Fibers and The Environment

Products to Protect the Environment

Manufactured fibers are used in many products that protect the environment, ranging from geotextiles for land stabilization and erosion prevention, to filtration materials that clean air and water, to special absorbents designed to remove spilled oil from waters and wetlands.

Fibers from Recycled Plastics

Some of the polymers used in common consumer plastics are the same as those used to make fibers. In these cases, recycled plastics can serve as a source of raw material for fiber production. One successful example of this is the production of polyester fiber from soda bottles — particularly good for recycling since they are almost always made of poly(ethylene terephthalate), usually referred to as PET, or simply, polyester. Plastic soda bottles are also easily identified by consumers for separation and recycling. They are available in large enough quantities to justify building recycling facilities.

This is a test caption of the Internet to see if we can due long captionsRecycling works well in this case, but choices about alternative products, and alternative ways to reduce them impact on the environment are not very often this straightforward. As a general example, the choice between paper or plastic in a given situation can be a complicated matter. For an excellent analysis on the point go to the website created by the Plastic Bag Information Clearinghouse to see their review on Paper or Plastic?

Life Cycle Assessments

A meaningful analysis and evaluation of any product's relationship to the environment must include a broad array of criteria including low-impact production, low-impact maintenance, and its classification as recyclable, reusable or incineratable. Primary considerations are low impact on plant and animal life, conservation of limited resources, and waste minimization.

Evaluating these criteria at all stages of a product's life cycle is a very complicated process. Environmental impacts associated with both production and maintenance, as well as end-of-life options, must be included. Life Cycle Assessment, or LCA, is the accepted analytical method for doing this.

The best current LCA methods call for a complete inventory of the inputs and outputs from all phases of a product's lifetime. The results can then be used to set priorities for efforts to reduce environmental effects.

Life Cycle Assessment of a Typical Fiber Product

As a demonstration of the applicability of standard Life Cycle Assessment methodology to consumer textile products, the American Fiber Manufacturers Association sponsored an LCA on a typical woman's knitted blouse made from polyester filament yarn. This garment was chosen as the test because it could be designed without materials (zippers, buttons, etc.), and it's manufacture is relatively simple. To read the complete report click here. LCA studies usually look at very specific energy sources, raw materials and production processes in a defined geographical location, but this project was conducted as a generic study of a garment made from a weighted industry average of inputs and outputs, for a particular fabric construction, dye and garment design.

Although the primary purpose of the polyester blouse LCA was to evaluate the application of the methods to a typical fiber-based consumer product, some of the results have some general application. The importance of considering the consumer use and maintenance was particularly striking. Although the results were magnified by the light weight of the garment studied, it was clear that laundering was responsible for far more pollutant emissions than all other phases of the life cycle combined.

Life cycle energy consumption was found to be the key factor in determining air and water emissions, as well as solid waste. Acquiring fuels (mining for coal, drilling for oil, etc.) and burning them to produce energy accounts for large amounts of greenhouse gases (primarily carbon dioxide) and other pollutant gases. Mining and drilling wastes, together with ash, soot and residue from cleaning stack emissions at power-generating facilities, are major solid waste producers. It followed that, water temperature and drying time were found to be the most important controllable factors. A consumer choice to switch from hot washing and machine drying to cold washing and line drying greatly reduces the environmental impacts associated with the garment.

Life Cycle Analysis (LCA): Woman's Knit Polyester Blouse

Resource and Environmental Profile Analysis of a Manufacturerd Apparel Product

Prepared for American Fiber Manufacturers Association by Franklin Associates, LTD (June 1993)

List of Tables

List of Figures

List of Acronyms and Abbreviations

AFMA	American Fiber Manufactures Association
BOD	Biological oxygen demand
Btu	British thermal unit
COD	Chemical oxygen demand
cu ft	Cubic Feet
DC	District of Columbia
DMT	Dimethyl terephthalate
EPA	Environmental Protection Agency
ETAD	Ecological and Toxicological Association of the Dyestuff Manufacturing Industry
Inc.	Incorporated
Kwh	Kilo-watt hour
lb	pound
LCA	Life cycle analysis
LCI	Life cycle inventory
Ltd.	Limited
PET	Polyethylene terephthalate
PTA	Purified terephthalic acid
MM	Million
MSW	Municipal solid waste
NW	Northwest
REPA	Resource and environmental profile analysis
SETAC	Society of Environmental Toxicology and Chemistry
U.S.	United States

Executive Summary

INTRODUCTION

This summary highlights a Resource and Environmental Profile Analysis (REPA) performed by Franklin Associates, Ltd. on the manufacture, use and disposal of a manufactured textile product, a polyester blouse. A REPA is Franklin Associates' historical term for a Life Cycle Inventory as described by the Environmental Protection Agency and the Society of Environmental Toxicology and Chemistry (SETAC). The study uses a comprehensive approach, encompassing all energy requirements, atmospheric emissions, waterborne wastes, and solid wastes (both industrial and postconsumer). Each major processing step, from the extraction or harvesting of raw materials from the earth to final disposition is included in this cradle-to-grave analysis. Detergent manufacture and home laundering are also included in the analysis.

Life cycle inventory studies provide energy and emissions data in physical units, such as Btu's of energy and pounds of emissions. This should not be confused with risk or impact assessments. An impact assessment is an attempt to determine the human health effects or ecological effects associated with a given material or product. At present, there is no single accepted method for performing a meaningful impact assessment on a life cycle basis.

RESEARCH PURPOSE

The American Fiber Manufacturers Association (AFMA) is exploring ways to evaluate and improve the overall environmental impact of manufactured fiber products. In order to understand the true life cycle consequences, AFMA undertook a life cycle analysis study of a typical manufactured product and process flow - in this case, for a 100% polyester fiber (polyethylene terephthalate) knit fabric woman's blouse apparel item. The results from the research effort are described both in this executive summary and the accompanying detailed report.

RESULTS AND DISCUSSION

Results from this research effort are described on the basis of energy use and releases of emissions to the environment (air, water, and land) per one million wearings. Raw material requirements to meet the one million wearings basis were calculated using an average blouse life span of 40 wearings. Wash load requirements were calculated on the basis of one million wearings by factoring in both load size (20 blouses) and frequency of laundering (after every two wearings). A more detailed description of these assumptions can be found both later in this final report and in the accompanying detailed data appendices.

Energy Requirements

The results of the energy consumption analysis are presented in Figures ES-1, ES-2, and ES-3. Figure ES-1 indicates the split in energy consumption among consumer use operations (laundering, manufacture and use of detergent, blouse disposal), blouse manufacturing operations (resin to apparel), and blouse disposal. As the figure indicates, approximately 82 percent of the total energy requirements are related to consumer use. Most of this energy is consumed in the home laundry operation. Of this energy requirement, approximately twothirds of the energy is for washing (including heating water) and one-third for drying.

Figure ES-2 highlights one portion of Figure ES-1, blouse manufacturing requirements. As this figure indicates, resin manufacture and fabric production are the two largest energy consuming operations during the blouse manufacturing process. Resin manufacturing includes all operations from oil and gas extraction through resin production. Fabric production includes texturizing, knitting, dyeing, and finishing. It should be noted that the categories described in Figure ES-2 include associated industrial packaging requirements.

In Figure ES-3, the consumer use portion of ES-1 is assessed. The home laundering section of the pie chart uses 97 percent of the consumer use total, while the detergent manufacture requires only 3 percent.

Environmental Emissions

When interpreting results for emissions or releases to the environment, it is important to keep in mind that the data are much more variable than energy data.

Solid Wastes. The results of the solid waste generation analysis are presented in Figures ES-4, ES-5, ES-6, and ES-7 on a volume basis. As Figure ES-4 indicates, 90 percent of the solid waste is related to consumer use and blouse disposal, not manufacturing requirements to produce the blouse. The consumer use value includes municipal wastewater treatment sludge created from the washing operation, wastes related to energy generation, detergent production and packaging wastes, and ultimately postconsumer disposal of the blouses.

Figure ES-5 highlights the solid waste contributions of the blouse manufacturing operations. Fabric production and apparel manufacture create the largest volume of solid waste from the manufacturing operations. Most of the fabric waste is from process solid waste including wastewater treatment sludges. Most of apparel manufacturing solid waste is created from packaging used in transporting the finished blouses to the retailer and consumer. Together, resin and fiber production account for less than 30 percent of blouse manufacturing related solid waste.

