8	1.83	14.3		1.21	803
Mexico	16.7	93.8	7.20	7.00	4.50		5.31	135
Total	637	222	45.0	8.83	18.8		6.52	938

Source: Franklin Associates, Ltd.

Table 9-7

SOLID WASTE BY WEIGHT AND VOLUME FOR MANUFACTURE OF 100,000 WOVEN POLYPROPYLENE SUGAR SACKS

	Process Waste		Fuel Waste		Postconsumer Waste		Total Solid Waste	
	kg	cubic meter	kg	cubic meter	kg	cubic meter	kg	cubic meter
Sugar Sacks								
United States	33.0	0.041	531	0.24			564	0.28
Mexico	55.8	0.070	239	0.30	9,500	24.0	9,795	24.4
Total Solid Waste	88.8	0.11	770	0.54	9,500	24.0	10,359	24.6

Source: Franklin Associates, Ltd.

Table 9-8a

SUMMARY OF ATMOSPHERIC EMISSIONS FOR WOVEN POLYPROPYLENE SUGAR SACKS
(Emissions per 100,000 items)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Atmospheric Emissions (kg)						
Particulates	2.24	8.65	10.9	2.31	9.76	12.1
Nitrogen Oxides	10.4	40.5	50.9		35.6	35.6
Hydrocarbons	239	126	365		36.4	36.4
Sulfur Oxides	12.5	46.8	59.3		161	161
Carbon Monoxide	2.19	19.5	21.6		29.5	29.5
Aldehydes	0.095	0.18	0.28		0.41	0.41
Methane		0.28	0.28		0.091	0.091
Other Organics		2.36	2.36		8.33	8.33
Kerosene		0.0014	0.0014		4.24E-04	4.24E-04
Ammonia	0.012	0.0018	0.014		0.010	0.010
Lead	3.43E-06	0.0012	0.0012		0.0057	0.0057
Fossil Carbon Dioxide		16,509	16,509		9,097	9,097
Hydrogen Chloride	3.68E-04	5.43E-05	4.23E-04		2.94E-04	2.94E-04
Mercury		5.65E-05	5.65E-05		5.33E-04	5.33E-04
Chlorine	4.90E-04		4.90E-04		0.079	0.079
Chromium Compounds		0.0030	0.0030		0.0076	0.0076
Manganese Compounds		0.0048	0.0048		0.010	0.010
Nickel Compounds		0.0035	0.0035		0.047	0.047
Antimony					9.68E-04	9.68E-04
Arsenic		0.0015	0.0015		0.0045	0.0045
Beryllium		1.71E-04	1.71E-04		4.37E-04	4.37E-04
Cadmium					0.0040	0.0040
Cobalt		1.15E-04	1.15E-04		0.0027	0.0027
Selenium		4.43E-05	4.43E-05		0.0011	0.0011
Sulfuric Acid					7.00	7.00
Na2O2					2.32E-04	2.32E-04
KO2					2.32E-04	2.32E-04
V2O5					2.32E-04	2.32E-04

Source: Franklin Associates, Ltd.

Table 9-8b

SUMMARY OF WATERBORNE EMISSIONS FOR WOVEN POLYPROPYLENE SUGAR SACKS
(Emissions per 100,000 items)

	United States			Mexico		
Waterborne Emissions (kg)	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Acid	1.24	4.00E-07	1.24		2.16E-06	2.16E-06
Metal Ion	0.051	0.0085	0.059		0.041	0.041
Dissolved Solids	33.6	5.49	39.1		1.30	1.30
Suspended Solids	3.48	0.0045	3.48		0.15	0.15
BOD	1.99	0.0049	2.00		0.49	0.49
COD	4.15	0.023	4.17		0.81	0.81
Phenol	1.86E-04	2.74E-05	2.14E-04		0.0091	0.0091
Sulfides	0.56		0.56		0.0049	0.0049
Oil	0.75	0.22	0.97		0.51	0.51
Sulfuric Acid		3.21	3.21		0.76	0.76
Iron	0.0010	0.30	0.30		0.19	0.19
Ammonia	0.0044	6.43E-04	0.0050		0.083	0.083
Chromium	1.08E-05	1.59E-06	1.24E-05		0.0012	0.0012
Lead	4.81E-06	7.09E-07	5.52E-06		3.84E-06	3.84E-06
Zinc	0.011	1.04E-05	0.011		5.62E-05	5.62E-05
Phosphates	0.063		0.063			

Source: Franklin Associates, Ltd.

All of the atmospheric and waterborne emissions for operations in Mexico, except atmospheric particulate emissions, are fuel related. The fuel-related emissions are a result of production and combustion of fuels that supply energy for manufacturing operations and transportation of raw materials and finished products. Process atmospheric particulate emissions in Mexico are produced during production of the filler material used during production of the woven polypropylene fabric.

Disposal Energy and Environmental Emissions

Table 9-9 presents the energy requirements for the operation of packer trucks and landfill equipment to dispose of postconsumer solid waste from the polypropylene pancake syrup bottle systems and the woven polypropylene sugar sacks. This equipment is assumed to use diesel as a fuel source; therefore, this energy is derived from petroleum.

The fuel-related environmental emissions for the operation of packer trucks and landfill equipment to dispose of postconsumer solid waste from the polypropylene pancake syrup bottle systems and the woven polypropylene sugar sacks are presented in Tables 9-10 and 9-11, respectively.

Table 9-9

ENERGY REQUIREMENTS FOR DISPOSAL OF POLPROPYLENE PACKAGING
(gigajoules for units disposed per 100,000 items)

	Packer Truck Energy	Landfill Equipment Energy	Total Disposal Energy
Polypropylene Pancake Syrup Bottle			
Polypropylene Bottle	0.94	0.56	1.50
Polypropylene Closure and Cap	0.34	0.21	0.55
Package Total	1.29	0.76	2.05
Woven Polypropylene Sugar Sack	1.40	0.83	2.23

Source: Franklin Associates, Ltd.

Table 9-10

SUMMARY OF FUEL-RELATED ENVIRONMENTAL EMISSIONS FOR DISPOSAL OF POLYPROPYLENE PANCAKE SYRUP CONTAINERS
(Emissions for units disposed per 100,000 items)

	Packer Truck Emissions	Landfill Equipment Emissions	Total Disposal Emissions
Atmospheric Emissions (kg)			
Particulates	0.12	0.072	0.19
Nitrogen Oxides	1.62	0.96	2.59
Hydrocarbons	0.41	0.25	0.66
Sulfur Oxides	0.38	0.23	0.61
Carbon Monoxide	0.52	0.31	0.83
Aldehydes	0.025	0.015	0.040
Methane	1.79E-04	1.06E-04	2.85E-04
Other Organics	2.72E-06	1.62E-06	4.34E-06
Kerosene	8.83E-08	5.24E-08	1.41E-07
Ammonia	1.35E-04	8.03E-05	2.16E-04
Lead	9.08E-06	5.39E-06	1.45E-05
Fossil Carbon Dioxide	93.9	55.7	150
Hydrogen Chloride	3.99E-06	2.37E-06	6.36E-06
Mercury	2.96E-07	1.76E-07	4.72E-07
Chlorine	7.02E-05	4.17E-05	1.12E-04
Chromium Compounds	2.47E-06	1.46E-06	3.93E-06
Manganese Compounds	2.74E-06	1.62E-06	4.36E-06
Nickel Compounds	2.71E-05	1.61E-05	4.31E-05
Antimony	5.83E-07	3.46E-07	9.29E-07
Arsenic	1.66E-06	9.98E-07	2.66E-06
Beryllium	1.40E-07	8.32E-08	2.23E-07
Cadmium	2.08E-06	1.24E-06	3.32E-06
Cobalt	1.65E-06	9.79E-07	2.63E-06
Selenium	6.33E-07	3.76E-07	1.01E-06
Sulfuric Acid	0.0044	0.0026	0.0070
Na_2O_2	2.69E-06	1.60E-06	4.29E-06
KO_2	2.69E-06	1.60E-06	4.28E-06
V_2O_5	2.69E-06	1.60E-06	4.29E-06
Solid Waste (kg)	0.15	0.092	0.25
Solid Waste (cu m)	1.94E-04	1.15E-04	3.08E-04
Waterborne Emissions (kg)			
Acid	6.61E-09	4.01E-09	1.06E-08
Metal Ion	1.24E-04	7.53E-05	2.00E-04
Dissolved Solids	0.0054	0.0033	0.0087
Suspended Solids	4.47E-04	2.71E-04	7.18E-04
BOD	0.0015	9.00E-04	0.0024
COD	0.0025	0.0015	0.0040
Phenol	2.79E-05	1.69E-05	4.47E-05
Sulfides	1.51E-05	9.14E-06	2.42E-05
Oil	0.0015	9.15E-04	0.0024
Sulfuric Acid	3.54E-05	2.14E-05	5.68E-05
Iron	1.13E-05	6.83E-06	1.81E-05
Ammonia	2.55E-04	1.55E-04	4.10E-04
Chromium	3.60E-06	2.18E-06	5.78E-06
Lead	1.17E-08	7.10E-09	1.88E-08
Zinc	1.72E-07	1.04E-07	2.76E-07

Source: Franklin Associates, Ltd.

Table 9-11

SUMMARY OF FUEL-RELATED ENVIRONMENTAL EMISSIONS FOR DISPOSAL OF WOVEN POLYPROPYLENE SUGAR SACKS
(Emissions for units disposed per 100,000 items)

	Packer Truck Emissions	Landfill Equipment Emissions	Total Disposal Emissions
Atmospheric Emissions (kg)			
Particulates	0.13	0.078	0.21
Nitrogen Oxides	1.77	1.04	2.81
Hydrocarbons	0.45	0.27	0.72
Sulfur Oxides	0.42	0.25	0.66
Carbon Monoxide	0.56	0.33	0.90
Aldehydes	0.027	0.016	0.043
Methane	1.94E-04	1.15E-04	3.09E-04
Other Organics	2.96E-06	1.74E-06	4.70E-06
Kerosene	9.59E-08	5.66E-08	1.52E-07
Ammonia	1.47E-04	8.67E-05	2.34E-04
Lead	9.88E-06	5.82E-06	1.57E-05
Fossil Carbon Dioxide	102	60.1	162
Hydrogen Chloride	4.34E-06	2.56E-06	6.89E-06
Mercury	3.22E-07	1.90E-07	5.12E-07
Chlorine	7.63E-05	4.50E-05	1.21E-04
Chromium Compounds	2.68E-06	1.58E-06	4.26E-06
Manganese Compounds	2.98E-06	1.75E-06	4.73E-06
Nickel Compounds	2.94E-05	1.73E-05	4.68E-05
Antimony	6.34E-07	3.74E-07	1.01E-06
Arsenic	1.83E-06	1.08E-06	2.91E-06
Beryllium	1.52E-07	8.98E-08	2.42E-07
Cadmium	2.27E-06	1.34E-06	3.60E-06
Cobalt	1.79E-06	1.06E-06	2.85E-06
Selenium	6.88E-07	4.06E-07	1.09E-06
Sulfuric Acid	0.0048	0.0028	0.0076
Na2O2	2.92E-06	1.72E-06	4.64E-06
KO2	2.92E-06	1.72E-06	4.64E-06
V2O5	2.92E-06	1.72E-06	4.64E-06
Solid Waste (kg)	0.17	0.10	0.27
Solid Waste (cu m)	2.10E-04	1.24E-04	3.34E-04
Waterborne Emissions (kg)			
Acid	6.61E-09	4.01E-09	1.06E-08
Metal Ion	1.24E-04	7.53E-05	2.00E-04
Dissolved Solids	0.0054	0.0033	0.0087
Suspended Solids	4.47E-04	2.71E-04	7.18E-04
BOD	0.0015	9.00E-04	0.0024
COD	0.0025	0.0015	0.0040
Phenol	2.79E-05	1.69E-05	4.47E-05
Sulfides	1.51E-05	9.14E-06	2.42E-05
Oil	0.0015	9.15E-04	0.0024
Sulfuric Acid	3.54E-05	2.14E-05	5.68E-05
Iron	1.13E-05	6.83E-06	1.81E-05
Ammonia	2.55E-04	1.55E-04	4.10E-04
Chromium	3.60E-06	2.18E-06	5.78E-06
Lead	1.17E-08	7.10E-09	1.88E-08
Zinc	1.72E-07	1.04E-07	2.76E-07

Source: Franklin Associates, Ltd.

Chapter 10

ENERGY AND ENVIRONMENTAL RESULTS FOR POLYSTYRENE PACKAGING

INTRODUCTION

This chapter provides a summary of the energy requirements and environmental emissions for the production, recycling and disposal of the following packaging materials in Mexico:

- 240 ml high-impact polystyrene (HIPS) yogurt containers
- Expanded polystyrene (EPS) crates for grapes

The basis for the results presented in this chapter is 100,000 packaging units. Supporting data for the polystyrene packaging systems are presented in Appendix L of the separately bound Appendix document. Data for production of the aluminum foil seal used on the yogurt container can be found in Appendix C.

The postconsumer recovery rates for the polystyrene packaging systems examined in this study are assumed to be zero.