Figure ES-1

SUMMARY OF TOTAL ENERGY REQUIREMENTS PER MILLION WEARINGS (total energy requirements 1,607.4 mil BTU)

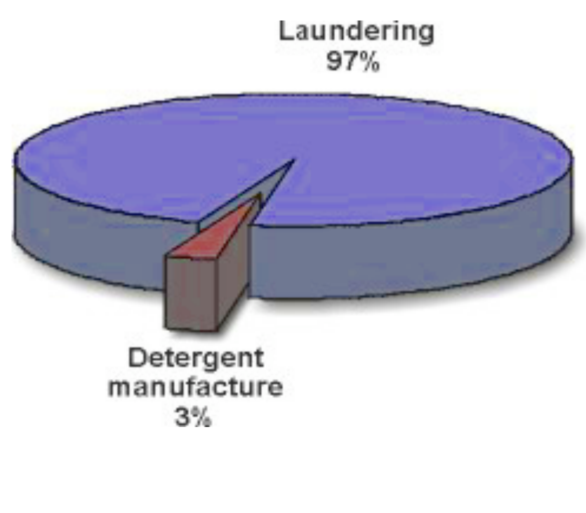


Figure ES-2
ALLOCATION OF MANUFACTURING ENERGY REQUIREMENTS

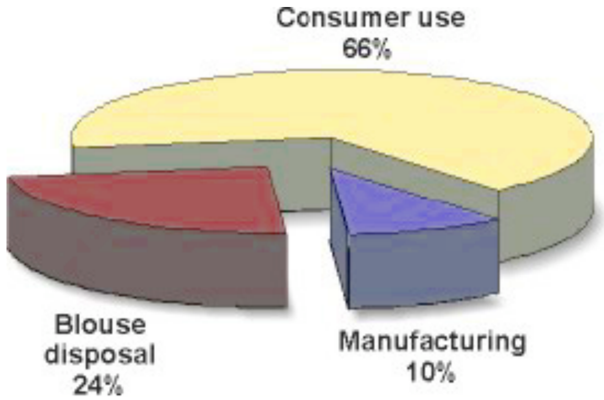


Figure ES-3
ALLOCATION OF CONSUMER USE ENERGY REQUIREMENTS

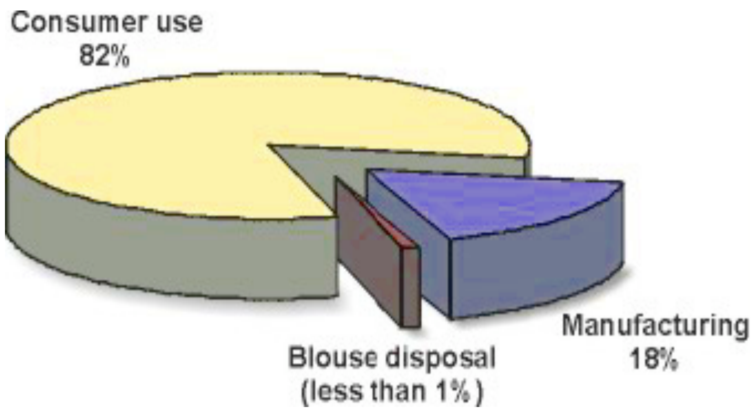
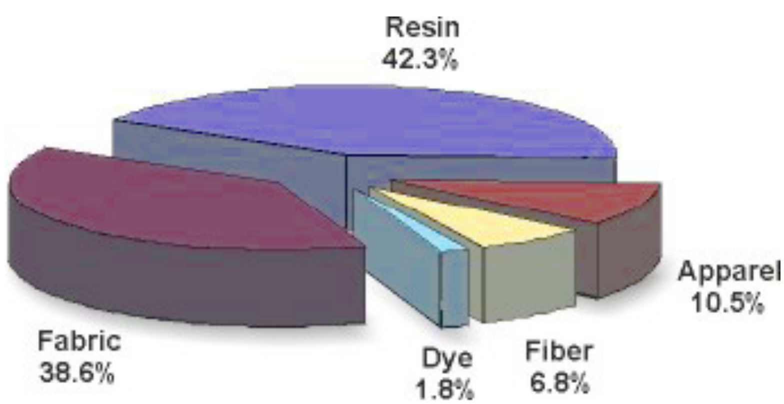


Figure ES-4
SUMMARY OF TOTAL SOLID WASTES PER MILLION WEARINGS (total solid wastes 647.3 cubic feet)



The solid waste produced by consumer use is scrutinized in Figure ES-6. Laundering produced 95 percent of the solid waste, as compared to the detergent manufacture, which only generated 5 percent As mentioned above, the solid waste for the laundering includes municipal wastewater treatment sludge created from the washing operation and wastes related to energy generation.

In Figure ES-7, the solid waste is categorized by type, process-related, fuel-related, or postconsumer. As is shown in the figure, almost sixty percent of the total solid waste is fuel-related, which is ultimately from the fuel used to produce the energy needed in the system. Thirty-eight percent of the total is postconsumer solid waste, which comes from consumer use and disposal. Only 2 percent of the total is process-related solid waste, which is comprised of manufacturing the product.

Atmospheric and Waterborne Emissions. Detailed tables describing the atmospheric and waterborne emissions from manufacture, use, and disposal can be found at the end of Chapter 2 of the final report. The interpretation of these emissions is quite complex because of the diversity of chemicals released to the environment. This summary will focus on the major emission categories.

In the category of atmospheric emissions, the five largest emissions by weight were: particulates, nitrogen oxides, hydrocarbons, sulfur oxides, and carbon monoxide. Most of these emissions were related to the generation of energy, in particular electricity for the laundering process. Over half of the emissions for each of these five categories is related to the fuels consumed in the laundry operation.

Similar patterns of environmental releases can be found in examining the waterborne effluents. The six largest effluents on a weight basis are: dissolved solids, chemical oxygen demand(COD), biological oxygen demand (BOD), acid, iron, and suspended solids. Wastewater from the laundry operation accounted for large quantities of BOD, COD, suspended solids, and dissolved solids. Acid and iron releases came mostly from the burning of fossil fuels associated with the generation of energy. Appendix A describes both the typical atmospheric and waterborne releases associated with energy generation.

Figure ES-5

ALLOCATION OF MANUFACTURING CREATED SOLID WASTES

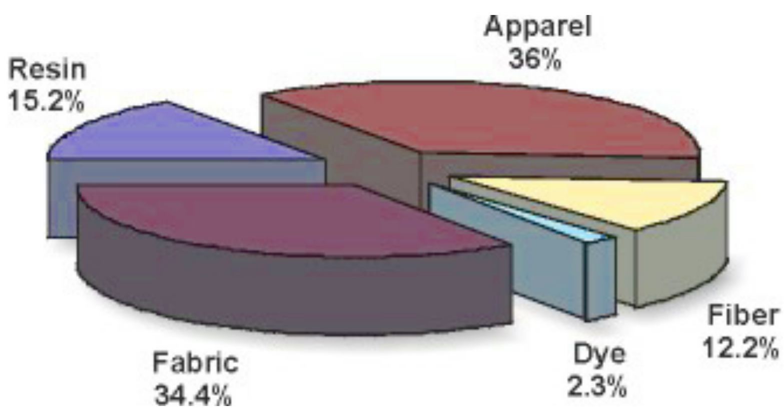
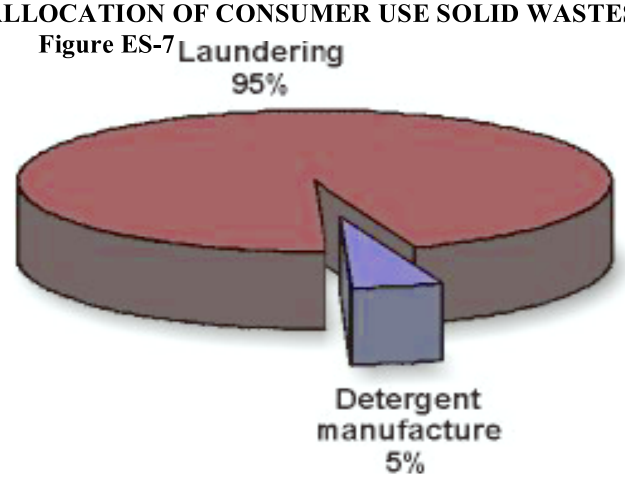


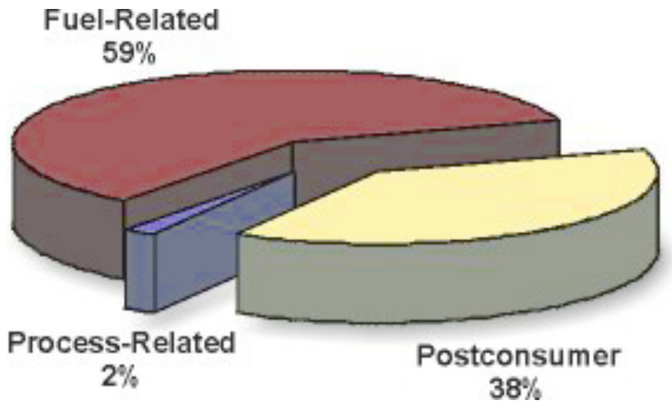
Figure ES-6

ALLOCATION OF CONSUMER USE SOLID WASTES

Figure ES-7



ALLOCATION OF SOLID WASTE BY TYPE (by volume)



KEY FINDINGS

As this research effort indicates, all operations during the life cycle of a product have some environmental and energy effects. The results of this study illustrate the importance of inventorying the broad range of environmental discharges and energy requirements of a product rather than focusing on only one aspect such as solid waste or air pollution. While single-factor analyses are sometimes useful, the development of realistic approaches to environmental protection and improvement require a more holistic evaluation of all environmental and resource consequences.

This research effort indicated both the breadth of operations that must be analyzed in a complete evaluation of all stages of a product's life as well as some of the difficulties in conducting such a study. While the primary focus of this study was on a manufactured polyester product, research required in order to complete the analysis included many diverse topics. For example, topics such as tree harvesting for secondary packaging production, detergents used in the laundering operation, and uranium ore mining for energy generation were explored.

Data gathering and limiting assumptions were both very time intensive operations of this study. As is typical with research efforts of this magnitude, data were developed from many different sources: government references, company specific, and industry provided. Collecting data from each of these sources involved both a large amount of time (approximately 8 months) and extensive follow-up conversations to verify the data. For the most part, industry data was readily available with the difficulty being in locating the correct person to provide the data. Consumer use data proved much more difficult to locate.

Several assumptions were made in the course of this study. The major assumptions affecting the results of this study involved the consumer use and maintenance of the product. Life span (wearings) and laundering practices had the single largest effect on the study results. For example, doubling the wear life would in essence cut in half the raw material requirements. Changes in apparel maintenance habits (blouses per wash load or wearings between laundering) would significantly alter the single largest component of this study, laundering. Where assumptions were made regarding consumer use and maintenance a conservative approach was taken choosing the lower impacts for these operations (i.e. putting the greater burden on the production operations).

In this study for example, it was demonstrated that the manufacture of a particular reusable product was not the most significant consequence for an energy and environmental analysis; instead, improvements measures should be aimed at the efficiency of home laundering devices, reducing the need for heated water in laundering, and decreasing electrical energy demand. It may also be possible to develop "easy care" fabrics requiring lower consumer maintenance. These improvements would have much greater potential benefit than improving the product manufacturing processes. (Quite the contrary conclusion might come from a product that is single use in nature.)

IDENTIFIED NEEDS

A company undertaking a life cycle analysis study of similar scope will be faced by several data gathering challenges. As mentioned earlier, consumer use and maintenance data proved very difficult to locate in this study. The data that did exist was often too broad in scope to be applied to the specific nature of this study. It is hopeful that in the future more research will be conducted into several areas of consumer use and apparel maintenance. Specifically, research is needed in the areas of apparel life span and laundering habits. In terms of apparel life span, it would be useful to conduct research into the average number of wearings and chronological life span from purchase to disposal. Laundering habit research into number of wearings between laundering, wash load size, wash load temperature, and dryer time requirements would be extremely beneficial to future LCA researchers.

Chapter I STUDY APPROACH AND METHODOLOGY INTRODUCTION

A resource and environmental profile analysis (REPA), such as this study, quantifies the energy use and environmental emissions associated with the manufacture, use and disposal of specific products. This background information can be used as the basis for further study of the potential improvement of resource use and environmental effects associated with a given product. It can also pinpoint areas where process or product changes would be most beneficial in terms of reducing energy use or emissions. 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.

Resource and environmental profile analyses have been performed by Franklin Associates Ltd. since the early 1970s, both domestically and internationally. They are an example of what has recently been called an environmental life cycle analysis. These studies have been prepared by Franklin Associates for a wide range of clients representing a wide range of interests. These include the U.S. Environmental Protection Agency (EPA), Federal Energy Administration, National Science Foundation, The Aluminum Association, The Society of The Plastics Industry, and the American Paper Institute.

PURPOSE

The purpose of this study is to assess the energy requirements and environmental emissions for manufacture, use, and disposal of a manufactured fiber product. Specifically, the study evaluates the life cycle of a knit polyester blouse. The term “system” in this study is defined as the blouse itself plus all primary and secondary packaging components. The analysis involves all steps in the life cycle of each system, including extraction of raw materials from the earth, processing these materials into usable components, fabric production, apparel manufacture, transportation of materials and products to the next processing step, blouse laundry, and final disposition.

Resource and environmental profile analyses (REPAs) such as this study are defined by the Society of Environmental Toxicology and Chemistry (SETAQ as life cycle inventories. SETAC and the U.S. Environmental Protection Agency define life cycle analysis as being composed of three separate but interrelated components: life cycle inventory, life cycle impact analysis, and life cycle improvement analysis. This analysis is an inventory analysis and not an impact analysis or a risk assessment. Risk assessment is an attempt to determine the human health effects or ecological effects associated with a given material or product. At present, there is no accepted method for performing meaningful risk assessment on a life cycle basis.

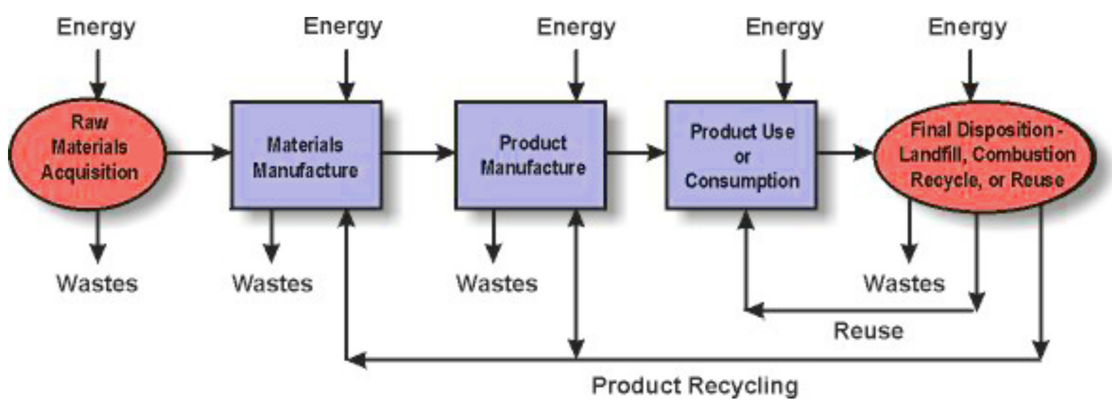


Figure 1-1. General materials flow for “cradle-to-grave” analysis of a product system.

METHODOLOGY

Franklin Associates, Ltd. has developed a methodology for performing resource and environmental profile analyses. This methodology has been documented for the U.S. Environmental Protection Agency and is incorporated in the EPA report Life-cycle Assessment Inventory Guidelines and Principles. The methodology is also consistent with the life cycle inventory methodology described in A Technical Framework for Life-cycle Assessment, a workshop report produced by the Society of Environmental Toxicology and Chemistry. 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 over two decades.

The first step in performing a REPA is to determine which specific manufacturing processes must be evaluated. A complete materials balance is then performed for each individual process. A standard unit of output, such as 1,000 pounds, is used as the basis for all calculations. 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 materials balance, energy requirements, and emissions to reflect the portion of each attributable to the product being considered. Figure 1-2 illustrates a common adjustment concept. The data appendices accompanying this report detail the data collected for this research analysis.

Once the detailed material balance, energy requirements, and environmental emissions have been established for 1,000 pounds of output for each process of a system, a master flow (Figure 1-3) chart is made. This flow chart shows the raw materials from each process that are required to manufacture the blouse system components.

The quantities of energy and solid wastes which result from the entire life cycle have been totaled in this study. The various types of energy are converted to British thermal units (Btu) and added. Solid wastes are also totaled and presented in both pounds and cubic feet of waste. 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.

Actual process flow diagram

Using coproduct allocation, the flow diagram utilized in the REPA for product ‘A’, which accounts for 2/3 of the output, would be as shown below.

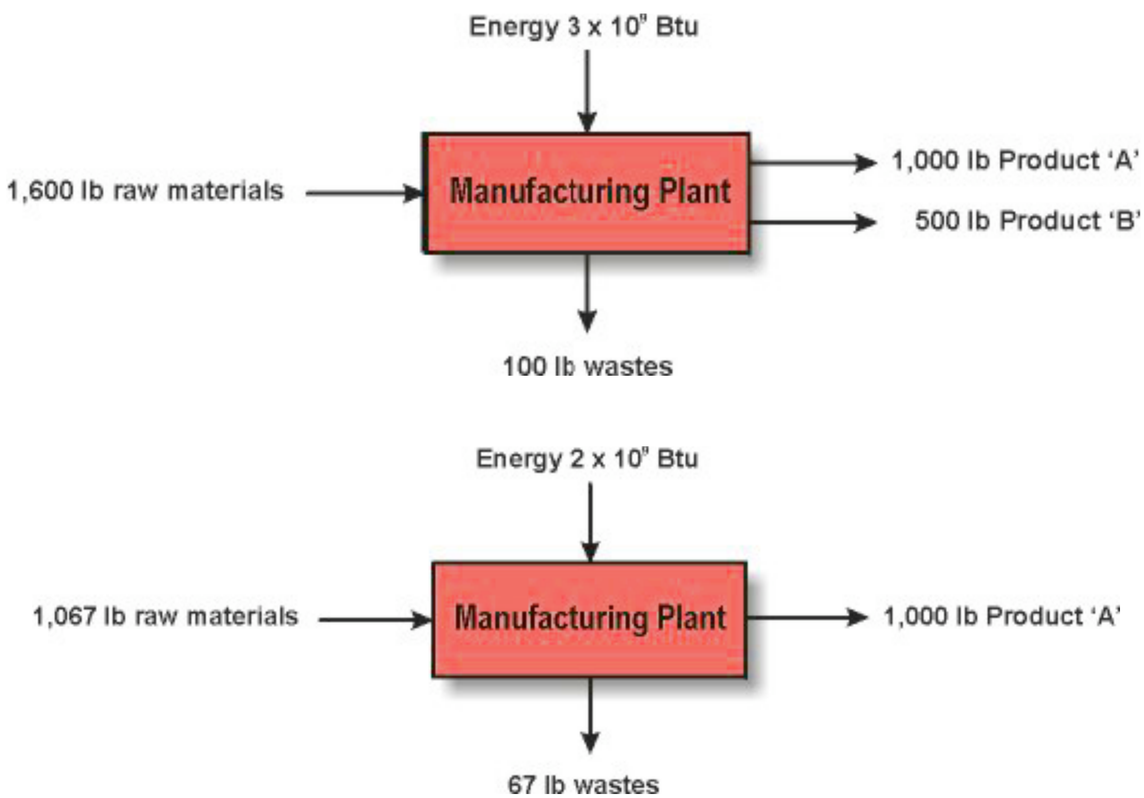


Figure 1-2. Flow diagrams illustrating coproduct allocation for product ‘A’.