DATA SOURCES

It is assumed for this study that the polystyrene resin used to manufacture packaging in Mexico is produced in Mexico. Data specific to Mexico for the production of styrene monomer, mineral oil (used as a modifier in HIPS) and the blowing agent used for EPS production were not available for this study. Therefore, data taken from Franklin Associates' database for similar operations in the United States were used to estimate the situation in Mexico for these production systems. Polybutadiene used as a modifier for HIPS production is assumed to be produced in the United States. Data for production of this material are taken from Franklin Associates' database.

Data for the production of EPS in Mexico were derived from information supplied by two producers in Mexico, data for HIPS production were supplied by one producer in Mexico, data for yogurt cup production were supplied by two producers in Mexico, and data for EPS crate production were supplied by one producer in Mexico.

Aluminum foil used to make the seal for the yogurt cup is assumed to be produced in the United States. Data for aluminum foil production were taken from Franklin Associates' database. Data for fabrication of the seal were not available; however, the resource requirements and environmental emission for this step were assumed to be negligible.

RESULTS AND DISCUSSION

HIPS Yogurt Cups

Manufacturing Energy Requirements. Table 10-1 presents the energy requirements for the manufacture of 100,000 HIPS yogurt containers. The energy usage is categorized by country and grouped by container and seal.

Process energy accounts for about 50 percent of the total energy for the system. The HIPS container uses about 88 percent of the process energy. Ninety-eight percent of the process energy for the container is used in Mexico to produce the resin and the container. Process energy used in the United States for the container is used to produce polybutadiene (used as a modifier for the HIPS). About 12 percent of the total process energy is used in the United States to produce the aluminum foil for the seal.

Transportation energy accounts for about three percent of the total energy. About 88 percent of the transportation energy is allocated to the container, the rest is used for the foil seal. Ninety-seven percent of the transportation energy for the container is used in Mexico. Transportation energy is the only use of energy in Mexico for the foil seal.

The energy of material resource accounts for 48 percent of the total energy for the system. About 95 percent of the total energy of material resource is used in Mexico to produce polystyrene resin for the container. The energy of material resource for the aluminum foil seal (about one percent of the total energy for the system) represents metallurgical coke and petroleum pitch used during the aluminum smelting step.

Table 10-2 presents the energy profile for production of HIPS yogurt containers. Natural gas accounts for about 40 percent and petroleum accounts for about 51 percent of the total energy for the system. About 36 percent of the natural gas energy and about 65 percent of the petroleum energy used in Mexico is the energy of material resource for polystyrene resin production.

Manufacturing Environmental Emissions

Solid Waste. Table 10-3 presents the solid waste for manufacturing 100,000 HIPS yogurt containers and foil seals. Included in this table is the postconsumer solid waste generated from disposal of the container and seal.

Table 10-1

ENERGY REQUIREMENTS FOR MANUFACTURE OF 100,000 HIPS YOGURT CONTAINERS

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total
HIPS Yogurt Containers								
United States	1.23	31%	0.10	3%	2.62	66%	3.95	100%
Mexico	58.5	47%	3.15	3%	62.2	50%	124	100%
Total Energy	59.7	47%	3.25	3%	64.8	51%	128	100%
Aluminum Foil Seal								
United States	8.25	88%	0.36	4%	0.81	9%	9.41	100%
Mexico			0.071	100%			0.071	100%
Total Energy	8.25	87%	0.43	4%	0.81	9%	9.48	100%
Package Total								
United States	9.48	71%	0.46	3%	3.43	26%	13.4	100%
Mexico	58.5	47%	3.22	3%	62.2	50%	124	100%
Total Energy	63.0	50%	3.67	3%	65.6	48%	137	100%

Source: Franklin Associates, Ltd.

Table 10-2

ENERGY PROFILES FOR MANUFACTURE OF 100,000 HIPS YOGURT CONTAINERS
(GJ per 100,000 Items)

	Energy Profile							
	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Total Energy
HIPS Yogurt Containers								
United States	3.63	0.18	0.15	0.0073	0.057		0.00[illegible]	4.02
Mexico	49.4	68.1	1.88	1.84	1.17		1.38	124
Total	53.1	68.2	2.03	1.84	1.23		1.39	128
Aluminum Foil Seal								
United States	2.14	1.54	3.36	1.54	0.81		0.016	9.41
Mexico		0.071						0.071
Total	2.14	1.61	3.36	1.54	0.81		0.016	9.48
Package Total								
United States	5.76	1.72	3.52	1.55	0.87		0.021	13.4
Mexico	49.4	68.1	1.88	1.84	1.17		1.38	124
Total	55.2	69.9	5.39	3.38	2.05		1.41	137

Source: Franklin Associates, Ltd.

Table 10-3

SOLID WASTE BY WEIGHT AND VOLUME FOR MANUFACTURE OF 100,000 HIPS YOGURT CONTAINERS

	Process Waste		Fuel Waste		Postconsumer Waste		Total Solid Waste	
	kg	cubic meter	kg	cubic meter	kg	cubic meter	kg	cubic meter
HIPS Yogurt Containers								
United States	0.038	4.8E-05	2.15	0.0027			2.19	0.0027
Mexico	44.2	0.055	62.9	0.079	1,171	5.56	1,278	5.69
Total Solid Waste	44.2	0.055	65.0	0.081	1,171	5.56	1,280	5.70
Aluminum Foil Seal								
United States	73.2	0.091	42.9	0.054			116	0.14
Mexico			0.0085	1.1E-05	41.1	0.13	41.1	0.13
Total Solid Waste	73.2	0.091	42.9	0.054	41.1	0.13	157	0.27
Package Total								
United States	73.3	0.091	45.0	0.056			118	0.15
Mexico	44.2	0.055	62.9	0.079	1,212	5.68	1,319	5.82
Total Solid Waste	117	0.15	106	0.13	1,212	5.68	1,437	5.97

Source: Franklin Associates, Ltd.

Process solid waste accounts for about eight percent of the total solid waste weight and about three percent of the solid waste volume.

Fuel-related solid waste makes up eight percent of the solid waste weight and two percent of the solid waste volume.

Postconsumer solid waste accounts for 84 percent of the total solid waste weight and about 95 percent of the total solid waste volume.

Atmospheric and Waterborne Emissions. The total atmospheric and waterborne emissions for manufacturing HIPS yogurt containers and foil seals are presented in Table 10-4a and 10-4b, respectively.

Process atmospheric and waterborne emissions released in Mexico come from production of the polystyrene resin and fabrication of the container.

Expanded Polystyrene Crates for Grapes

Manufacturing Energy Requirements. Table 10-5 presents the energy requirements for the manufacture of 100,000 EPS crates. All of the energy for this system is used in Mexico.

Process energy makes up 60 percent of the total energy for the system. About 61 percent of the process energy is used during the crate fabrication step.

Transportation energy accounts for four percent of the total process energy for the system.

The energy of material resource accounts for 36 percent of the total energy for the system. This energy represents the natural gas and petroleum raw materials used to produce the polystyrene resin.

Table 10-6 presents the energy profile for production of EPS crates. Natural gas accounts for about 32 percent of the total energy for the system, and petroleum accounts for another 63 percent of the total energy. The energy of material resource for the system makes up about 31 percent of the natural gas energy and 41 percent of the petroleum energy.

Manufacturing Environmental Emissions

Solid Waste. Table 10-7 presents the solid waste for manufacturing 100,000 EPS crates. Included in this table is the postconsumer solid waste generated from disposal of the crates.

Process solid waste accounts for about one percent of the total solid waste weight and less than one percent of the total solid waste volume for the system.

Table 10-4a

SUMMARY OF ATMOSPHERIC EMISSIONS FOR HIPS YOGURT CONTAINERS
(Emissions per 100,000 items)

	United States			Mexico		
Atmospheric Emissions (kg)	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Particulates	1.64	0.68	2.31	0.46	2.57	3.03
Nitrogen Oxides	0.015	2.12	2.13	1.64	11.7	13.3
Hydrocarbons	2.13	2.02	4.16	46.2	29.5	75.7
Sulfur Oxides	0.75	3.44	4.19	7.75	51.3	59.1
Carbon Monoxide	4.12	0.76	4.87	0.13	7.72	7.35
Aldehydes	5.7E-04	0.0080	0.0086	0.080	0.086	0.17
Methane		0.0052	0.0052		0.059	0.059
Other Organics		0.051	0.051	0.18	1.23	1.41
Kerosene		8.2E-05	8.2E-05		1.1E-04	1.1E-04
Ammonia	4.1E-04	1.0E-04	5.2E-04	0.056	0.0025	0.058
Lead	2.0E-08	9.9E-05	9.9E-05	1.4E-06	0.0019	0.0019
Hydrogen Fluoride	0.090		0.090			
Fossil Carbon Dioxide	61.3	565	626		4,944	4,944
Hydrogen Chloride	2.2E-06	3.1E-06	5.3E-06	1.5E-04	7.5E-05	2.2E-04
Mercury	1.3E-06	4.3E-06	6.1E-06		1.4E-04	1.4E-04
Chlorine	4.7E-06		4.7E-06	0.0020	0.021	0.023
Chromium Compounds		2.5E-04	2.5E-04		0.0020	0.0020
Manganese Compounds		4.1E-04	4.1E-04		0.0028	0.0028
Nickel Compounds		2.3E-04	2.3E-04		0.013	0.013
Antimony		1.4E-07	1.4E-07		2.6E-04	2.6E-04
Arsenic		1.3E-04	1.3E-04		0.0012	0.0012
Beryllium		1.5E-05	1.5E-05		1.2E-04	1.2E-04
Cadmium		2.2E-06	2.2E-06		0.0011	0.0011
Cobalt		5.8E-06	5.8E-06		7.4E-04	7.4E-04
Selenium		2.2E-06	2.2E-06		2.9E-04	2.9E-04
Sulfuric Acid					1.93	1.93
Na_2O_2					1.9E-04	1.9E-04
KO_2					1.9E-04	1.9E-04
V_2O_5					1.9E-04	1.9E-04

Source: Franklin Associates, Ltd.

Table 10-4b

SUMMARY OF WATERBORNE EMISSIONS FOR HIPS YOGURT CONTAINERS (Emissions per 100,000 items)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Waterborne Emissions (kg)						
Acid	0.0094	2.3E-08	0.0094	0.041	5.5E-07	0.041
Metal Ion	0.022	4.8E-04	0.022	0.020	0.010	0.031
Dissolved Solids	0.21	0.28	0.50	4.85	0.46	5.31
Suspended Solids	1.03	2.5E-04	1.03	0.74	0.037	0.77
BOD	0.12	2.3E-04	0.12	0.58	0.12	0.70
COD	0.95	0.0013	0.95	1.17	0.21	1.37
Phenol	7.5E-06	1.5E-06	9.0E-06	0.013	0.0023	0.016
Sulfides	5.0E-07		5.0E-07	0.030	0.0013	0.031
Oil	0.19	0.0056	0.20	0.34	0.15	0.49
Sulfuric Acid		0.28	0.28		0.20	0.20
Iron	0.0023	0.070	0.072	4.0E-04	0.050	0.050
Hydrocarbons				0.0011		0.0011
Ammonia	0.0044	3.7E-05	0.0044	0.042	0.021	0.063
Chromium	6.4E-08	9.0E-08	1.5E-07	5.9E-04	3.0E-04	8.9E-04
Lead	3.1E-08	4.0E-08	7.2E-08	1.9E-06	9.8E-07	2.9E-06
Zinc	4.2E-07	5.9E-07	1.0E-06	3.7E-04	1.4E-05	3.9E-04
Fluorides	0.013		0.013			
Cyanide	1.4E-05		1.4E-05			
Nickel	2.7E-09		2.7E-09			
Mercury	4.9E-09		4.9E-09			
Phosphates	0.038		0.038	0.0035		0.0035
Chloride				6.1E-04		6.1E-04

Source: Franklin Associates, Ltd.

Table 10-5

ENERGY REQUIREMENTS FOR MANUFACTURE OF 100,000 EPS CRATES

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total
Expanded Polystyrene Crates								
Mexico	3,181	60%	229	4%	1,908	36%	5,318	100%
Total Energy	3,181	60%	229	4%	1,908	36%	5,318	100%

Source: Franklin Associates, Ltd.

Table 10-6

ENERGY PROFILES FOR MANUFACTURE OF 100,000 EPS CRATES
(GJ per 100,000 Items)

	Energy Profile							
	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Total Energy
Expanded Polystyrene Crates								
Mexico	1,686	3,382	74.8	73.0	46.7		55.1	5,318
Total	1,686	3,382	74.8	73.0	46.7		55.1	5,318

Source: Franklin Associates, Ltd.

Table 10-7

SOLID WASTE BY WEIGHT AND VOLUME FOR MANUFACTURE OF 100,000 EPS CRATES

	Process Waste		Fuel Waste		Postconsumer Waste		Total Solid Waste	
	kg	cubic meter	kg	cubic meter	kg	cubic meter	kg	cubic meter
Expanded Polystyrene Crates								
Mexico	455	0.57	2,638	3.29	32,700	334	35,793	338
Total Solid Waste	455	0.57	2,638	3.29	32,700	334	35,793	338

Source: Franklin Associates, Ltd.

Fuel related solid-waste makes up about seven percent of the total solid waste weight and one percent of the total solid waste volume.

Postconsumer solid waste makes up the remaining 91 percent of the solid waste weight and 99 percent of the total solid waste volume. The postconsumer solid waste volume for the system is high because of the relatively low landfill density for the container.

Atmospheric and Waterborne Emissions. The total atmospheric and waterborne emissions for manufacturing EPS crates are presented in Table 10-8a and 10-8b, respectively.

Process emissions represent the largest source for some of the atmospheric emissions categories, while fuel-related emissions are the source of more emissions for other categories. Over half of the process atmospheric hydrocarbon emissions come from the styrene monomer production step. The EPS polymerization step produced almost all (98 percent) of the other organic emissions.

Process emissions are the source of the greatest emissions for many of the waterborne emissions categories, such as acid, dissolved solids, suspended solids, BOD, COD and oil emissions.

Disposal Energy and Environmental Emissions

Table 10-9 presents the energy requirements for the operation of packer trucks and landfill equipment to dispose of postconsumer solid waste from the HIPS yogurt container systems and the EPS crates. This equipment is assumed to use diesel as a fuel source; therefore, this energy is derived from petroleum.

The fuel-related environmental emissions for the operation of packer trucks and landfill equipment to dispose of postconsumer solid waste from the HIPS yogurt container systems and the EPS crates are presented in Tables 10-10 and 10-11, respectively.

Table 10-8a

SUMMARY OF ATMOSPHERIC EMISSIONS FOR EPS CRATES
(Emissions per 100,000 items)

	Mexico		
	Process Emissions	Fuel Emissions	Total Emissions
Atmospheric Emissions (kg)			
Particulates	13.6	184	197
Nitrogen Oxides	48.0	493	541
Hydrocarbons	1,365	1,347	2,712
Sulfur Oxides	227	4,047	4,274
Carbon Monoxide	3.69	553	557
Aldehydes	2.43	4.00	6.42
Methane		2.52	2.52
Other Organics	155	97.6	252
Kerosene		0.0045	0.0045
Ammonia	1.64	0.21	1.85
Lead	4.3E-05	0.13	0.13
Fossil Carbon Dioxide		264,547	264,547
Hydrogen Chloride	0.0046	0.0063	0.011
Mercury		0.012	0.012
Chlorine	0.061	0.88	0.94
Chromium Compounds		0.11	0.11
Manganese Compounds		0.13	0.13
Nickel Compounds		1.12	1.12
Antimony		0.024	0.024
Arsenic		0.074	0.074
Beryllium		0.0063	0.0063
Cadmium		0.087	0.087
Cobalt		0.068	0.068
Selenium		0.026	0.026
Sulfuric Acid		171	171
Na2O2		0.0089	0.0089
KO2		0.0089	0.0089
V2O5		0.0089	0.0089
Styrene Monomer	19.0		19.0

Source: Franklin Associates, Ltd.

Table 10-9b

SUMMARY OF WATERBORNE WASTES FOR EPS CRATES
(Emissions per 100,000 items)

	Mexico		
	Process Emissions	Fuel Emissions	Total Emissions
Waterborne Wastes (kg)			
Acid	2.57	4.6E-05	2.57
Metal Ion	0.64	0.87	1.50
Dissolved Solids	85.2	38.1	123
Suspended Solids	50.3	3.11	53.4
BOD	81.3	10.3	91.6
COD	137	17.2	155
Phenol	0.43	0.19	0.62
Sulfides	0.87	0.11	0.97
Oil	19.4	11.4	30.8
Sulfuric Acid		8.06	8.06
Iron	0.012	2.03	2.05
Hydrocarbons	0.031		0.031
Ammonia	1.31	1.78	3.09
Chromium	0.018	0.025	0.044
Lead	6.0E-05	8.2E-05	1.4E-04
Zinc	0.011	0.0012	0.012
Fluorides	0.52		0.52
Phosphates	0.061		0.061

Source: Franklin Associates, Ltd.

Table 10-9

ENERGY REQUIREMENTS FOR DISPOSAL OF POLYSTYRENE PACKAGING
(gigajoules for units disposed per 100,000 items)

	Packer Truck Energy	Landfill Equipment Energy	Total Disposal Energy
HIPS Yogurt Containers			
HIPS Container	0.32	0.19	0.51
Aluminum Foil Seal	0.0074	0.0043	0.012
Package Total	0.33	0.20	0.53
Expanded Polystyrene Crates	19.3	11.5	30.8

Source: Franklin Associates, Ltd.

Table 10-10

SUMMARY OF FUEL-RELATED ENVIRONMENTAL EMISSIONS FOR DISPOSAL OF HIPS YOGURT CONTAINERS
(Emissions for units disposed per 100,000 items)

	Packer Truck Emissions	Landfill Equipment Emissions	Total Disposal Emissions
Atmospheric Emissions (kg)			
Particulates	0.031	0.019	0.050
Nitrogen Oxides	0.42	0.25	0.66
Hydrocarbons	0.11	0.063	0.17
Sulfur Oxides	0.098	0.058	0.16
Carbon Monoxide	0.13	0.079	0.21
Aldehydes	0.0064	0.0038	0.010
Methane	4.58E-05	2.71E-05	7.29E-05
Other Organics	6.97E-07	4.13E-07	1.11E-06
Kerosene	2.26E-08	1.34E-08	3.60E-08
Ammonia	3.46E-05	2.05E-05	5.52E-05
Lead	2.33E-06	1.38E-06	3.70E-06
Fossil Carbon Dioxide	24.0	14.2	38.3
Hydrogen Chloride	1.02E-06	6.05E-07	1.63E-06
Mercury	7.59E-08	4.50E-08	1.21E-07
Chlorine	1.80E-05	1.07E-05	2.86E-05
Chromium Compounds	6.32E-07	3.74E-07	1.01E-06
Manganese Compounds	7.01E-07	4.15E-07	1.12E-06
Nickel Compounds	6.93E-06	4.11E-06	1.10E-05
Antimony	1.49E-07	8.85E-08	2.38E-07
Arsenic	4.31E-07	2.55E-07	6.86E-07
Beryllium	3.59E-08	2.13E-08	5.71E-08
Cadmium	5.34E-07	3.16E-07	8.50E-07
Cobalt	4.22E-07	2.50E-07	6.73E-07
Selenium	1.62E-07	9.61E-08	2.58E-07
Sulfuric Acid	0.0011	6.66E-04	0.0018
Na2O2	6.38E-07	4.08E-07	1.10E-06
KO2	6.88E-07	4.08E-07	1.10E-06
V2O5	6.88E-07	4.08E-07	1.10E-06
Solid Waste (kg)	0.040	0.024	0.063
Solid Waste (cu m)	4.96E-05	2.94E-05	7.39E-05
Waterborne Emissions (kg)			
Acid	6.61E-09	4.01E-09	1.06E-08
Metal Ion	1.24E-04	7.53E-05	2.00E-04
Dissolved Solids	0.0054	0.0033	0.0087
Suspended Solids	4.47E-04	2.71E-04	7.18E-04
BOD	0.0015	9.00E-04	0.0024
COD	0.0025	0.0015	0.0040
Phenol	2.79E-05	1.69E-05	4.47E-05
Sulfides	1.31E-05	9.14E-06	2.42E-05
Oil	0.0015	9.15E-04	0.0024
Sulfuric Acid	3.54E-05	2.14E-05	5.68E-05
Iron	1.13E-05	6.83E-06	1.31E-05
Ammonia	2.55E-04	1.55E-04	4.10E-04
Chromium	3.60E-06	2.18E-06	5.78E-06
Lead	1.17E-08	7.10E-09	1.38E-08
Zinc	1.72E-07	1.04E-07	2.76E-07

Source: Franklin Associates, Ltd.

Table 10-11

SUMMARY OF FUEL-RELATED ENVIRONMENTAL EMISSIONS FOR DISPOSAL OF EPS CRATES
(Emissions for units disposed per 100,000 items)

	Packer Truck Emissions	Landfill Equipment Emissions	Total Disposal Emissions
Atmospheric Emissions (kg)			
Particulates	1.83	1.09	2.91
Nitrogen Oxides	24.3	14.5	38.8
Hydrocarbons	6.21	3.70	9.9
Sulfur Oxides	5.75	3.43	9.18
Carbon Monoxide	7.78	4.63	12.4
Aldehydes	0.37	0.22	0.60
Methane	0.0027	0.0016	0.0043
Other Organics	4.08E-05	2.43E-05	6.50E-05
Kerosene	1.32E-06	7.87E-07	2.11E-06
Ammonia	0.0020	0.0012	0.0032
Lead	1.36E-04	8.10E-05	2.17E-04
Fossil Carbon Dioxide	1,405	837	2,242
Hydrogen Chloride	5.97E-05	3.56E-05	9.53E-05
Mercury	4.44E-06	2.64E-06	7.08E-06
Chlorine	0.0011	6.26E-04	0.0017
Chromium Compounds	3.69E-05	2.20E-05	5.89E-05
Manganese Compounds	4.10E-05	2.44E-05	6.54E-05
Nickel Compounds	4.05E-04	2.41E-04	6.46E-04
Antimony	8.73E-06	5.20E-06	1.39E-05
Arsenic	2.52E-05	1.50E-05	4.02E-05
Beryllium	2.10E-06	1.25E-06	3.35E-06
Cadmium	3.12E-05	1.86E-05	4.98E-05
Cobalt	2.47E-05	1.47E-05	3.94E-05
Selenium	9.48E-06	5.65E-06	1.51E-05
Sulfuric Acid	0.066	0.039	0.10
Na2O2	4.02E-05	2.40E-05	6.42E-05
KO2	4.02E-05	2.40E-05	6.42E-05
V2O5	4.02E-05	2.40E-05	6.42E-05
Solid Waste (kg)	2.32	1.38	3.70
Solid Waste (cu m)	0.0029	0.0017	0.0046
Waterborne Emissions (kg)			
Acid	6.61E-09	4.01E-09	1.06E-08
Metal Ion	1.24E-04	7.53E-05	2.00E-04
Dissolved Solids	0.0054	0.0033	0.0087
Suspended Solids	4.47E-04	2.71E-04	7.18E-04
BOD	0.0015	9.00E-04	0.0024
COD	0.0025	0.0015	0.0040
Phenol	2.79E-05	1.69E-05	4.47E-05
Sulfides	1.51E-05	9.14E-06	2.42E-05
Oil	0.0015	9.15E-04	0.0024
Sulfuric Acid	3.54E-05	2.14E-05	5.68E-05
Iron	1.13E-05	6.83E-06	1.81E-05
Ammonia	2.55E-04	1.55E-04	4.10E-04
Chromium	3.60E-06	2.18E-06	5.78E-06
Lead	1.17E-08	7.10E-09	1.88E-08
Zinc	1.72E-07	1.04E-07	2.76E-07

Source: Franklin Associates, Ltd.

Chapter 11

ENERGY AND ENVIRONMENTAL RESULTS FOR METALLIZED POLYPROPYLENE FILM SNACK PACKS

INTRODUCTION

This chapter provides a summary of the energy requirements and environmental emissions for the production, recycling and disposal of metallized polypropylene film snack packs. The basis for the results presented in this chapter is 100,000 snack packs. Supporting data for metallized film and snack pouch production are presented in Appendix M of the separately bound Appendix document. Data for production of the polypropylene resin can be found in Appendix K. Data for the production of aluminum (used to metallize the film) can be found in Appendix C

The postconsumer recovery rate for the metallized film pouches examined in this study is assumed to be zero.

DATA SOURCES

The polypropylene resin used to produce the film and the aluminum wire used to metallize the film examined in this study are assumed to be produced in the United States. Although one BOPP manufacturer reported that their aluminum wire came from Germany, no data were available for German aluminum wire production; thus, aluminum wire data represent 100 percent U.S. production. Data for production of polypropylene resin and aluminum wire were taken from Franklin Associates' database.

Data for polypropylene film production and metallization in Mexico were supplied by two producers in that country. Data from manufacturers for the production of snack pouches in Mexico were not available for this study. Therefore, these data were estimated from information supplied by equipment manufacture's in the United States and from Franklin Associates' database.

RESULTS AND DISCUSSION

Manufacturing Energy Requirements. Table 11-1 presents the energy requirements for the manufacture of 100,000 metallized polypropylene film snack packs. The energy usage is categorized by country.

Process energy accounts for about 50 percent of the total energy for the system. About 51 percent of the process energy is used in the United States to manufacture polypropylene resin and aluminum wire.

Transportation energy accounts for seven percent of the total energy. About 81 percent of the transportation energy is used in Mexico.

Table 11-1

ENERGY REQUIREMENTS FOR MANUFACTURE OF 100,000 METALLIZED POLYPROPYLENE FILM SNACK PACKS

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total
Snack Packs								
United States	5.56	36%	0.27	2%	9.52	62%	15.3	100%
Mexico	5.37	82%	1.17	18%			6.54	100%
Total Energy	10.9	50%	1.44	7%	9.52	44%	21.9	100%

Source: Franklin Associates, Ltd.

The energy of material resource accounts for 44 percent of the total energy for the system. About 99 percent of the energy of material resource is used in the United States for polypropylene resin production. The remainder is used for aluminum wire production to produce metallurgical coke and petroleum pitch for aluminum smelting.

Table 11-2 presents the energy profile for production of metallized polypropylene film snack packs. Natural gas accounts for about 55 percent of the total energy for the system. Petroleum accounts for another 35 percent of the total energy. Almost all of the natural gas energy (96 percent) is used in the United States.