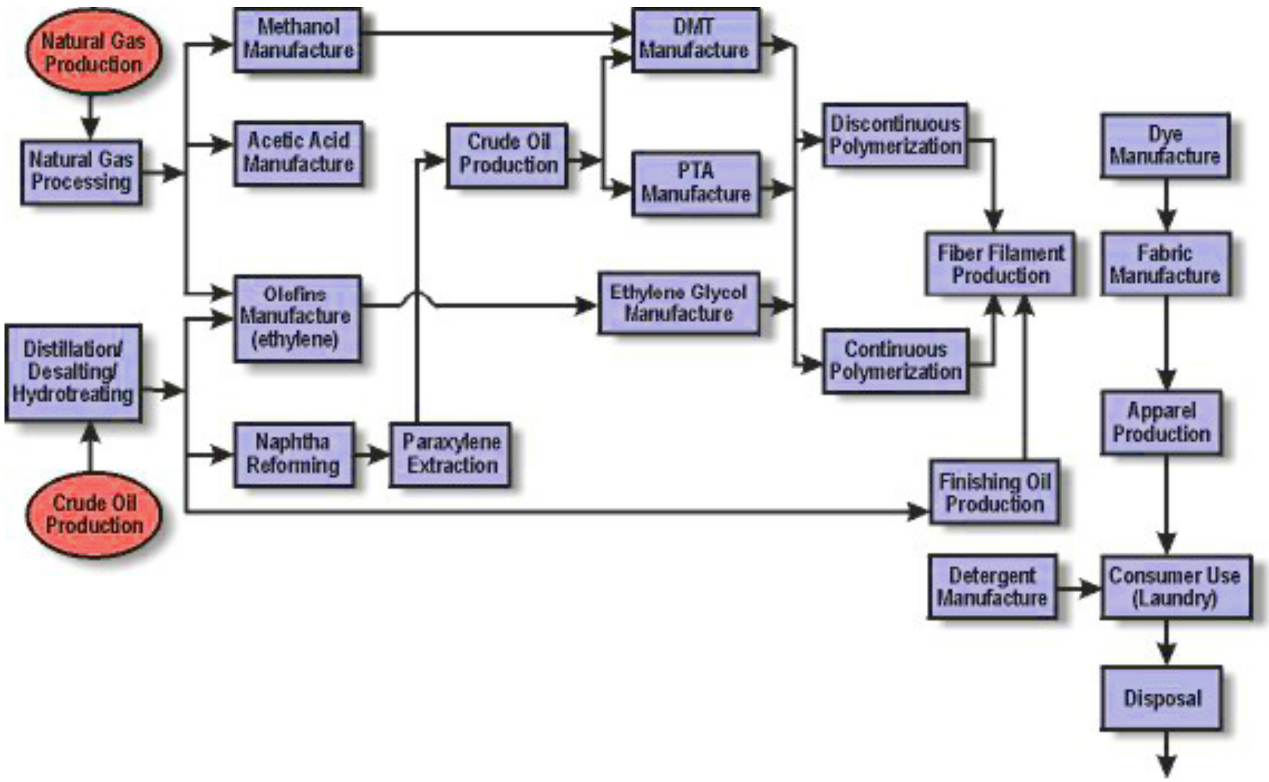


Figure 1-3. Flow diagram for the manufacture, consumer use, and disposal of a woman's knit polyester blouse.

PRODUCT EXAMINED

In order to provide AFMA member companies with a better understanding of the benefits of the product life cycle analysis methodology, a common manufactured product was chosen as the basis for this research project. Specifically, this research effort focused upon the life cycle analysis of a woman's polyester blouse. The results of the study were normalized to a basis of one million wearings of blouses. Table 2-1 describes the specific blouse examined.

DATA SOURCES

Over the past 20 years, Franklin Associates has performed over 150 REPA studies which have examined the energy requirements and emissions associated with the manufacture and use of a variety of products and packaging materials. Therefore, many of the basic industry descriptions, raw materials requirements, and data for packaging components from previous studies are used as a starting point for this analysis. The primary sources used for the necessary revisions to our existing database are technical literature, government publications, published industry statistics, and personal interviews with industry representatives.

DATA GATHERING

Data gathering involved analyzing data needs in several life cycle steps. The results of this analysis are grouped according to these "steps." A discussion of operations included in each of these steps can be found in Table 1-1. For this study, project specific data requirements necessitated revisions for the following processes: resin manufacture, fiber production, dye manufacture, fabric production, apparel production, consumer use (laundry), and disposal options. The following narrative describes data gathering in each of these areas.

Table 1-1
PROCESS STEPS TO BE EXAMINED

PET Resin Manufacture	all operations from gas and oil extraction to resin production, including transportation and packaging between operations
PET Fiber Manufacture	all operations after resin manufacture to production of filament fiber for shipment to fabric mill, including transportation
PET Fiber Packaging	all operations to produce and transport all packaging materials shipped with fiber to fabric mill - primarily corrugated, plastic wrap, and wood.
Dye Manufacture	all operations to produce disperse blue 79:1, including transportation and packaging to the fabric mill
Fabric Manufacture	texturizing, knitting, dyeing, and finishing operations, including transportation between operations
Fabric Packaging	manufacture of packaging to transport fabric to apparel operations
Detergent Manufacture	manufacture and transportation of detergent components
Detergent Packaging	manufacture of consumer detergent packaging
Laundry	required home laundry operations (washing, drying, and water heating)
Postconsumer Disposal	operations for the disposal of municipal solid waste (transportation to landfill or combustion facility)

Source: Franklin Associates, Ltd.

Resin Manufacture

Polyester resin data were collected from AFMA member companies. Both Dimethyl terephthalate (DMT) and purified terephthalic acid (PTA) processes were included as were continuous and discontinuous operations. Once all data were gathered, market share information provided by AFMA was used in developing composite resin data. The difficulty of gathering data for resin manufacture was in identifying the appropriate company contacts.

Fiber Manufacture

Polyester filament fiber data were collected from AFMA member companies. The data collection process was very similar to collecting resin data. Questions arose as to where resin manufacture ends and fiber production starts.

Fabric Manufacture

Most of the fabric manufacturing data used in this study were extracted from research conducted by the Institute of Textile Technology in Charlottesville Virginia. The data represent the "generic" manufacture of fabric from manufactured fiber. The data were in most cases a general representation of all fabric production operations and not task specific (texturizing, knitting, dyeing, and finishing). The environmental data were also generalized plant data and in some cases dated from the mid-1970s. The dyeing process emission data likely included other dyes besides the blue dye specifically analyzed in this study. Very little data were available from the trade association representing this industry, American Textile Manufacturers Institute.

Dye Manufacture

Dye manufacturing data were provided by ETAD (Ecological and Toxicological Association of the Dyestuff Manufacturing Industry) as representative for the production of disperse blue 79:1. This data were specific to this particular blue dye and would not apply to other possible colors or types of dye.

Apparel Manufacture

Data were developed by Franklin Associates from confidential apparel industry sources. The trade association representing this industry, American Apparel Manufacturers Association, does not currently collect data relevant to this study. The apparel manufacturing process is a very technologically diverse industry and is difficult to assimilate into a single "average" value. Fortunately, the impacts from this operation are small and the limited data sources are not viewed as a major problem.

Consumer Use

The major consumer use processes are home laundry (wash, dry, hot water heating) and detergent manufacture. For this study, new research was conducted in the areas of washing temperature, load size, and dryer time. For load size and dryer time, the data gathered indicated much variability based on operator preferences /habits. Because these operations have such a large contribution to this life cycle analysis study, it is suggested that additional research be conducted to better document data in these areas.

Blouse Disposal Options

As will be discussed in detail later in this chapter, discarded textile products are often reused or recycled. However, documented data sources identifying the quantities of apparel products diverted from the waste stream do not exist. This analysis chose to focus on manufacturing and consumer use and consequently, did not evaluate options other than landfilling and combustion. A more in-depth analysis of waste management options may be useful in attempting to identify alternative uses for waste apparel products.

RELIABILITY OF RESULTS

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 easily to standard error analysis techniques. However, the reliability of the study can be assessed in other ways.

An important consideration is whether the conclusions are correct. For example, a specific conclusion depends on the accuracy of the numbers that were combined to arrive at that conclusion. There are several subsystems in the blouse system, so there are several numbers added together to arrive at the total values. Each number by itself contributes little to the total, so the accuracy of each number by itself has a small impact on the overall accuracy of the total. The best available numbers have been used in this study; however, there is no analytical method for assessing the accuracy of each number to any degree of confidence. In many cases, plant personnel reported actual plant data. The data reported may represent operations for the previous year or may be representative of the upcoming year. All data are scrutinized when they are received to evaluate whether or not they are representative of the type of operation or process being evaluated. The data used in this report are the best which can be found at this time.

There are several other important points with regard to data accuracy. 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 subprocesses that make a larger than average contribution to the total, special care is taken with the data quality.

REPA data are not amenable to standard statistical analysis. Appendix I presents approximate rules for judging whether conclusions can or cannot be reached using REPA results, based upon our knowledge of error and variability of the data. The rule suggested is that if system totals of energy or postconsumer solid waste (by weight) for two product systems differ by 10 percent or more, we are 95 percent confident that the difference is significant. By this we mean that if other LCA practitioners performed this study using the same methodology and sampled the same populations, we are 95 percent confident that they would arrive at the same conclusion. However, the error and variability of other emission data (industrial solid waste, atmospheric emissions and waterborne wastes) is much greater, suggesting that significant differences exist only if the differences exceed 25 percent.