Manufacturing Environmental Emissions

Solid Waste. Table 11-3 presents the solid waste for manufacturing 100,000 metallized polypropylene film snack packs. Included in this table is the postconsumer solid waste generated from disposal of the snack packs.

Process solid waste accounts for about 10 percent of the total solid waste weight and about five percent of the total solid waste volume.

Fuel-related solid waste also makes up 10 percent of the solid waste weight and five percent of the solid waste volume.

Postconsumer solid waste accounts for the remaining 80 percent of the total solid waste weight and 90 percent of the total solid waste volume.

Atmospheric and Waterborne Emissions. The total atmospheric and waterborne emissions for manufacturing metallized polypropylene film snack packs are presented in Table 11-4a and 11-4b, respectively.

All of the atmospheric emissions for operations in Mexico are fuel related. These emissions are a result of production and combustion of fuels to produce energy for manufacturing operations and transportation of raw materials and finished products.

Process waterborne emissions released in Mexico are produced during production of the metallized film.

Table 11-2

ENERGY PROFILES FOR MANUFACTURE OF 100,000 METALLIZED POLYPROPYLENE FILM SNACK PACKS
(GJ per 100,000 Items)

	Energy Profile							
	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Total Energy
Snack Packs								
United States	11.6	2.44	0.89	0.13	0.31		0.023	15.3
Mexico	0.57	5.15	0.25	0.24	0.15		0.18	6.54
Total	12.1	7.59	1.14	0.37	0.46		0.20	21.9

Source: Franklin Associates, Ltd.

Table 11-3

SOLID WASTE BY WEIGHT AND VOLUME FOR MANUFACTURE OF 100,000 METALLIZED POLYPROPYLENE FILM SNACK PACKS

	Process Waste		Fuel Waste		Postconsumer Waste		Total Solid Waste	
	kg	cubic meter	kg	cubic meter	kg	cubic meter	kg	cubic meter
Snack Packs								
United States	5.30	0.0066	12.3	0.015			17.6	0.022
Mexico	15.9	0.020	8.42	0.011	173	0.44	197	0.47
Total Solid Waste	21.2	0.026	20.7	0.026	173	0.44	215	0.49

Source: Franklin Associates, Ltd.

Table 11-4a

SUMMARY OF ATMOSPHERIC EMISSIONS FOR METALLIZED POLYPROPYLENE FILM SNACK PACKS
(Emissions per 100,000 items)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Atmospheric Emissions (kg)						
Particulates	0.15	0.20	0.34		0.45	0.45
Nitrogen Oxides	0.19	0.85	1.04		1.46	1.46
Hydrocarbons	4.43	2.39	6.82		1.71	1.71
Sulfur Oxides	0.28	1.05	1.32		8.73	8.73
Carbon Monoxide	0.31	0.39	0.70		1.47	1.47
Aldehydes	0.0018	0.0037	0.0055		0.021	0.021
Methane		0.0054	0.0054		0.0036	0.0036
Other Organics		0.044	0.044		0.36	0.36
Kerosene		2.93E-05	2.93E-05		1.46E-05	1.46E-05
Ammonia	2.58E-04	3.74E-05	2.95E-04		5.47E-04	5.47E-04
Lead	6.46E-08	2.73E-05	2.74E-05		2.76E-04	2.76E-04
Fossil Carbon Dioxide	4.00	330	334		453	453
Hydrogen Chloride	6.95E-06	1.10E-06	8.05E-06		1.61E-05	1.61E-05
Mercury	1.17E-07	1.26E-06	1.38E-06		2.83E-05	2.83E-05
Chlorine	9.37E-06		9.37E-06		0.0028	0.0028
Chromium Compounds		6.82E-05	6.82E-05		3.06E-04	3.06E-04
Manganese Compounds		1.10E-04	1.10E-04		3.89E-04	3.89E-04
Nickel Compounds		7.58E-05	7.58E-05		0.0026	0.0026
Antimony					5.41E-05	5.41E-05
Arsenic		3.40E-05	3.40E-05		1.96E-04	1.96E-04
Beryllium		3.94E-06	3.94E-06		1.76E-05	1.76E-05
Cadmium					2.05E-04	2.05E-04
Cobalt		2.39E-06	2.39E-06		1.53E-04	1.53E-04
Selenium		9.16E-07	9.16E-07		5.87E-05	5.87E-05
Sulfuric Acid					0.39	0.39
Na2O2					1.17E-05	1.17E-05
KO2					1.17E-05	1.17E-05
V2O5					1.17E-05	1.17E-05

Source: Franklin Associates, Ltd.

Table 11-4b

SUMMARY OF WATERBORNE EMISSIONS FOR
METALLIZED POLYPROPYLENE FILM SNACK PACKS
(Emissions per 100,000 items)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Waterborne Emissions (kg)						
Acid	0.023	3.12E-09	0.023		1.19E-07	1.19E-07
Metal Ion	0.0024	1.72E-04	0.0025		0.0022	0.0022
Dissolved Solids	0.63	0.11	0.75	0.080	0.098	0.18
Suspended Solids	0.12	9.14E-05	0.12	0.0069	0.0080	0.015
BOD	0.041	9.98E-05	0.041	0.0052	0.027	0.032
COD	0.13	4.73E-04	0.13	0.075	0.044	0.12
Phenol	3.92E-06	5.57E-07	4.48E-06		5.00E-04	5.00E-04
Sulfides	0.010		0.010		2.71E-04	2.71E-04
Oil	0.015	0.0042	0.019	0.0033	0.028	0.031
Sulfuric Acid		0.074	0.074		0.026	0.026
Iron	1.71E-04	0.019	0.019	3.29E-04	0.0066	0.0069
Ammonia	3.65E-04	1.31E-05	3.78E-04		0.0046	0.0046
Chromium	2.04E-07	3.23E-08	2.36E-07		6.45E-05	6.45E-05
Lead	9.09E-08	1.44E-08	1.05E-07	1.73E-04	2.10E-07	1.73E-04
Zinc	1.95E-04	2.11E-07	1.95E-04		3.08E-06	3.08E-06
Phosphates	0.0012		0.0012			

Source: Franklin Associates, Ltd.

Disposal Energy and Environmental Emissions

Table 11-5 presents the energy requirements for the operation of packer trucks and landfill equipment to dispose of postconsumer solid waste from the metallized polypropylene film snack pack systems. This equipment is assumed to use diesel as a fuel source; therefore, this energy is derived from petroleum.

The fuel-related environmental emissions for the operation of packer trucks and landfill equipment to dispose of postconsumer solid waste from the metallized polypropylene film snack pack systems are presented in Table 11-6.

Table 11-5

ENERGY REQUIREMENTS FOR DISPOSAL OF METALLIZED POLYPROPYLENE FILM SNACK PACKS
(gigajoules for units disposed per 100,000 items)

	Packer Truck Energy	Landfill Equipment Energy	Total Disposal Energy
Snack Packs	0.026	0.015	0.041

Source: Franklin Associates, Ltd.

Table 11-6

SUMMARY OF FUEL-RELATED ENVIRONMENTAL EMISSIONS FOR DISPOSAL OF METALLIZED POLYPROPYLENE FILM SNACK PACKS
(Emissions for units disposed per 100,000 items)

	Packer Truck Emissions	Landfill Equipment Emissions	Total Disposal Emissions
Atmospheric Emissions (kg)			
Particulates	0.0024	0.0014	0.0038
Nitrogen Oxides	0.032	0.019	0.051
Hydrocarbons	0.0082	0.0048	0.013
Sulfur Oxides	0.0076	0.0045	0.012
Carbon Monoxide	0.010	0.0061	0.016
Aldehydes	4.96E-04	2.93E-04	7.89E-04
Methane	3.54E-06	2.09E-06	5.63E-06
Other Organics	5.39E-08	3.18E-08	8.57E-08
Kerosene	1.75E-09	1.03E-09	2.78E-09
Ammonia	2.68E-06	1.58E-06	4.26E-06
Lead	1.80E-07	1.06E-07	2.86E-07
Fossil Carbon Dioxide	1.86	1.10	2.96
Hydrogen Chloride	7.90E-08	4.66E-08	1.26E-07
Mercury	5.87E-09	3.46E-09	9.33E-09
Chlorine	1.39E-06	8.20E-07	2.21E-06
Chromium Compounds	4.89E-08	2.88E-08	7.77E-08
Manganese Compounds	5.42E-08	3.20E-08	8.62E-08
Nickel Compounds	5.36E-07	3.16E-07	8.52E-07
Antimony	1.16E-08	6.81E-09	1.84E-08
Arsenic	3.33E-08	1.96E-08	5.30E-08
Beryllium	2.78E-09	1.64E-09	4.41E-09
Cadmium	4.13E-08	2.43E-08	6.56E-08
Cobalt	3.27E-08	1.93E-08	5.19E-08
Selenium	1.25E-08	7.39E-09	1.99E-08
Sulfuric Acid	8.70E-05	5.13E-05	1.38E-04
Na2O2	5.32E-08	3.14E-08	8.46E-08
KO2	5.32E-08	3.14E-08	8.46E-08
V2O5	5.32E-08	3.14E-08	8.46E-08
Solid Waste (kg)	0.0031	0.0018	0.0049
Solid Waste (cu m)	3.83E-06	2.26E-06	6.09E-06
Waterborne Emissions (kg)			
Acid	6.61E-09	4.01E-09	1.06E-08
Metal Ion	1.24E-04	7.53E-05	2.00E-04
Dissolved Solids	0.0054	0.0033	0.0087
Suspended Solids	4.47E-04	2.71E-04	7.18E-04
BOD	0.0015	9.00E-04	0.0024
COD	0.0025	0.0015	0.0040
Phenol	2.79E-05	1.69E-05	4.47E-05
Sulfides	1.51E-05	9.14E-06	2.42E-05
Oil	0.0015	9.15E-04	0.0024
Sulfuric Acid	3.54E-05	2.14E-05	5.68E-05
Iron	1.13E-05	6.83E-06	1.81E-05
Ammonia	2.55E-04	1.55E-04	4.10E-04
Chromium	3.60E-06	2.18E-06	5.78E-06
Lead	1.17E-08	7.10E-09	1.88E-08
Zinc	1.72E-07	1.04E-07	2.76E-07

Source: Franklin Associates, Ltd.

Chapter 12

ENERGY AND ENVIRONMENTAL RESULTS FOR GABLE TOP MILK CARTONS

INTRODUCTION

This chapter provides a summary of the energy requirements and environmental emissions for the production, recycling and disposal of LDPE-coated paperboard gable top milk cartons. The basis for the results presented in this chapter is 100,000 gable top cartons. Supporting data for gable top carton production are presented in Appendix N of the separately bound Appendix document. Data for production of paperboard can be found in Appendix D. Data for the production of LDPE resin (used to coat the paperboard) can be found in Appendix I

The postconsumer recovery rate for the gable top cartons examined in this study is assumed to be zero.

DATA SOURCES

Production of the LDPE-coated bleached paperboard examined in this study, and all of the materials needed to produce it, is assumed to take place in the United States. Data for production of LDPE-coated bleached paperboard were taken from Franklin Associates' database.

Data for gable top carton production in Mexico were supplied by one producer in that country.

RESULTS AND DISCUSSION

Manufacturing Energy Requirements. Table 12-1 presents the energy requirements for the manufacture of 100,000 gable top milk cartons. The energy usage is categorized by country.

Process energy accounts for about 79 percent of the total energy for the system About 96 percent of the process energy is used in the United States to manufacture LDPE-coated paperboard.

Transportation energy accounts for 10 percent of the total energy. About 35 percent of the transportation energy is used in Mexico.

The energy of material resource accounts for 11 percent of the total energy for the system. All of this energy is used in the United States for polypropylene resin production.

Table 12-1

ENERGY REQUIREMENTS FOR MANUFACTURE OF 100,000 GABLE TOP MILK CARTONS

Gable Top Milk Cartons	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total
United States	170	81%	14.8	7%	24.2	12%	209	100%
Mexico	6.95	47%	7.94	53%			14.9	100%
Total Energy	177	79%	22.8	10%	24.2	11%	224	100%

Source: Franklin Associates, Ltd.

Table 12-2 presents the energy profile for production of gable top milk cartons. Wood is the largest source of energy for the system in the United States. Wood supplies energy for manufacture of the paperboard and supplies about 30 percent of the energy used in the United States for this system. Natural gas and petroleum each account for about 24 percent of the total energy used for the system in the United States. Petroleum supplies the majority of the energy (80 percent) used in Mexico.

Manufacturing Environmental Emissions

Solid Waste. Table 12-3 presents the solid waste for manufacturing 100,000 gable top milk cartons. Included in this table is the postconsumer solid waste generated from disposal of the cartons.

Process solid waste accounts for about nine percent of the total solid waste weight and about six percent of the total solid waste volume.

Fuel-related solid waste makes up 15 percent of the solid waste weight and 10 percent of the solid waste volume.

Postconsumer solid waste accounts for the remaining 76 percent of the total solid waste weight and 84 percent of the total solid waste volume.

Atmospheric and Waterborne Emissions. The total atmospheric and waterborne emissions for manufacturing gable top milk cartons are presented in Table 12-4a and 12-4b, respectively.