There is another dimension to the reliability of the data. Certain numbers do not stand alone, but rather affect several numbers in the system. An example is the weight of the garment. This number is multiplied by every number related to a change in the garment weight. Consequently, a change in garment weight could cause very different results for this study.

Another issue is the variability of common practice. This study reports average, or typical, behavior and therefore does not apply to individual actions that deviate from the norm. Also, a particular set of material

suppliers was used to provide data for this study. If a different set of suppliers is used to develop the average data, the average data might vary enough to affect the results of the report.
In summary, for the particular data sources used and for the specific methodology described in this report, the reliability of the results of this report is good. However, using this study to make decisions in specific cases which may differ significantly from those described here may lead to erroneous conclusions.

ENERGY REQUIREMENTS

The average energy requirements for each industrial process are first quantified in terms of fuel or electricity units such as cubic feet of natural gas, gallons of diesel fuel, or kilowatt-hours (kwh) of electricity. Transportation requirements are developed in the conventional units of ton-miles by each transport mode (e.g. truck, rail, barge, etc.). Statistical data for the average efficiency of each transportation mode are used to convert from ton-miles to fuel consumption. The data for these conversions are presented in Appendix A of this report.
Once the fuel consumption for each industrial process and transportation step is quantified, the fuel units are converted to Btu using the conversion factors shown in Appendix A. These conversion factors have been developed to account for the energy required to extract, transport, and process the fuels and to account for the energy content of the fuels. The energy to extract, transport, and process fuels into a usable form is labeled precombustion energy. For electricity, precombustion energy calculations include adjustments for the average efficiency of conversion of fuel to electricity, and for transmission losses in power lines.
The REPA methodology assigns raw materials that are derived from fossil fuels with the fuel-energy equivalent. Therefore, the total energy requirement for coal, natural gas, or petroleum-based raw materials includes the fuel energy of the material (called energy of material resource or inherent energy). For example, this energy allocation would be applied to plastics of which natural gas and petroleum are the primary material resources. No fuel-energy equivalent is assigned to combustible materials, such as wood, that are not major fuel sources in this country.
The Btu values for fuels and electricity consumed in each industrial process are summed and categorized into an energy profile according to the six basic energy sources listed below:

- Natural gas
- Petroleum
- Coal
- Hydropower
- Nuclear
- Wood-derived (self-generated power in pulp mills)

Also included in the systems energy profile are the Btu values for an transportation steps and all fossil fuel-derived raw materials.

ENVIRONMENTAL EMISSIONS

Environmental emissions include air releases, solid wastes, and waterborne wastes. Through the various data sources identified earlier, every effort is made to obtain actual industry data. Emission standards are often used as a guide when operating data are not available.
The scope of this analysis is to identify where and what wastes 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 emissions.

Atmospheric Emissions

These emissions include all state and federally regulated substances reported from the individual facility. Emissions are reported as pounds of emission per unit of product output. 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. Some of the most commonly reported atmospheric emissions are particulates, nitrogen oxides, hydrocarbons, sulfur oxides, and carbon monoxide. Carbon dioxide emissions were not quantified in this study.

Waterborne Wastes

As with atmospheric emissions, waterborne wastes include all state and federally regulated substances reported from the individual facility. Waterborne wastes are reported as pounds of effluent per unit of product output. The values reported are the average quantity of effluents still present in the wastewater stream after wastewater treatment, and represent discharges into receiving waters. Some of the most commonly reported waterborne wastes are biological oxygen demand (BOD), chemical oxygen demand (COD), suspended solids, dissolved solids, iron, chromium, acid, and ammonia.

Solid Wastes

This category includes solid wastes generated from all sources that are landfilled or disposed in some other way. This also includes materials that are burned to ash at combustion facilities. It does not include materials that are recycled. When a product is evaluated on an environmental basis, attention is often focused on postconsumer wastes. Industrial wastes generated during the manufacture of the product are sometimes overlooked. It is important to examine both industrial and postconsumer wastes. Industrial solid wastes include wastewater treatment sludges, solids collected in air pollution control devices, trim or waste materials from manufacturing operations that are not recycled, fuel combustion residues such as the ash generated by burning coal or wood, and mineral extraction wastes. Postconsumer solid wastes are the blouses and packaging materials that are disposed by consumers after they have fulfilled their use. The blouses and secondary packaging materials become postconsumer wastes if they are not recycled or composted.

GENERAL DECISIONS

Some general decisions are always necessary to limit a study such as this to a reasonable scope. It is important to know what those decisions are. The principal decisions and limitations for this study are discussed in the following sections.

Data Sources

The primary data sources utilized in this study were discussed previously in this chapter. When data are obtained from many sources, it is important to critically review the sources and content of the information prior to using it. In some cases, past experience provides a basis for data evaluation to determine the reasonableness of content. Franklin Associates believes that the data used in this study are both accurate and representative of typical conditions for each industry.

Geographic Scope

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

Precombustion Energy and Emissions

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

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

Electricity

In general, detailed data do not exist on the fuels used to generate the electricity consumed by each industry. Therefore, the national average fuel consumption by electrical utilities is used for most industries. Appendix A (separate document) describes in detail the development of the electrical energy conversion values used in this study.

Postconsumer Waste Combustion

Except for materials that are recycled or reused, postconsumer waste in the United States is normally either landfilled or burned. Based on the national average, approximately 16 percent of postconsumer municipal solid waste, after recycling and reuse, is burned in a combustion facility with the released energy recovered. The energy released from the combustion of those postconsumer materials not recycled or landfilled is considered an energy credit and is subtracted from the total energy requirements of the system. Postconsumer solid waste also results from postconsumer materials being burned in municipal solid waste (MSW) combustion facilities. The resultant postconsumer solid waste is in the form of ash from the burned materials. No atmospheric emissions are included with the combustion of the solid waste because no data currently exist detailing the emissions produced from burning specific products such as PET blouses.

Reuse and Recycling

After the original consumer has discarded an apparel item, several forms of reuse or recycling can occur. The product could be landfilled, worn again by another consumer, used as a rag, or converted into another product (such as filling or stuffing). The polyester product could also be collected and recycled into another polyester product. Very little documented statistical data exist on the current reuse and recycling of apparel products. Consequently, and in keeping with the primary goal of this project to orient AFMA member companies with the life cycle concept, this research project only considers the disposal of apparel products. While apparel can be and is often diverted from the waste stream, the authors of this study decided to focus the analysis upon manufacturing and consumer use.

System Components Not Included

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

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

Space Conditioning. The fuels and power consumed to heat, cool, and light manufacturing establishments are omitted from the calculations in most cases. For 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 have not been included in this analysis.

Miscellaneous Materials and Additives. Selected materials such as catalysts, pigments, or other additives which total less than one percent of the net process inputs are not included in the analysis. Omitting such factors helps keep the scope of the study focused and manageable within limited budget and time constraint.

Chapter Two - ENERGY AND ENVIRONMENTAL RESULTS

INTRODUCTION

This chapter provides a detailed summary of energy requirements and environmental emissions for a woman's knit polyester blouse. The results were developed using a REPA analysis. Results are reported on an equivalent basis of one million wearings of blouses. The analysis considers all primary and secondary packaging components in each part of the system as well as the laundering of blouses. At the end of the chapter, the results of manufacturing one polyester blouse is discussed in detail.

SYSTEM DESCRIPTION

In this study, the term "system" refers to the woman's knit polyester blouse and all secondary packaging required to deliver the blouse to the user. This analysis includes, in addition to manufacture of all components from raw materials, transportation of materials and products between each processing step, laundering, and disposition of the blouse.

The basis for this study is one million wearings of polyester blouses. It is assumed that each blouse is worn 40 times before being disposed. Also, it is assumed each blouse is worn twice before it is washed. In practice, many blouses are laundered after each wearing. If blouses are assumed to be laundered after each wearing, the energy and emissions for laundering would be twice as great as reported here.

All disposed blouses are assumed to be landfilled, with 16 percent of the postconsumer solid waste combusted with energy recovery. Reuse of blouses (e.g. through donation to a charity or use as rags) is not evaluated in this report.

Table 2-1 displays the component weight data for one knit polyester blouse and the secondary packaging required to deliver the blouses to the retailer. From a survey of retail stores, it was found that numerous ways of packaging blouses are used. The only secondary packaging included in this study is for transporting the apparel from the garment manufacture to the retailer. For this operation, a corrugated shipping is typically used. This shipping box is assumed to hold 50 blouses and weigh 2.0 pounds empty. This study did not include packaging required to take the blouse from the retailer to the consumer's home.

RESULTS AND DISCUSSION

Tables 2-2 through 2-7 describe the results of this complete REPA analysis. Tables 2-2 through 2-4 report the energy requirements for the system, organized in various formats. Tables 2-5 through 2-7 contain data on solid waste generation, atmospheric emissions and waterborne wastes, respectively. At the end of the chapter, Tables 2-8 through 2-10 show the energy requirements, solid waste, and atmospheric and waterborne releases for the manufacture of one blouse.

Table 2-1

WEIGHT OF ONE WOMAN'S KNIT POLYESTER BLOUSE AND PACKAGING

	Weight per blouse
Knit polyester fiber	.119 pounds
Dye	.004 pounds
Corrugated Shipper (includes wood packaging)	.0456 pounds
Plastic	.0005 pounds

Source:Franklin Associates, Ltd.