All of the atmospheric emissions, except hydrocarbons, and all of the waterborne emissions for operations in Mexico are fuel related. The fuel-related emissions are a result of production and combustion of fuels to produce energy for manufacturing operations and transportation of raw materials and finished products. The process hydrocarbon emissions are produced during manufacture of the carton blanks.

Disposal Energy and Environmental Emissions

Table 12-5 presents the energy requirements for the operation of packer trucks and landfill equipment to dispose of postconsumer solid waste from the gable top cartons. This equipment is assumed to use diesel as a fuel source; therefore, this energy is derived from petroleum.

The fuel-related environmental emissions for the operation of packer trucks and landfill equipment to dispose of postconsumer solid waste from the gable top cartons are presented in Table 12-6.

Table 12-2

ENERGY PROFILES FOR MANUFACTURE OF 100,000 GABLE TOP MILK CARTONS
(GJ per 100,000 Items)

	Energy Profile							
	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Total Energy
Gable Top Milk Cartons								
United States	50.4	51.4	36.4	0.81	6.32	62.9	0.54	209
Mexico	1.67	11.9	0.40	0.39	0.25		0.29	14.9
Total	52.1	63.3	36.8	1.20	6.57	62.9	0.83	224

Source: Franklin Associates, Ltd.

Table 12-3

SOLID WASTE BY WEIGHT AND VOLUME FOR MANUFACTURE OF 100,000 GABLE TOP MILK CARTONS

	Process Waste		Fuel Waste		Postconsumer Waste		Total Solid Waste	
	kg	cubic meter	kg	cubic meter	kg	cubic meter	kg	cubic meter
Gable Top Milk Cartons								
United States	366	0.46	613	0.77			978	1.22
Mexico	0.086	1.1E-04	14.1	0.018	3,185	6.56	3,199	6.57
Total Solid Waste	366	0.46	627	0.78	3,185	6.56	4,178	7.79

Source: Franklin Associates, Ltd.

Table 12-4a

SUMMARY OF ATMOSPHERIC EMISSIONS FOR
GABLE TOP MILK CARTONS
(Emissions per 100,000 items)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Atmospheric Emissions (kg)						
Particulates	0.91	15.2	16.2		1.36	1.36
Nitrogen Oxides	0.62	34.8	35.4		6.49	6.49
Hydrocarbons	12.7	28.4	41.1	2.48	4.83	7.31
Sulfur Oxides	3.45	43.2	46.6		11.2	11.2
Carbon Monoxide	0.11	57.5	57.7		5.82	5.82
Aldehydes	0.0058	3.14	3.14		0.13	0.13
Methane		0.067	0.067		0.0069	0.0069
Other Organics		4.00	4.00		2.97	2.97
Kerosene		6.10E-04	6.10E-04		2.40E-05	2.40E-05
Ammonia	0.0013	0.0048	0.0060		0.0013	0.0013
Lead	1.62E-07	0.0015	0.0015		3.67E-04	3.67E-04
Fossil Carbon Dioxide		3,357	3,357		1,060	1,060
Non-Fossil Carbon Dioxide	23.3	5,574	5,598			
Hydrogen Chloride	1.74E-05	1.41E-04	1.58E-04		3.71E-05	3.71E-05
Mercury	1.73E-04	1.16E-04	2.88E-04		3.12E-05	3.12E-05
Chlorine	1.25E-04		1.25E-04		0.0047	0.0047
Odorous Sulfur	2.48		2.48			
Chromium Compounds		0.0030	0.0030		4.35E-04	4.35E-04
Manganese Compounds		0.0045	0.0045		5.95E-04	5.95E-04
Nickel Compounds		0.0090	0.0090		0.0028	0.0028
Antimony					5.69E-05	5.69E-05
Arsenic		0.0016	0.0016		2.62E-04	2.62E-04
Beryllium		1.73E-04	1.73E-04		2.50E-05	2.50E-05
Cadmium					2.33E-04	2.33E-04
Cobalt		4.70E-04	4.70E-04		1.61E-04	1.61E-04
Selenium		1.30E-04	1.30E-04		6.18E-05	6.18E-05
Sulfuric Acid					0.41	0.41
Na2O2					2.76E-05	2.76E-05
KO2					2.76E-05	2.76E-05
V2O5					2.76E-05	2.76E-05

Source: Franklin Associates, Ltd.

Table 12-4b

SUMMARY OF WATERBORNE EMISSIONS FOR GABLE TOP MILK CARTONS
(Emissions per 100,000 items)

	United States			Mexico		
Waterborne Emissions (kg)	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Acid	1.06	1.04E-06	1.06		2.73E-07	2.73E-07
Metal Ion	0.0088	0.022	0.031		0.0051	0.0051
Dissolved Solids	3.13	12.6	15.7		0.23	0.23
Suspended Solids	14.9	0.012	14.9		0.018	0.018
BOD	3.94	0.013	3.96		0.061	0.061
COD	9.20	0.060	9.26		0.10	0.10
Phenol	1.13E-05	7.11E-05	8.24E-05		0.0011	0.0011
Sulfides	0.027		0.027		6.22E-04	6.22E-04
Oil	0.040	0.17	0.21		0.064	0.064
Sulfuric Acid		2.92	2.92		0.043	0.043
Iron	4.69E-05	0.73	0.73		0.011	0.011
Ammonia	2.38E-04	0.0017	0.0019		0.011	0.011
Chromium	5.55E-06	4.12E-06	9.67E-06		1.48E-04	1.48E-04
Lead	4.85E-07	1.84E-06	2.32E-06		4.34E-07	4.34E-07
Zinc	4.98E-04	2.69E-05	5.25E-04		7.09E-06	7.09E-06
Nickel	2.58E-07		2.58E-07			
Mercury	4.70E-07		4.70E-07			
Phosphates	0.0030		0.0030			

Source: Franklin Associates, Ltd.

Table 12-5

ENERGY REQUIREMENTS FOR DISPOSAL OF GABLE TOP MILK CARTONS
(gigajoules for units disposed per 100,000 items)

	Packer Truck Energy	Landfill Equipment Energy	Total Disposal Energy
Gable Top Milk Cartons	0.39	0.23	0.61

Source: Franklin Associates, Ltd.

Table 12-6

SUMMARY OF FUEL-RELATED ENVIRONMENTAL EMISSIONS FOR DISPOSAL OF GABLE TOP MILK CARTONS
(Emissions for units disposed per 100,000 items)

	Packer Truck Emissions	Landfill Equipment Emissions	Total Disposal Emissions
Atmospheric Emissions (kg)			
Particulates	0.037	0.021	0.058
Nitrogen Oxides	0.49	0.28	0.78
Hydrocarbons	0.13	0.073	0.20
Sulfur Oxides	0.12	0.067	0.18
Carbon Monoxide	0.16	0.091	0.25
Aldehydes	0.0076	0.0044	0.012
Methane	5.41E-05	3.13E-05	8.53E-05
Other Organics	8.23E-07	4.76E-07	1.30E-06
Kerosene	2.67E-08	1.54E-08	4.21E-08
Ammonia	4.09E-05	2.37E-05	6.46E-05
Lead	2.75E-06	1.59E-06	4.34E-06
Fossil Carbon Dioxide	28.4	16.4	44.8
Hydrogen Chloride	1.21E-06	6.98E-07	1.90E-06
Mercury	8.96E-08	5.19E-08	1.41E-07
Chlorine	2.12E-05	1.23E-05	3.35E-05
Chromium Compounds	7.46E-07	4.32E-07	1.18E-06
Manganese Compounds	8.27E-07	4.79E-07	1.31E-06
Nickel Compounds	8.18E-06	4.74E-06	1.29E-05
Antimony	1.76E-07	1.02E-07	2.78E-07
Arsenic	5.08E-07	2.94E-07	8.03E-07
Beryllium	4.24E-08	2.45E-08	6.69E-08
Cadmium	6.30E-07	3.65E-07	9.94E-07
Cobalt	4.99E-07	2.89E-07	7.87E-07
Selenium	1.91E-07	1.11E-07	3.02E-07
Sulfuric Acid	0.0013	7.68E-04	0.0021
Na2O2	8.12E-07	4.70E-07	1.28E-06
KO2	8.12E-07	4.70E-07	1.28E-06
V2O5	8.12E-07	4.70E-07	1.28E-06
Solid Waste (kg)	0.047	0.027	0.074
Solid Waste (cu m)	5.85E-05	3.39E-05	9.23E-05
Waterborne Emissions (kg)			
Acid	6.61E-09	4.01E-09	1.06E-08
Metal Ion	1.24E-04	7.53E-05	2.00E-04
Dissolved Solids	0.0054	0.0033	0.0087
Suspended Solids	4.47E-04	2.71E-04	7.18E-04
BOD	0.0015	9.00E-04	0.0024
COD	0.0025	0.0015	0.0040
Phenol	2.79E-05	1.69E-05	4.47E-05
Sulfides	1.51E-05	9.14E-06	2.42E-05
Oil	0.0015	9.15E-04	0.0024
Sulfuric Acid	3.54E-05	2.14E-05	5.68E-05
Iron	1.13E-05	6.83E-06	1.81E-05
Ammonia	2.55E-04	1.55E-04	4.10E-04
Chromium	3.60E-06	2.18E-06	5.78E-06
Lead	1.17E-08	7.10E-09	1.88E-08
Zinc	1.72E-07	1.04E-07	2.76E-07

Source: Franklin Associates, Ltd.

Chapter 13

ENERGY AND ENVIRONMENTAL RESULTS FOR ASEPTIC BRICKS FOR MILK

INTRODUCTION

This chapter provides a summary of the energy requirements and environmental emissions for the production, recycling and disposal of aluminum foil/LDPE/foodboard laminated aseptic bricks for milk. The basis for the results presented in this chapter is 100,000 aseptic bricks. Supporting data for foodboard and aseptic brick production are presented in Appendix O of the separately bound Appendix document. Data for production of aluminum foil can be found in Appendix C. Data for the production of LDPE resin can be found in Appendix I.

The postconsumer recovery rate for the aseptic bricks examined in this study is assumed to be zero.

DATA SOURCES

The LDPE resin and aluminum foil used to produce aseptic brick stock are assumed to be produced in the United States. Data for production of these materials were taken from Franklin Associates' database.

Producers of aseptic bricks in Mexico indicated the use of foodboard produced in both Brazil and Sweden. Data for the production of foodboard in Brazil were not available for this study; however, data for the production of foodboard in Sweden were available. Therefore, data for the foodboard examined in this study are derived from data supplied by one producer in Sweden.

Data for the production of aseptic brick stock were supplied by one producer in Mexico. Data for the fabrication of aseptic bricks from this material in Mexico were not available; therefore, data taken from Franklin Associates' database for similar operations in the United States were used to estimate aseptic brick production in Mexico.

RESULTS AND DISCUSSION

Manufacturing Energy Requirements. Table 13-1 presents the energy requirements for the manufacture of 100,000 aseptic bricks for milk. The energy usage is categorized by country.

Table 13-1

ENERGY REQUIREMENTS FOR MANUFACTURE OF 100,000 ASEPTIC BRICKS FOR MILK

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total
Aseptic Bricks								
Sweden	67.5	95%	3.57	5%			71.0	100%
United States	55.1	59%	2.19	2%	36.6	39%	93.9	100%
Mexico	9.06	65%	4.99	35%			14.0	100%
Total Energy	132	74%	10.7	6%	36.6	20%	179	100%

Source: Franklin Associates, Ltd.

Process energy accounts for about 74 percent of the total energy for the system. About half of the process energy is used in Sweden to manufacture foodboard. Production of LDPE resin and aluminum foil in the United States uses about 42 percent of the process energy.

Transportation energy accounts for six percent of the total energy. About 47 percent of the transportation energy is used in Mexico.

The energy of material resource accounts for 20 percent of the total energy for the system. All of this energy is used in the United States. Ninety-one percent of the energy is used for LDPE resin production, and the rest is used to make metallurgical coke and petroleum pitch used during aluminum smelting.

Table 13-2 presents the energy profile for production of aseptic bricks for milk. Wood is the largest source of energy for the system in Sweden, representing 46 percent of the energy used there to make the foodboard. Natural gas accounts for about 52 percent of the total energy used for the system in the United States. Petroleum supplies the majority of the energy (74 percent) used in Mexico.

Manufacturing Environmental Emissions

Solid Waste. Table 13-3 presents the solid waste for manufacturing 100,000 aseptic bricks for milk. Included in this table is the postconsumer solid waste generated from disposal of the aseptic bricks.

Process solid waste accounts for about 14 percent of the total solid waste weight and about nine percent of the total solid waste volume.

Fuel-related solid waste makes up nine percent of the solid waste weight and six percent of the solid waste volume.

Postconsumer solid waste accounts for the remaining 77 percent of the total solid waste weight and 85 percent of the total solid waste volume.

Atmospheric and Waterborne Emissions. The total atmospheric and waterborne emissions for manufacturing aseptic bricks for milk are presented in Table 13-4a and 13-4b, respectively.

All of the atmospheric emissions, except aldehydes and other organics, and all of the waterborne emissions for operations in Mexico are fuel related. The fuel-related emissions are a result of production and combustion of fuels to produce energy for manufacturing operations and transportation of raw materials and finished products. The process aldehydes and other organic emissions are produced during manufacture of the aseptic brick stock.

Table 13-2

ENERGY PROFILES FOR MANUFACTURE OF 100,000 ASEPTIC BRICKS FOR MILK
(GJ per 100,000 Items)

	Energy Profile							
	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Total Energy
Aseptic Bricks								
Sweden	1.73	9.76	0.12	6.95	19.4	32.8	0.33	71.0
United States	48.7	14.6	18.7	6.43	5 23		0.23	93.9
Mexico	1.93	10.3	0.54	0.53	0.34		0.40	14.0
Total	52.4	34.7	19.4	13.9	24.9	32.8	0.96	179

Source: Franklin Associates, Ltd.

Table 13-3

SOLID WASTE BY WEIGHT AND VOLUME FOR MANUFACTURE OF 100,000 ASEPTIC BRICKS FOR MILK

	Process Waste		Fuel Waste		Postconsumer Waste		Total Solid Waste	
	kg	cubic meter	kg	cubic meter	kg	cubic meter	kg	cubic meter
Aseptic Bricks								
Sweden	73.7	0.092	77.8	0.097			152	0.19
United States	296	0.37	244	0.30			540	0.67
Mexico	137	0.17	18.4	0.023	2,850	5.87	3,005	6.06
Total Solid Waste	506	0.63	340	0.42	2,850	5.87	3,696	6.92

Source: Franklin Associates, Ltd.

Table 13-4a

SUMMARY OF ATMOSPHERIC EMISSIONS FOR ASEPTIC BRICKS FOR MILK
(Emissions per 100,000 Items)

	Sweden			United States			Mexico		
Atmospheric Emissions (kg)	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Particulates	0.82	7.41	8.24	6.68	3.67	10.3		1.22	1.22
Nitrogen Oxides	0.020	41.9	41.9	0.73	11.6	12.4		5.12	5.12
Hydrocarbons	0.015	66.2	66.2	17.0	13.9	31.0		3.92	3.92
Sulfur Oxides	0.020	9.42	9.44	3.52	18.7	22.2		13.1	13.1
Carbon Monoxide	0.0045	21.7	21.8	16.6	4.18	20.8		4.96	4.96
Aldehydes		1.46	1.46	0.0085	0.038	0.046	1.48E-04	0.082	0.082
Methane					0.035	0.035		0.0081	0.0081
Other Organics		0.052	0.052		0.16	0.16	2.55E-05	2.00	2.00
Kerosene					4.91E-04	4.91E-04		3.21E-05	3.21E-05
Ammonia		0.0028	0.0028	0.0025	5.10E-04	0.0030		0.0011	0.0011
Lead		2.22E-05	2.22E-05	3.05E-07	5.34E-04	5.34E-04		4.55E-04	4.55E-04
Hydrogen Fluoride		0.019	0.019	0.36		0.36			
Fossil Carbon Dioxide	24.8	5,919	5,944	246	3,302	3,548		963	963
Hydrogen Chloride		0.021	0.021	3.28E-05	1.50E-05	4.78E-05		3.23E-05	3.23E-05
Metals		0.019	0.019						
Mercury	2.18E-04		2.18E-04	7.19E-06	2.31E-05	3.03E-05		4.09E-05	4.09E-05
Chlorine	0.033	0.0054	0.038	5.09E-05		5.09E-05		0.0061	0.0061
Hydrogen Sulfide	43.9		43.9						
Chromium Compounds					0.0014	0.0014		5.77E-04	5.77E-04
Manganese Compounds					0.0022	0.0022		7.92E-04	7.92E-04
Nickel Compounds					0.0013	0.0013		0.0036	0.0036
Antimony								7.44E-05	7.44E-05
Arsenic					6.75E-04	6.75E-04		3.46E-04	3.46E-04
Beryllium					7.90E-05	7.90E-05		3.32E-05	3.32E-05
Cadmium								3.06E-04	3.06E-04
Cobalt					3.29E-05	3.29E-05		2.10E-04	2.10E-04
Selenium					1.26E-05	1.26E-05		8.08E-05	8.08E-05
Sulfuric Acid								0.54	0.54
Na2O2								2.49E-05	2.49E-05
KO2								2.49E-05	2.49E-05
V2O5								2.49E-05	2.49E-05

Source: Franklin Associates, Ltd.

Table 13-4b

SUMMARY OF WATERBORNE EMISSIONS FOR ASEPTIC BRICKS FOR MILK
(Emissions per 100,000 items)

	Sweden			United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Waterborne Emissions (kg)									
Acid		0.020	0.020	0.12	1.11E-07	0.12		2.38E-07	2.38E-07
Metal Ion		0.019	0.019	0.091	0.0023	0.093		0.0045	0.0045
Dissolved Solids	1.16E-04	0.56	0.56	3.02	1.40	4.42		0.20	0.20
Suspended Solids	7.21	0.024	7.23	4.08	0.0012	4.08		0.016	0.016
BOD	18.7	0.021	18.7	0.41	0.0014	0.41		0.053	0.053
COD	65.3	0.027	65.3	3.55	0.0065	3.56		0.089	0.089
Phenol	9.93E-07	0.019	0.019	4.20E-05	7.60E-06	4.96E-05		0.0010	0.0010
Sulfides	0.0011	6.96E-04	0.0018	0.037		0.037		5.42E-04	5.42E-04
Oil		0.014	0.014	0.80	0.032	0.83		0.055	0.055
Sulfuric Acid					1.50	1.50		0.057	0.057
Iron				0.0095	0.37	0.38		0.014	0.014
Hydrocarbons	0.14	0.024	0.17						
Ammonia				0.018	1.78E-04	0.018		0.0092	0.0092
Chromium	8.07E-05		8.07E-05	9.60E-07	4.40E-07	1.40E-06		1.29E-04	1.29E-04
Lead	6.47E-06		6.47E-06	4.39E-07	1.96E-07	6.35E-07		4.22E-07	4.22E-07
Zinc	7.10E-05		7.10E-05	6.88E-04	2.88E-06	6.91E-04		6.18E-06	6.18E-06
Fluorides				0.051		0.051			
Cyanide				5.77E-05		5.77E-05			
Nickel	1.42E-05		1.42E-05	1.07E-08		1.07E-08			
Mercury	1.56E-05		1.56E-05	1.96E-08		1.96E-08			
Phosphates				0.16		0.16			
Phosphorus	0.076		0.076						
Nitrogen	1.00		1.00						
Other Chem.	1.96E-05		1.96E-05						

Source: Franklin Associates, Ltd.

Disposal Energy and Environmental Emissions

Table 13-5 presents the energy requirements for the operation of packer trucks and landfill equipment to dispose of postconsumer solid waste from the aseptic bricks. This equipment is assumed to use diesel as a fuel source; therefore, this energy is derived from petroleum.

The fuel-related environmental emissions for the operation of packer trucks and landfill equipment to dispose of postconsumer solid waste from the aseptic bricks are presented in Table 13-6.

Table 13-5

ENERGY REQUIREMENTS FOR DISPOSAL OF ASEPTIC BRICKS FOR MILK
(gigajoules for units disposed per 100,000 items)

	Packer Truck Energy	Landfill Equipment Energy	Total Disposal Energy
Aseptic Bricks	0.35	0.20	0.55

Source: Franklin Associates, Ltd.

Table 13-6

SUMMARY OF FUEL-RELATED ENVIRONMENTAL EMISSIONS FOR DISPOSAL OF ASEPTIC BRICKS FOR MILK
(Emissions for units disposed per 100,000 items)

	Packer Truck Emissions	Landfill Equipment Emissions	Total Disposal Emissions
Atmospheric Emissions (kg)			
Particulates	0.033	0.019	0.052
Nitrogen Oxides	0.44	0.25	0.69
Hydrocarbons	0.11	0.065	0.18
Sulfur Oxides	0.10	0.060	0.16
Carbon Monoxide	0.14	0.081	0.22
Aldehydes	0.0068	0.0039	0.011
Methane	4.84E-05	2.80E-05	7.64E-05
Other Organics	7.36E-07	4.26E-07	1.16E-06
Kerosene	2.39E-08	1.38E-08	3.77E-08
Ammonia	3.66E-05	2.12E-05	5.78E-05
Lead	2.46E-06	1.42E-06	3.88E-06
Fossil Carbon Dioxide	25.4	14.7	40.1
Hydrogen Chloride	1.08E-06	6.25E-07	1.70E-06
Mercury	8.02E-08	4.64E-08	1.27E-07
Chlorine	1.90E-05	1.10E-05	3.00E-05
Chromium Compounds	6.67E-07	3.86E-07	1.05E-06
Manganese Compounds	7.40E-07	4.28E-07	1.17E-06
Nickel Compounds	7.32E-06	4.24E-06	1.16E-05
Antimony	1.58E-07	9.13E-08	2.49E-07
Arsenic	4.55E-07	2.63E-07	7.18E-07
Beryllium	3.79E-08	2.19E-08	5.98E-08
Cadmium	5.64E-07	3.26E-07	8.90E-07
Cobalt	4.46E-07	2.58E-07	7.04E-07
Selenium	1.71E-07	9.91E-08	2.70E-07
Sulfuric Acid	0.0012	6.87E-04	0.0019
Na2O2	7.27E-07	4.21E-07	1.15E-06
KO2	7.27E-07	4.21E-07	1.15E-06
V2O5	7.27E-07	4.21E-07	1.15E-06
Solid Waste (kg)	0.042	0.024	0.066
Solid Waste (cu m)	5.23E-05	3.03E-05	8.26E-05
Waterborne Emissions (kg)			
Acid	6.61E-09	4.01E-09	1.06E-08
Metal Ion	1.24E-04	7.53E-05	2.00E-04
Dissolved Solids	0.0054	0.0033	0.0087
Suspended Solids	4.47E-04	2.71E-04	7.18E-04
BOD	0.0015	9.00E-04	0.0024
COD	0.0025	0.0015	0.0040
Phenol	2.79E-05	1.69E-05	4.47E-05
Sulfides	1.51E-05	9.14E-06	2.42E-05
Oil	0.0015	9.15E-04	0.0024
Sulfuric Acid	3.54E-05	2.14E-05	5.68E-05
Iron	1.13E-05	6.83E-06	1.81E-05
Ammonia	2.55E-04	1.55E-04	4.10E-04
Chromium	3.60E-06	2.18E-06	5.78E-06
Lead	1.17E-08	7.10E-09	1.88E-08
Zinc	1.72E-07	1.04E-07	2.76E-07

Source: Franklin Associates, Ltd.

Chapter 14

ENERGY AND ENVIRONMENTAL RESULTS FOR GLASS PACKAGING

INTRODUCTION

This chapter provides a summary of the energy requirements and environmental emissions for the production, recycling and disposal of the following packaging materials in Mexico:

- 500 ml refillable glass soft drink bottles
- 355 ml non-refillable glass soft drink bottles

The basis for the results presented in this chapter is 100,000 packaging units. Supporting data for the glass packaging systems are presented in Appendix P of the separately bound Appendix document. Data for production of the steel closures used on the bottles can be found in Appendix E.

The postconsumer recovery rate for the non-refillable glass bottle examined in this study is assumed to be 42 percent. The refillable glass bottle is assumed to have an average usage of 25 trips before it is discarded. The postconsumer recovery rate for the bottle after its useful lifetime is assumed to be 42 percent. The recovery rate for steel closures used on the bottles is assumed to be zero.

The glass used to make the bottles has a recycled content of 27 percent. Therefore, 27 percent of the postconsumer glass that is recovered is assumed to be recycled in a closed-loop system and the remaining 15 percent that is recovered is recycled in an open-loop system.

DATA SOURCES

Data for the production of glass bottles in Mexico were supplied by two glass bottle producers in Mexico. These producers indicated the use of raw materials produced in Mexico, with one exception. Soda ash used by these manufacturers is produced in the United States. Data for the production of the raw materials used to make glass in Mexico were not available for this analysis. Therefore, data for these process steps were estimated from data taken from Franklin Associates' database for similar operations in the United States.

Data for washing refillable glass bottles in Mexico were not available; therefore, data derived from information for washing and filling PET bottles in Mexico were used to estimate the data for glass bottles. Data for the average distance traveled and method used to collect refillable bottles were estimated based on information supplied by M.R. Servicios de Fomento Industrial S.A. de C.V., Mexico City.

Data for the production of steel sheet (used to make the closures) in the United States were taken from Franklin Associates' database. Data for the production of steel closures in Mexico were not available for this study. It is assumed that the resource requirements and environmental emissions for this step will be negligible.

RESULTS AND DISCUSSION

Refillable Glass Soft Drink Bottles

Manufacturing Energy Requirements. Table 14-1 presents the energy requirements for the manufacture of 100,000 refillable glass soft drink bottles, assuming 25 trips per bottle. The energy usage is categorized by country and grouped by bottle and closure.

Process energy accounts for about 87 percent of the total energy for the system. The glass bottle uses about 94 percent of the process energy. About 95 percent of the process energy for the bottle is used in Mexico. Process energy used in the United States to manufacture the bottle is for production of soda ash. All of the process energy for the closure is used in the United States to manufacture steel strip (energy for fabrication of the closures in Mexico is assumed to be negligible).

Transportation energy accounts for about eight percent of the total energy. About 75 percent of the transportation energy is allocated to the bottle. Ninety-four percent of the transportation energy for the bottle is used in Mexico. About 22 percent of the transportation energy used in Mexico for the system is used to collect empty containers.