In the discussion of results that follows, two energy values win not be considered significantly different if they are within 10 percent of each other. For solid waste volume, atmospheric emissions, and waterborne wastes, two totals will not be considered significantly different if they are within 25 percent of each other. The percent difference is defined as the difference between the two values divided by the average of the two values. A detailed discussion of the reliability of results can be found in Chapter 1.

Energy Requirements

Total Requirements. Table 2-2 shows the total and net energy for the system. Because 16 percent of postconsumer solid waste in the United States is combusted with energy recovery, an energy credit to the system is reported. Net energy requirements are determined by subtracting the energy credit from the total energy requirements. The energy credit reduces the total energy requirement for the system by less than one percent.

Categories of Energy. The total energy for each phase of the system disaggregated by process energy, transportation energy and energy of material resource is shown in Table 2-3. The energy of material resource is the fuel value of the crude oil and natural gas feedstocks used as raw materials (see Chapter 1 for additional explanation).

For all phases, the transportation energy comprises less than one percent of the total energy required by the system. The energy of material resource is less than one percent for every step except PET resin manufacture. Energy of material resource requires almost half of the energy for the resin manufacture step with the other half needed as process energy. Energy of material resource for PET resin manufacture is approximately four percent of the total system energy.

Table 2-2

TOTAL AND NET ENERGY REQUIREMENTS FOR 1,000,000 WEARINGS OF POLYESTER BLOUSES

	Million Btu
Total Energy Requirements	1,607.4
Energy Credit from Combustion	6.0
Net Energy Requirements	1,601.4

Source:Franklin Associates, Ltd.

Approximately 80 percent of the total system energy is process energy for laundering the blouses. This comes primarily from the heating of water for the washing machine. Seven percent of the total energy is process energy for fabric manufacturing. The resin manufacturing process uses four percent of the total energy. The process energy for all other phases in this system is approximately one percent or less of the total energy. Only a very small percentage of the overall energy consumption is required for postconsumer disposal.

Energy Sources. Table 2-4 shows energy categorized by the fuel source for each phase of the polyester blouse system. The quantity of energy used by each phase of the system for electricity generation, process energy, transportation of materials and products, and fuel-based raw materials is listed by the types of fuel resources used to provide that energy.

The primary fuels used for energy in each phase of the polyester blouse system are natural gas and coal. This is because the laundering equipment (washers, dryers, and water heaters) is fueled by either natural gas or electricity. Coal is used to generate more than 50 percent of the electricity used in the United States; therefore, high electricity use translates into high coal use. Petroleum use is the largest energy source for the PET resin manufacture. This is due to the energy of material resource requirement that is included in this phase. Use of wood for fuel is small and is associated only with the production of the paper-based secondary packaging.

Table 2-3
ENERGY REQUIREMENTS FOR 1,000,000 WEARINGS OF POLYESTER BLOUSES

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	mil Btu	% of total	mil Btu	% of total	mil Btu	% of total	mil Btu	% of total
PET Resin Manufacture	64.0	4.0	1.5	0.1	58.6	3.6	124.1	7.7
PET Fiber								
Manufacture	17.2	1.1	1.1	0.1	0.2	0.0	18.5	1.2
Packaging	1.4	0.1	0.0	0.0	0.2	0.0	1.6	0.1
Dye Manufacture	5.0	3.0	0.1	0.0	-	-	5.2	0.3
Fabric								
Manufacture	110.4	6.9	0.7	0.0	-	-	111.0	6.9
Packaging	1.9	0.1	0.1	0.0	0.1	0.0	2.0	0.1
Apparel								
Production	0.8	0.1	9.7	0.6	-	-	10.6	0.7
Packaging	19.7	1.2	0.5	0.0	-	-	20.2	1.3
Detergent								
Manufacture	21.1	1.3	2.2	0.1	6.5	0.4	29.7	1.8
Packaging	10.0	0.6	0.3	0.0	0.5	0.0	10.8	0.7
Laundry	1,273.0	0.0	-	-	-	-	1,273.0	79.2
Postconsumer Disposal	-	-	0.8	0.0	-	-	0.6	0.0
Total	**1,524.4**	**94.8**	**16.9**	**1.1**	**66.1**	**4.1**	**1,607.4**	**100.0**

Source: Franklin Associates, Ltd.

Table 2-4
ENERGY PROFILE FOR 1,000,000 WEARINGS OF POLYESTER BLOUSES (million Btu)

	Total Energy	Natural Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Energy Credit from Combustion	Net Energy
PET Resin Manufacture	124.1	38.9	64.3	13.8	2.3	4.7	-	0.1		
PET Fiber										
Manufacture	18.5	1.8	2.4	9.3	1.6	3.3	-	0.1		
Packaging	1.6	0.4	0.1	0.4	0.0	0.1	0.5	0.0		
Dye Manufacture	5.2	1.3	1.1	1.8	0.3	0.6	-	0.0		
Fabric										
Manufacture	111.0	15.2	49.3	29.9	5.4	11.1		0.2		
Packaging	2.0	0.4	0.2	0.5	0.0	0.1	0.8	0.0		
Apparel										
Production	10.6	0.1	9.8	0.5	0.1	0.2	-	0.0		
Packaging	20.2	2.9	1.5	5.2	0.5	1.0	9.1	0.0		
Detergent										
Manufacture	29.7	17.6	9.4	1.8	0.3	0.6	-	0.0		
Packaging	10.8	1.9	0.9	2.5	0.2	0.5	4.7	0.0		
Laundry	1,273.0	399.5	40.2	535.3	96.2	198.2	-	3.7		
Postconsumer Disposal	0.8	-	0.8	-	-	-	-	-		
Total	**1,607.4**	**480.0**	**179.9**	**601.0**	**107.0**	**220.4**	**15.2**	**4.1**	**6.0**	**1,601.4**

Source: Franklin Associates Ltd.

Solid Waste

Table 2-5 shows the total solid wastes for the system. The totals are disaggregated into industrial process wastes, industrial fuel-related wastes and postconsumer wastes. Solid wastes are reported by both weight and volume for each phase of the system. Weight-to-volume conversions for apparel are based on actual landfill measurements made at the University of Arizona under test conditions simulating landfill conditions. The landfill density factor used for apparel is 435 pounds per cubic yard. Several important observations can be drawn from the solid waste data in Table 2-5.

General Comments

- 65 percent of the total solid waste by volume is from the laundering phase of the system (predominantly from the burning of fuels)
- Postconsumer disposal of blouses contributes 10 percent by volume to the total solid waste generation
- Fabric manufacture and apparel packaging each account for approximately three percent of the total solid waste
- The remaining phases account for less than two percent each of the total weight and volume
- The industrial waste for this system accounts for 62 percent of the total volume of solid waste, while postconsumer waste account for the remaining 38 percent.

Production

- Over 95 percent of all industrial waste is from the generation of fuels

* • Less than five percent of industrial waste is process waste.

Consumer Use

- 63 percent by volume of the total postconsumer solid waste is from discarded blouses
- 26 percent of the postconsumer solid waste is from wastewater sludges from the laundry operation
- Packaging for the blouses and primary packaging for the detergent generate the remainder of the postconsumer solid waste.

Atmospheric Emissions and Waterborne Wastes

Air and water emissions are presented in Table 2-6 by specific emission. Large amounts of particulates, nitrogen oxides, hydrocarbons, sulfur oxides, and carbon monoxide are released as atmospheric emissions. These emissions are mostly fuel-related. The largest categories of waterborne effluents are dissolved solids, BOD, COD, acid, metal ions, oil, phosphates, iron, and suspended solids. Except for add, metal ions, and iron, these emissions are primarily process-related. All emission amounts reported reflect discharges after control or treatment measures.

Table 2-5
SOLID WASTES FOR 1,000,000 WEARINGS OF POLYESTER BLOUSES

	Industrial									
	Process Wastes		Fuel Wastes		Total Ind. Wastes		Postconsumer Wastes		Total Wastes	
	(lb)	(cu lb)	(lb)	(cu lb)	(lb)	(cu lb)	(lb)	(cu lb)	(lb)	(cu lb)
PET Resin Manufacture	29.9	0.6	448.8	9.0	478.7	9.6	-	-	478.7	9.6
PET Fiber										
Manufacture	25.0	1.5	288.0	5.8	313.0	7.3	-	-	313.0	7.3
Packaging	4.1	0.1	13.6	0.3	17.7	0.4	-	-	17.7	0.4
Dye Manufacture	15.3	0.3	56.8	1.1	72.1	1.4	-	-	72.1	1.4
Fabric										
Manufacture	30.3	1.9	950.7	19.0	981.0	20.9	-	-	981.0	20.9
Packaging	6.3	0.4	18.6	0.4	24.9	0.8	-	-	24.9	0.8
Apparel										
Production	30.0	1.9	16.4	0.3	46.4	2.2	-	-	46.4	2.2
Packaging	69.2	1.4	198.4	4.0	267.5	5.4	422.6	15.1	690.1	20.5
Detergent										
Manufacture	231.6	4.6	78.2	1.6	309.7	6.2	-	-	309.7	6.2
Packaging	30.6	1.9	98.5	2.0	129.1	3.9	349.1	13.2	478.2	17.1
Laundry	-	-	17,005.1	340. 1	17,005.1	340.1	3,250.0	65.0	20,255.1	405.1
Postconsumer Disposal	-	-	0.2	0.0	0.2	0.0	2,511.0	155.9	2,511.2	155.9
Total	**472.3**	**14.6**	**19,173.1**	**383.5**	**19,645.4**	**398.0**	**6,532.7**	**249.2**	**26,178.1**	**647.3**

Source: Franklin Associates, Ltd.