The energy of material resource accounts for six percent of the total energy for the system. All of this energy is used in the United States to manufacture steel sheet. This energy represents the coal used to make metallurgical coke and coke oven gas which is used as a raw material for steel production. While it is recognized that most of the energy content in the coke and coke oven gas is liberated during the production of steel, the methodology used in this study accounts for the energy derived from materials used as feedstocks on the basis of the energy content of the material that is extracted from the earth to produce the feedstocks (in this case coal).

Table 14-1

ENERGY REQUIREMENTS FOR MANUFACTURE OF 100,000 REFILLABLE GLASS SOFT DRINK BOTTLES

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total	GJ	Percent of Total
Refillable Glass Bottle								
United States	2.43	91%	0.23	9%			2.66	100%
Mexico	49.9	94%	3.44	6%			53.3	100%
Total Energy	52.3	93%	3.66	7%			56.0	100%
Steel Closure								
United States	3.51	45%	0.83	11%	3.54	45%	7.88	100%
Mexico			0.38	100%			0.38	100%
Total Energy	3.51	43%	1.21	15%	3.54	43%	8.25	100%
Package Total								
United States	5.94	56%	1.06	10%	3.54	34%	10.5	100%
Mexico	49.9	93%	3.81	7%			53.7	100%
Total Energy	55.8	87%	4.87	8%	3.54	6%	64.2	100%

Source: Franklin Associates, Ltd.

Table 14-2 presents the energy profile for production of refillable glass soft drink bottles. Together, natural gas and petroleum account for about 85 percent of the total energy for the system. About 81 percent of the total natural gas energy and 94 percent of the total petroleum energy are used in Mexico for bottle production.

Manufacturing Environmental Emissions

Solid Waste. Table 14-3 presents the solid waste for manufacturing 100,000 glass soft drink bottles. Included in this table is the postconsumer solid waste generated from disposal of glass bottles after their last trip.

Process solid waste accounts for about 34 percent of the total solid waste weight and about 39 percent of the total solid waste volume. About 87 percent of the process solid waste is produced in the United States for steel strip production.

Fuel-related solid waste makes up three percent of the solid waste weight and volume.

Postconsumer solid waste accounts for 63 percent of the total solid waste weight and about 58 percent of the total solid waste volume.

Atmospheric and Waterborne Emissions. The total atmospheric and waterborne emissions for manufacturing refillable glass soft drink bottles are presented in Table 14-4a and 14-4b, respectively.

Most of the atmospheric particulate emissions in Mexico and all of the non-fossil carbon dioxide and silicon dioxide emissions are process related. Ninety-six percent of the particulate emissions and all of the non-fossil carbon dioxide and silicon dioxide emissions are produced during the glass production step. Most of the other atmospheric emissions are fuel-related. These emissions are a result of production and combustion of fuels to produce energy for manufacturing operations and transportation of raw materials and finished products.

Most of the waterborne dissolved solids process emissions released in Mexico are from bottle washing. Most of the other process waterborne emissions released in Mexico are from the production of caustic soda used to clean the refillable bottles.

Table 14-2

ENERGY PROFILES FOR MANUFACTURE OF 100,000 REFILLABLE GLASS SOFT DRINK BOTTLES
(GJ per 100,000 items assuming 25 trips per bottle)

	Energy Profile							
	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Total Energy
Refillable Glass Bottle								
United States	2.43	0.21						2.65
Mexico	17.3	31.3	1.48	1.33	0.86		1.01	53.3
Total	19.8	31.5	1.48	1.33	0.86		1.01	56.0
Steel Closure								
United States	1.63	1.26	4.54	0.048	0.37		0.032	7.88
Mexico		0.38						0.38
Total	1.63	1.64	4.54	0.048	0.37		0.032	8.25
Package Total								
United States	4.06	1.47	4.54	0.048	0.37		0.032	10.5
Mexico	17.3	31.7	1.48	1.33	0.86		1.01	53.7
Total	21.4	33.2	06.0	1.38	1.23		1.04	64.2

Source: Franklin Associates, Ltd.

Table 14-3

SOLID WASTE BY WEIGHT AND VOLUME FOR MANUFACTURE OF 100,000 REFILLABLE GLASS SOFT DRINK BOTTLES
(assuming 25 trips per bottle)

	Process Waste		Fuel Waste		Postconsumer Waste		Total Solid Waste	
	kg	cubic meter	kg	cubic meter	kg	cubic meter	kg	cubic meter
Refillable Glass Bottle								
United States	19.8	0.025	0.21	2.6E-04			20.0	0.025
Mexico	81.7	0.10	50.6	0.063	1,183	0.71	1,316	0.88
Total Solid Waste	101	0.13	50.8	0.063	1,183	0.71	1,336	0.90
Steel Closure								
United States	668	0.83	15.5	0.019			683	0.85
Mexico			0.045	5.7E-05	230	0.70	230	0.70
Total Solid Waste	668	0.83	15.5	0.019	230	0.70	913	1.55
Package Total								
United States	687	0.86	15.7	0.020			703	0.88
Mexico	81.7	0.10	50.7	0.063	1,413	1.41	1,546	1.57
Total Solid Waste	769	0.96	66.3	0.083	1,413	1.41	2,249	2.45

Source: Franklin Associates, Ltd.

Table 14-4a

SUMMARY OF ATMOSPHERIC EMISSIONS FOR
REFILLABLE GLASS SOFT DRINK BOTTLES
(Emissions per 100,000 items assuming 25 trips per bottle)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Atmospheric Emissions (kg)						
Particulates	4.80	0.37	5.16	78.2	3.28	81.5
Nitrogen Oxides	0.15	1.61	1.77		25.6	25.6
Hydrocarbons	0.56	2.75	3.32		22.0	22.0
Sulfur Oxides	0.75	1.43	2.19	6.9E-04	39.4	39.4
Carbon Monoxide	5.40	1.06	6.45	0.079	11.5	11.6
Aldehydes		0.020	0.020		0.35	0.35
Methane		0.0058	0.0058		0.038	0.038
Other Organics		0.28	0.28		1.34	1.34
Kerosene		4.0E-05	4.0E-05		8.2E-05	8.2E-05
Ammonia	0.0082	1.8E-04	0.0084		0.0034	0.0034
Lead	3.0E-06	3.5E-05	3.8E-05		0.0015	0.0015
Fossil Carbon Dioxide	369	444	813		4,119	4,119
Non-Fossil Carbon Dioxide				90.5		90.5
Hydrogen Chloride		5.2E-06	5.2E-06		9.9E-05	9.9E-05
Mercury		1.7E-06	1.7E-06	4.3E-05	1.1E-04	1.5E-04
Chlorine				2.5E-05	0.017	0.017
Chromium Compounds	1.8E-06	9.0E-05	9.1E-05		0.0016	0.0016
Manganese Compounds	4.0E-05	1.4E-04	1.8E-04		0.0022	0.0022
Nickel Compounds	4.7E-07	9.3E-05	9.4E-05		0.0094	0.0094
Zinc Compounds	3.1E-05		3.1E-05			
Copper Compounds	3.4E-06		3.4E-06			
Antimony					1.9E-04	1.9E-04
Arsenic		4.3E-05	4.3E-05		9.3E-04	9.3E-04
Beryllium		5.1E-06	5.1E-06		9.0E-05	9.0E-05
Cadmium					8.1E-04	8.1E-04
Cobalt		2.8E-06	2.8E-06		5.5E-04	5.5E-04
Selenium		1.1E-06	1.1E-06		2.1E-04	2.1E-04
Sulfuric Acid					1.42	1.42
Na2O2					1.8E-04	1.8E-04
KO2					1.8E-04	1.8E-04
V2O5					1.8E-04	1.8E-04
Silicon Dioxide				1.68		1.68

Source: Franklin Associates, Ltd.

Table 14-4b

SUMMARY OF WATERBORNE EMISSIONS FOR REFILLABLE GLASS SOFT DRINK BOTTLES
(Emissions per 100,000 items assuming 25 trips per bottle)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Waterborne Emissions (kg)						
Acid	0.23	3.8E-08	0.23		7.3E-07	7.3E-07
Metal Ion		8.1E-04	8.1E-04		0.014	0.014
Dissolved Solids	0.11	0.48	0.59	38.5	0.60	39.1
Suspended Solids	0.014	4.3E-04	0.015	0.37	0.049	0.42
BOD		4.7E-04	4.7E-04	1.3E-06	0.16	0.16
COD		0.0022	0.0022	1.3E-06	0.27	0.27
Phenol	1.5E-04	2.6E-06	1.5E-04		0.0031	0.0031
Sulfides				1.2E-05	0.0017	0.0017
Oil	0.0013	0.0085	0.0098		0.18	0.18
Sulfuric Acid		0.094	0.094		0.16	0.16
Iron	0.057	0.024	0.080		0.040	0.040
Ammonia	7.1E-04	6.2E-05	7.7E-04		0.028	0.028
Chromium		1.5E-07	1.5E-07		4.0E-04	4.0E-04
Lead	6.3E-07	6.8E-08	7.0E-07	6.3E-08	1.3E-06	1.4E-06
Zinc	1.1E-05	1.0E-06	1.2E-05	6.3E-08	1.9E-05	1.9E-05
Cyanide	3.5E-04		3.5E-04			
Nickel				6.3E-08		6.3E-08
Mercury				1.2E-07		1.2E-07

Source: Franklin Associates, Ltd.

Non-Refillable Glass Soft Drink Bottles

Manufacturing Energy Requirements. Table 14-5 presents the energy requirements for the manufacture of 100,000 non-refillable glass soft drink bottles. The energy usage is categorized by country and grouped by bottle and closure.

Process energy accounts for about 88 percent of the total energy for the system. The glass bottle uses about 98 percent of the process energy. About 90 percent of the process energy for the bottle is used in Mexico.

Transportation energy accounts for about 11 percent of the total energy. About 95 percent of the transportation energy is allocated to the bottle. Ninety-two percent of the transportation energy for the bottle is used in Mexico.

The energy of material resource accounts for two percent of the total energy for the system. All of this energy is used in the United States for steel-strip production.

Table 14-6 presents the energy profile for production of non-refillable glass bottles. Together, natural gas and petroleum account for about 90 percent of the total energy for the system. About 83 percent of the total natural gas energy and 96 percent of the total petroleum energy are used in Mexico for bottle production.

Manufacturing Environmental Emissions

Solid Waste. Table 14-7 presents the solid waste for manufacturing 100,000 non-refillable glass soft drink bottles. Included in this table is the postconsumer solid waste generated from disposal of the bottle.

Process solid waste accounts for about 13 percent of the total solid waste weight and about 21 percent of the total solid waste volume.

Fuel-related solid waste makes up two percent of the total solid waste weight and three percent of the total solid waste volume.

Postconsumer solid waste accounts for 86 percent of the total solid waste weight and about 76 percent of the total solid waste volume.

Atmospheric and Waterborne Emissions. The total atmospheric and waterborne emissions for manufacturing non-refillable glass soft drink bottles are presented in Table 14-8a and 14-8b, respectively.

Table 14-5

ENERGY REQUIREMENTS FOR MANUFACTURE OF 100,000 NON-REFILLABLE GLASS SOFT DRINK BOTTLES

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	GJ	Percent of total	GJ	Percent of total	GJ	Percent of total	GJ	Percent of total
Non-Refillable Glass Bottle								
United States	19.7	92%	1.74	8%			21.4	100%
Mexico	175	89%	21.2	11%			196	100%
Total Energy	194	89%	22.9	11%			217	100%
Steel Closure								
United States	3.51	45%	0.83	11%	3.54	45%	7.88	100%
Mexico			0.38	100%			0.38	100%
Total Energy	3.51	43%	1.21	15%	3.54	43%	8.25	100%
Package Total								
United States	23.2	79%	2.57	9%	3.54	12%	29.3	100%
Mexico	175	89%	21.6	11%			196	100%
Total Energy	198	88%	24.1	11%	3.54	2%	226	100%

Source: Franklin Associates, Ltd.

Table 14-6

ENERGY PROFILES FOR MANUFACTURE OF 100,000 NON-REFILLABLE GLASS SOFT DRINK BOTTLES
(GJ per 100,000 Items)

	Energy Profile							
	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Total Energy
Non-Refillable Glass Bottle								
United States	19.7	1.74						21.4
Mexico	104	74.6	5.28	5.13	3.30		3.89	196
Total	124	76.3	5.28	5.13	3.30		3.89	218
Steel Closure								
United States	1.63	1.26	4.54	0.048	0.37		0.032	7.88
Mexico		0.38						0.38
Total	1.63	1.64	4.54	0.048	0.37		0.032	8.25
Package Total								
United States	21.3	3.00	4.54	0.048	0.37		0.032	29.3
Mexico	104	75.0	5.28	5.13	3.30		3.89	197
Total	125	78.0	9.82	5.18	3.67		3.92	226

Source: Franklin Associates, Ltd.

Table 14-7

SOLID WASTE BY WEIGHT AND VOLUME FOR MANUFACTURE OF 100,000 NON-REFILLABLE GLASS SOFT DRINK BOTTLES

	Process Waste		Fuel Waste		Postconsumer Waste		Total Solid Waste	
	kg	cubic meter	kg	cubic meter	kg	cubic meter	kg	cubic meter
Non-Refillable Glass Bottle								
United States	160	0.20	1.69	0.0021			162	0.20
Mexico	626	0.78	178	0.22	9,570	5.76	10,374	6.76
Total Solid Waste	786	0.98	180	0.22	9,570	5.76	10,535	6.97
Steel Closure								
United States	668	0.83	15.5	0.019			683	0.85
Mexico			0.045	5.71E-05	230	0.70	230	0.70
Total Solid Waste	668	0.83	15.5	0.019	230	0.70	913	1.55
Package Total								
United States	827	1.03	17.1	0.021			845	1.05
Mexico	626	0.78	178	0.22	9,800	6.46	10,604	7.46
Total Solid Waste	1,453	1.81	195	0.24	9,800	6.46	11,448	8.52

Source: Franklin Associates, Ltd.

Table 14-8a

SUMMARY OF ATMOSPHERIC EMISSIONS FOR NON-REFILLABLE GLASS SOFT DRINK BOTTLE (Emissions per 100,000 items)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Atmospheric Emissions (kg)						
Particulates	16.5	0.73	17.2	633	8.07	641
Nitrogen Oxides	0.15	3.86	4.02		36.3	36.3
Hydrocarbons	0.56	12.9	13.4		97.1	97.1
Sulfur Oxides	0.75	2.26	3.02		149	149
Carbon Monoxide	5.40	2.02	7.41	0.64	28.1	28.7
Aldehydes		0.045	0.045		0.38	0.38
Methane		0.027	0.027		0.19	0.19
Other Organics		0.32	0.32		7.01	7.01
Kerosene		4.3E-05	4.3E-05		3.1E-04	3.1E-04
Ammonia	0.0082	3.4E-04	0.0085		0.0080	0.0080
Lead	3.0E-06	3.9E-05	4.2E-05		0.0061	0.0061
Fossil Carbon Dioxide	369	1,468	1,837		15,978	15,978
Non-Fossil Carbon Dioxide				732		732
Hydrogen Chloride		1.0E-05	1.0E-05		2.4E-04	2.4E-04
Mercury		2.1E-06	2.1E-06		4.0E-04	4.0E-04
Chlorine					0.059	0.059
Chromium Compounds	1.8E-06	9.8E-05	1.0E-04		0.0057	0.0057
Manganese Compounds	4.0E-05	1.5E-04	1.9E-04		0.0078	0.0078
Nickel Compounds	4.7E-07	1.2E-04	1.2E-04		0.035	0.035
Zinc Compounds	3.1E-05		3.1E-05			
Copper Compounds	3.4E-06		3.4E-06			
Antimony					7.2E-04	7.2E-04
Arsenic		4.8E-05	4.8E-05		0.0034	0.0034
Beryllium		5.6E-06	5.6E-06		3.3E-04	3.3E-04
Cadmium					0.0030	0.0030
Cobalt		4.4E-06	4.4E-06		0.0020	0.0020
Selenium		1.7E-06	1.7E-06		7.9E-04	7.9E-04
Sulfuric Acid					5.34	5.34
Na2O2					0.0010	0.0010
KO2					0.0010	0.0010
V2O5					0.0010	0.0010
Silicon Dioxide				13.6		13.6

Source: Franklin Associates, Ltd.

Table 14-8b

SUMMARY OF WATERBORNE EMISSIONS FOR NON-REFILLABLE GLASS SOFT DRINK BOTTLE
(Emissions per 100,000 items)

	United States			Mexico		
	Process Emissions	Fuel Emissions	Total Emissions	Process Emissions	Fuel Emissions	Total Emissions
Waterborne Emissions (kg)						
Acid	0.23	7.4E-08	0.23		1.7E-06	1.7E-06
Metal Ion		0.0016	0.0016		0.033	0.033
Dissolved Solids	0.84	0.96	1.79		1.45	1.45
Suspended Solids	0.014	3.3E-04	0.015	2.97	0.12	3.08
BOD		9.1E-04	9.1E-04		0.39	0.39
COD		0.0043	0.0043		0.65	0.65
Phenol	1.5E-04	5.1E-06	1.6E-04		0.0073	0.0073
Sulfides					0.0040	0.0040
Oil	0.0013	0.026	0.027		0.48	0.48
Sulfuric Acid		0.10	0.10		0.56	0.56
Iron	0.057	0.026	0.082		0.14	0.14
Ammonia	7.1E-04	1.2E-04	8.3E-04		0.067	0.067
Chromium		2.9E-07	2.9E-07		9.5E-04	9.5E-04
Lead	6.3E-07	1.3E-07	7.6E-07		3.1E-06	3.1E-06
Zinc	1.1E-05	1.9E-06	1.3E-05		4.5E-05	4.5E-05
Cyanide	3.5E-04		3.5E-04			

Source: Franklin Associates, Ltd.

Most of the atmospheric particulate emissions in Mexico and all of the non-fossil carbon dioxide and silicon dioxide emissions are process related. Ninety-six percent of the particulate emissions and all of the non-fossil carbon dioxide and silicon dioxide emissions are produced during the glass production step. Most of the other atmospheric emissions are fuel-related. These emissions are a result of production and combustion of fuels to produce energy for manufacturing operations and transportation of raw materials and finished products.

All of the process suspended solid waterborne emissions released in Mexico are from the production of glass sand. All other waterborne emissions in Mexico are fuel related.

Disposal Energy and Environmental Emissions

Table 14-9 presents the energy requirements for the operation of packer trucks and landfill equipment to dispose of postconsumer solid waste from refillable glass soft drink bottle system (after the last filling) and non-refillable glass soft drink bottle system. This equipment is assumed to use diesel as a fuel source; therefore, this energy is derived from petroleum.

The fuel-related environmental emissions for the operation of packer trucks and landfill equipment to dispose of postconsumer solid waste from the refillable glass soft drink bottle system and the non-refillable glass soft drink bottle system are presented in Tables 14-10 and 14-11, respectively.

Table 14-9

ENERGY REQUIREMENTS FOR DISPOSAL OF GLASS PACKAGING
(gigajoules for units disposed per 100,000 items)

	Packer Truck Energy	Landfill Equipment Energy	Total Disposal Energy
Refillable Glass Soft Drink Bottle*			
Glass Bottle	0.041	0.024	0.065
Steel Closure	0.038	0.024	0.062
Package Total	0.078	0.048	0.13
Non-refillable Glass Soft Drink Bottle			
Glass Bottle	0.33	0.20	0.53
Steel Closure	0.038	0.024	0.062
Package Total	0.37	0.22	0.59

* Allocated over 25 trips per bottle before disposal.

Source: Franklin Associates, Ltd.

Table 14-10

SUMMARY OF FUEL-RELATED ENVIRONMENTAL EMISSIONS FOR DISPOSAL OF REFILLABLE GLASS SOFT DRINK BOTTLES
(Emissions for units disposed per 100,000 items)*

	Packer Truck Emissions	Landfill Equipment Emissions	Total Disposal Emissions
Atmospheric Emissions (kg)			
Particulates	0.0074	0.0046	0.012
Nitrogen Oxides	0.099	0.061	0.16
Hydrocarbons	0.025	0.015	0.041
Sulfur Oxides	0.023	0.014	0.038
Carbon Monoxide	0.032	0.020	0.051
Aldehydes	0.0015	9.42E-04	0.0025
Methane	1.09E-05	6.72E-06	1.76E-05
Other Organics	1.66E-07	1.02E-07	2.68E-07
Kerosene	5.37E-09	3.32E-09	8.68E-09
Ammonia	8.23E-06	5.09E-06	1.33E-05
Lead	5.52E-07	3.41E-07	8.94E-07
Fossil Carbon Dioxide	5.71	3.53	9.24
Hydrogen Chloride	2.43E-07	1.50E-07	3.93E-07
Mercury	1.80E-08	1.11E-08	2.92E-08
Chlorine	4.27E-06	2.64E-06	6.91E-06
Chromium Compounds	1.50E-07	9.27E-08	2.43E-07
Manganese Compounds	1.66E-07	1.03E-07	2.69E-07
Nickel Compounds	1.65E-06	1.02E-06	2.66E-06
Antimony	3.55E-08	2.19E-08	5.74E-08
Arsenic	1.02E-07	6.32E-08	1.65E-07
Beryllium	8.52E-09	5.27E-09	1.38E-08
Cadmium	1.27E-07	7.83E-08	2.05E-07
Cobalt	1.00E-07	6.20E-08	1.62E-07
Selenium	3.85E-08	2.38E-08	6.23E-08
Sulfuric Acid	2.67E-04	1.65E-04	4.32E-04
Na_2O_2	1.63E-07	1.01E-07	2.64E-07
KO_2	1.63E-07	1.01E-07	2.64E-07
V_2O_5	1.63E-07	1.01E-07	2.64E-07
Solid Waste (kg)	0.0094	0.0058	0.015
Solid Waste (cu m)	1.18E-05	7.27E-06	1.90E-05
Waterborne Emissions (kg)			
Acid	6.61E-09	4.01E-09	1.06E-08
Metal Ion	1.24E-04	7.53E-05	2.00E-04
Dissolved Solids	0.0054	0.0033	0.0087
Suspended Solids	4.47E-04	2.71E-04	7.18E-04
BOD	0.0015	9.00E-04	0.0024
COD	0.0025	0.0015	0.0040
Phenol	2.79E-05	1.69E-05	4.47E-05
Sulfides	1.51E-05	9.14E-06	2.42E-05
Oil	0.0015	9.15E-04	0.0024
Sulfuric Acid	3.54E-05	2.14E-05	5.68E-05
Iron	1.13E-05	6.83E-06	1.81E-05
Ammonia	2.55E-04	1.55E-04	4.10E-04
Chromium	3.60E-06	2.18E-06	5.78E-06
Lead	1.17E-08	7.10E-09	1.88E-08
Zinc	1.72E-07	1.04E-07	2.76E-07

* Allocated over 25 trips per bottle before disposal.

Source: Franklin Associates, Ltd.

Table 14-11

SUMMARY OF FUEL-RELATED ENVIRONMENTAL EMISSIONS FOR DISPOSAL OF NON-REFILLABLE GLASS SOFT DRINK BOTTLES
(Emissions for units disposed per 100,000 items)

	Packer Truck Emissions	Landfill Equipment Emissions	Total Disposal Emissions
Atmospheric Emissions (kg)			
Particulates	0.035	0.021	0.056
Nitrogen Oxides	0.46	0.28	0.74
Hydrocarbons	0.12	0.072	0.19
Sulfur Oxides	0.11	0.066	0.18
Carbon Monoxide	0.15	0.090	0.24
Aldehydes	0.0071	0.0043	0.011
Methane	5.09E-05	3.06E-05	8.17E-05
Other Organics	7.75E-07	4.69E-07	1.24E-06
Kerosene	2.51E-08	1.52E-08	4.03E-08
Ammonia	3.85E-05	2.33E-05	6.18E-05
Lead	2.59E-06	1.57E-06	4.15E-06
Fossil Carbon Dioxide	26.7	16.2	42.9
Hydrogen Chloride	1.14E-06	6.88E-07	1.82E-06
Mercury	8.44E-08	5.11E-08	1.35E-07
Chlorine	2.00E-05	1.21E-05	3.21E-05
Chromium Compounds	7.02E-07	4.25E-07	1.13E-06
Manganese Compounds	7.79E-07	4.72E-07	1.25E-06
Nickel Compounds	7.70E-06	4.66E-06	1.24E-05
Antimony	1.66E-07	1.01E-07	2.67E-07
Arsenic	4.79E-07	2.90E-07	7.69E-07
Beryllium	3.99E-08	2.41E-08	6.40E-08
Cadmium	5.93E-07	3.59E-07	9.52E-07
Cobalt	4.70E-07	2.84E-07	7.54E-07
Selenium	1.30E-07	1.09E-07	2.39E-07
Sulfuric Acid	0.0012	7.57E-04	0.0020
Na2O2	7.65E-07	4.63E-07	1.23E-06
KO2	7.65E-07	4.63E-07	1.23E-06
V2O5	7.65E-07	4.63E-07	1.23E-06
Solid Waste (kg)	0.044	0.027	0.071
Solid Waste (cu m)	5.51E-05	3.33E-05	8.84E-05
Waterborne Emissions (kg)			
Acid	6.61E-09	4.01E-09	1.06E-06
Metal Ion	1.24E-04	7.53E-05	2.00E-04
Dissolved Solids	0.0054	0.0033	0.0087
Suspended Solids	4.47E-04	2.71E-04	7.18E-04
BOD	0.0015	9.00E-04	0.0024
COD	0.0025	0.0015	0.0040
Phenol	2.79E-05	1.69E-05	4.47E-05
Sulfides	1.51E-05	9.14E-06	2.42E-05
Oil	0.0015	9.15E-04	0.0024
Sulfuric Acid	3.54E-05	2.14E-05	5.68E-05
Iron	1.13E-05	6.83E-06	1.31E-05
Ammonia	2.55E-04	1.55E-04	4.10E-04
Chromium	3.60E-06	2.18E-06	5.78E-06
Lead	1.17E-08	7.10E-09	1.38E-08
Zinc	1.72E-07	1.04E-07	2.76E-07

Source: Franklin Associates, Ltd.