Table 2-6
SUMMARY OF ENVIRONMENTAL EMISSIONS FOR1,000,000 WEARINGS OF POLYESTER BLOUSES

	Process Pollutants	Fuel Related Pollutants	Total Pollutants
Atmospheric (lb)			
Particulates	20.75	525	545
Nitrogen Oxides	5.14	915	920
Hydrocarbons	82.11	469	551
Sulfur Oxides	14.35	1,377	1,391
Carbon Monoxide	44.47	272	317
Aldehydes	1.90	2.52	4.42
Methane	-	1.89	1.89
Other Organics	13.74	10.09	23.83
Odorous Sulfur	0.098	-	0.098
Kerosene	-	0.046	0.046
Ammonia	0.052	0.31	0.37
Hydrogen Fluoride	0.017	-	0.017
Antimony	3.6E-06	-	3.6E-06
Lead	0.019	0.0024	0.021
Mercury	5.3E-05	-	5.3E-05
Chlorine	0.82	-	0.82
Acetaldehyde	0.060	-	0.060
1,4-dioxane	0.0030	-	0.0030
Ethylene Glycol	0.060	-	0.060
Dowtherm	0.060	-	0.060
Sulfuric Acid	3.0E-05	-	3.0E-05
Waterborne (lb)	–	–	
Acid	0.59	112	112
Metal Ion	-	27.99	27.99
Fluorides	8.5E-04	-	8.5E-04
Dissolved Solids	3,399	146	3,545
Suspended Solids	79.94	0.47	80.42
BOD	338	0.31	338
COD	550	0.87	551
Phenol	0.010	0.079	0.089
Sulfides	0.062	0.079	0.14
Oil	13.41	0.16	13.56
Sulfuric Acid	–	0.97	0.97
Iron	–	83.15	83.15
Cyanide	–	–	–
Alkalinity	0.43	–	0.43
Chromium	0.013	–	0.013
Aluminum	–	–	–
Nickel	–	–	–
Mercury	3.0E-07	–	3.0E-07
Lead	–	–	–
Phosphates	57.51	–	57.51
Phosphorus	–	–	–
Nitrogen	0.027	–	0.027
Zinc	–	–	–
Ammonia	1.73	–	1.73
Pesticides	1.1E-04	–	1.1E-04
Other Chemicals	0.39	–	0.39
Herbicides	2.3E-04	–	2.3E-04

Source: Franklin Associates, Ltd.

Table 2-7 displays the atmospheric emissions and waterborne wastes for each phase of the polyester blouse system. Consistent with energy and solid waste results, laundering the blouses is also the main source of emissions. Particulates, nitrogen oxides, hydrocarbons, sulfur oxides, and carbon monoxide are the main emissions in this phase. Fabric manufacture and PET resin manufacture have higher amounts of most of the atmospheric emissions than the other process steps. These are still very small compared to laundering.

As with the atmospheric emissions, the largest amount of waterborne effluents results from laundering. The main waterborne effluents in laundering include dissolved solids, BOD, COD, add, iron, and suspended solids. These effluents result from the generation of the electricity used to run the washer, dryer, and hot water heaters. PET resin manufacture, fabric manufacture, and apparel manufacture contribute significant amounts of certain waterborne effluents, but these are still very small compared to the laundering.

Summary of Results for Manufacturing One Polyester Blouse

The energy requirements for manufacturing one blouse are found in Table 2-8. Most of this energy is split between the PET resin manufacture and the fabric manufacture. All other steps use less than seven percent of the total energy. Seventy-five percent of the total energy required is process energy, while inherent energy accounts for 20 percent and transportation energy uses 5 percent.

Table 2-9 contains the solid waste for manufacturing one blouse. By weight or volume, the fabric manufacture clearly produces more solid waste than any other process step at 44 percent of the total. The PET resin manufacture generates approximately 20 percent of the total solid waste by weight or volume. The PET fiber manufacturing and the packaging for the apparel also produce significant amounts.

The atmospheric emissions and waterborne effluents are displayed in Table 2-10. Although the laundering process has been deleted, the main atmospheric emissions are still particulates, nitrogen oxides, hydrocarbons, sulfur oxides, and carbon monoxide. The releases are mainly from the PET resin manufacture and the fabric manufacture. The waterborne effluent is composed mostly of dissolved solids, suspended solids, COD, and alkalinity. Most of these effluents are produced by the fabric manufacturing step. The PET resin manufacture releases over 50 percent of the dissolved solids, and the apparel manufacture produces all of the alkalinity.

Table 2-7
ENVIRONMENTAL EMISSIONS BY COMPONENT FOR 1,000,000 WEARINGS OF POLYESTER BLOUSES

	PET Resin Mfg	**Fiber**		**Dye Mfg**	**Fabric**		**Apparel**		**Detergent**		**Laundry**	**Postconsumer Disposal**	**Total**
Atmospheric (lb)		Mfg	Packaging		Mfg	Packaging	Production	Packaging	Mfg	Packaging			
Particulates	14.76	14.00	0.66	2.06	27.36	0.95	2.40	10.31	10.95	4.83	457	0.34	545
Nitrogen Oxides	34.80	12.78	0.76	2.99	56.24	1.00	14.99	10.52	11.54	5.29	768	1.60	920
Hydrocarbons	101	2.93	0.60	1.37	33.86	0.52	5.52	4.37	18.62	2.81	379	0.50	551
Sulfur Oxides	51.25	21.31	0.92	5.98	87.75	1.25	5.03	13.25	5.42	6.50	1,192	0.31	1,391
Carbon Monoxide	48.09	3.99	1.94	0.84	14.52	2.92	13.09	31.98	3.54	16.48	178	1.43	317
Carbon Dioxide	8,500	2,200	220	640	14,000	310	1,500	3,300	2,800	1,700	150,000	110	185,280
Aldehydes	1.83	0.13	0.064	0.0082	0.14	0.098	0.35	1.08	0.053	0.56	0.092	0.027	4.42
Methane	0.074	0.015	0.0011	0.0044	0.0088	0.0014	7.2E-04	0.014	0.048	0.0069	1.64	-	1.89
Other Organics	13.62	0.76	0.026	0.060	0.57	0.038	6.89	0.41	0.21	0.21	0.12	0.86	23.83
Odorous Sulfur			0.0033			0.0050		0.055	0.0085	0.027			0.098
Kerosene	9.8E-04	6.6E-04	1.6E-05	1.3E-04	0.0023	2.0E-05	3.5E-05	2.1E-04	1.3E-04	1.0E-04	0.041		0.046
Ammonia	0.096	0.0052	3.1E-04	0.0043	0.12	3.9E-04	0.024	0.0040	0.017	0.0021	0.092	0.0018	0.37
Hydrogen Fluoride									0.017				0.017
Antimony	3.6E-06												3.6E-06
Lead	4.3E-04	3.8E-05	6.8E-04	3.2E-05	9.0E-04	0.0010	1.8E-04	0.012	3.1E-05	0.0056	6.9E-04	1.4E-05	0.021
Mercury			2.3E-07	4.7E-05		3.5E-07		3.9E-06		1.9E-06			5.3E-05
Chlorine			0.0020	0.40		0.0031		0.034	0.36	0.016			0.82
Acetaldehyde	0.060												0.060
1,4-dioxane	0.0030												0.0030
Ethylene Glycol	0.060												0.060
Dowtherm	0.060												0.060
Sulfuric Acid	3.0E-05												3.0E-05
Waterborne (lb)													
Acid	2.57	1.73	0.069	0.81	5.62	0.093	0.098	0.99	0.34	0.48	99.59	9.2E-04	112
Metal Ion	0.65	0.43	0.016	0.085	1.42	0.022	0.027	0.23	0.084	0.11	24.91	4.6E-04	27.99
Fluorides									8.5E-04				8.5E-04
Dissolved Solids	40.14	1.53	0.14	1.01	26.98	0.16	4.81	1.52	127	0.84	3,341	0.37	3,545
Suspended Solids	2.14	0.0077	0.15	0.047	14.30	0.23	0.036	2.53	7.33	1.00	52.64	0.0028	80.42
BOD	1.54	0.035	0.092	0.018	8.97	0.14	0.024	1.51	0.11	0.55	325	0.0018	338
COD	22.08	0.10	0.0067	0.012	27.60	0.0035	0.065	0.17	0.37	0.011	500	0.0051	551
Phenol	0.015	0.0013	6.6E-05	0.0011	0.039	9.2E-05	0.0059	9.8E-04	0.0019	5.1E-04	0.023	4.6E-04	0.089
Sulfides	0.014	0.0013	6.2E-05	0.0011	0.091	8.6E-05	0.0059	9.2E-04	0.0023	4.1E-04	0.023	4.6E-04	0.14

Oil	0.39	0.0045	7.6E-04	0.0022	13.03	3.9E-04	0.0012	0.0019	0.070	0.0025	0.047	9.2E-04	13.56
Sulfuric Acid	0.021	0.015	3.5E-04	0.0027	0.049	4.3E-04	7.5E-04	0.0044	0.028	0.0021	0.87	7.9E-06	0.97
Iron	1.78	1.26	0.030	0.23	4.18	0.037		0.37	0.024	0.18	74.78		83.09
Cyanide													
Alkalinity							0.064		0.043				0.49
Chromium	0.0012	2.4E-06	4.6E-07		0.012	1.6E-07			8.9E-05	1.1E-06			0.013
Aluminum													
Nickel													
Mercury			1.3E-09	2.7E-07		2.0E-09		2.2E-08		1.0E-08			3.0E-07
Lead													
Phosphates			2.8E-04			4.3E-04		0.0047		8.1E-04	57.50		57.51
Phosphorus													
Nitrogen			0.0012			0.0019		0.0020		0.0035			0.027
Zinc													
Ammonia	1.73	1.5E-05	1.7E-05			2.2E-05		2.3E-04	4.1E-04	1.1E-04			1.73
Pesticides			5.1E-06			7.9E-06		8.7E-05		1.5E-05			1.1E-04
Other Chemicals	0.39												0.39
Herbicides			1.0E-05		1.6E-05		1.7E-04			2.9E-05			2.3E-04

Source Franklin Associates, Ltd.

Table 2-8

ENERGY REQUIREMENTS FOR THE MANUFACTURE OF ONE POLYESTER BLOUSE

	Process Energy		Transportation Energy		Energy of Material Resource		Total Energy	
	Btu	% of total	Btu	% of total	Btu	% of total	Btu	% of total
PET Resin Manufacture	2559.9	21.8	59.1	0.5	2343.6	20.0	4962.6	42.3
PET Fiber								
Manufacture	688.5	5.9	43.2	0.4	9.7	0.1	741.5	6.3
Packaging	54.3	0.5	1.6	0.0	8.4	0.1	64.3	0.5
Dye Manufacture	201.8	1.7	4.7	0.0			206.5	1.8
Fabric								
Manufacture	4,414.3	37.7	26.7	0.2			4441.0	37.9
Packaging	74.1	0.6	2.0	0.0	2.9	0.0	78.9	0.7
Apparel								
Production	33.2	0.3	389.0	3.3			422.2	3.6
Packaging	786.0	6.7	21.1	0.2			807.1	6.9
Total	**8,812.1**	**75.2**	**547.4**	**4.7**	**2364.6**	**20.2**	**11,724.2**	**100.0**

Source: Franklin Associates, Ltd.

Table 2-9

SOLID WASTES FOR THE MANUFACTURE OF ONE POLYESTER BLOUS

	Process Wastes		Fuel Wastes		Total Ind. Wastes		Postconsumer Wastes		Total Wastes	
	(lb)	(cu ft)	(lb)	(cu ft)	(lb)	(cu ft)	(lb)	(cu ft)	(lb)	(cu ft)
PET Resin Manufacture	1.2E-03	2.4E-05	0.018	3.6E-04	0.019	3.8E-04			0.019	3.8E-04
PET Fiber										
Manufacture	1.0E-03	6.2E-05	0.012	2.3E-04	0.013	2.9E-04			0.013	2.9E-04
Packaging	1.7E-04	3.3E-06	5.4E-04	1.1E-05	7.1E-04	1.4E-05			7.1E-04	1.4E-05
Dye Manufacture	6.1E-04	1.2E-05	2.3E-03	4.5E-05	2.9E-03	5.8E-05			2.9E-03	5.8E-05
Fabric										
Manufacture	1.2E-03	7.5E-05	0.038	7.6E-04	0.039	8.4E-04			0.039	8.4E-04
Packaging	2.5E-04	1.6E-05	7.5E-04	1.5E-05	1.0E-03	3.1E-05			1.0E-03	3.1E-05
Apparel										
Production	1.2E-03	7.4E-05	6.6E-04	1.3E-05	1.9E-03	8.8E-05			1.9E-03	8.8E-05
Packaging	2.8E-03	5.5E-05	7.9E-03	1.6E-04	0.011	2.1E-04			0.011	2.1E-04
Total	**8.4E-03**	**3.2E-04**	**0.080**	**0.002**	**0.088**	**0.002**			**1.9E-03**	**0.088**

Source: Franklin Associates, Ltd.

Table 2-10
ENVIRONMENTAL EMISSIONS BY COMPONENT FOR THE MANUFACTURE OF ONE POLYESTER BLOUSE

	PET Resin Mfg	**Fiber**		**Dye Mfg**	**Fabric**		**Apparel**		**Total**
		Manufacture	Packaging		Manufacture	Packaging	Production	Packaging	
Atmospheric (lb)									
Particulates	5.9E-04	5.6E-04	2.6E-05	8.2E-05	0.0011	3.8E-05	9.6E-05	4.1E-04	0.0029
Nitrogen Oxides	0.0014	5.1E-04	3.0E-05	1.2E-04	0.0022	4.0E-05	6.0E-04	4.2E-04	0.0054
Hydrocarbons	0.0040	1.2E-04	2.4E-05	5.5E-05	0.0014	2.1E-05	2.2E-04	1.8E-04	0.0060
Sulfur Oxides	0.0021	8.5E-04	3.7E-05	2.4E-04	0.0035	5.0E-05	2.0E-04	5.3E-04	0.0075
Carbon Monoxide	0.0019	1.6E-04	7.7E-05	3.4E-05	5.8E-04	1.2E-04	5.2E-04	0.0013	0.0047
Carbon Dioxide	0.34	0.088	0.0088	0.026	0.57	0.012	0.059	0.13	1.2
Aldehydes	7.3E-05	5.2E-06	2.6E-06	3.3E-07	5.7E-06	3.9E-06	1.4E-05	4.3E-05	1.3E-04
Methane	2.9E-06	6.1E-07	4.6E-08	1.7E-07	3.5E-05	5.4E-08	2.9E-06	5.5E-07	7.9E-06
Other Organics	5.5E-04	3.1E-05	1.1E-06	2.4E-06	2.3E-05	1.5E-06	2.8E-04	1.7E-05	9.0E-04
Odorous Sulfur			1.3E-07			2.0E-07		2.2E-06	2.5E-06
Kerosene	3.9E-08	2.8E-08	6.5E-10	5.0E-09	9.2E-08	8.1E-10	1.4E-09	8.2E-09	1.7E-07
Ammonia	3.8E-06	2.1E-07	1.5E-08	1.7E-07	4.8E-06	1.6E-08	9.5E-07	1.6E-07	1.0E-05
Hydrogen Fluoride									
Antimony	1.4E-10								1.4E-10
Lead	1.7E-08	1.5E-09	2.7E-08	1.3E-09	3.6E-08	4.2E-08	7.1E-09	4.6E-07	5.9E-07
Mercury			9.2E-12	1.9E-09		1.4E-11		1.5E-10	2.0E-09
Chlorine			8.2E-08	1.6E-05		1.2E-07		1.4E-06	1.8E-05
Acetaldehyde	2.4E-06								2.4E-06

1,4-dioxane	1.2E-07								1.2E-07
Ethylene Glycol	2.4E-06								2.4E-06
Dowtherm	2.4E-06								2.4E-06
Sulfuric Acid	1.2E-09								1.2E-09
Waterborne (lb)									
Acid	1.0E-04	6.9E-05	2.7E-06	3.3E-05	2.2E-04	3.7E-06	3.9E-06	3.9E-05	4.8E-04
Metal Ion	2.6E-05	1.7E-05	6.4E-07	3.4E-06	5.7E-05	8.7E-07	1.1E-06	9.2E-06	1.2E-04
Fluorides									
Dissolved Solids	0.0016	6.1E-05	5.8E-06	4.1E-05	0.0011	6.3E-06	1.9E-04	6.1E-05	0.0031
Suspended Solids	8.6E-05	3.1E-07	6.1E-06	1.9E-06	5.7E-04	9.2E-06	1.4E-06	1.0E-04	7.8E-04
BOD	6.1E-05	1.4E-06	3.7E-06	7.2E-07	3.6E-04	5.5E-06	9.5E-07	6.0E-05	4.9E-04
COD	8.8E-04	4.2E-06	2.7E-07	4.7E-07	0.0011	1.4E-07	2.6E-06	6.7E-07	0.0020
Phenol	5.8E-07	5.0E-08	2.6E-09	4.3E-08	1.6E-06	3.7E-09	2.4E-07	3.9E-06	2.5E-06
Sulfides	5.8E-07	5.0E-08	2.5E-09	4.3E-08	3.6E-06	3.5E-09	2.4E-07	3.7E-06	4.6E-06
Oil	1.6E-05	1.8E-07	3.1E-08	8.6E-08	5.2E-04	1.6E-06	4.7E-07	7.4E06	5.4E-04
Sulfuric Acid	8.3E-07	5.9E-07	1.4E-08	1.1E-07	1.9E-06	1.7E-08	3.0E-06	1.8E-07	3.7E-06
Iron	7.1E-05	5.0E-05	1.2E-06	9.2E-06	1.7E-04	1.5E-06	2.6E-06	1.5E-05	3.2E-04
Cyanide									
Alkalinity							0.064		0.064
Chromium	4.9E-08	9.5E-11	1.8E-11		4.8E-07	6.2E-12			5.3E-07
Aluminum									
Nickel									
Mercury			5.3E-14	1.1E-11		8.0E-14		8.9E-13	1.2E-11
Lead									
Phosphates			1.1E-08			1.7E-08		1.9E-07	2.2E-07
Phosphorus									
Nitrogen			4.9E-08			7.4E-08		8.2E-07	9.4E-07
Zinc									
Ammonia	6.9E-05	6.2E-10	6.7E-10			8.8E-10		9.3E-09	6.9E-05
Pesticides			2.1E-10			3.1E-10		3.5E-09	4.0E-09
Other Chemicals	1.6E-05								1.6E-05
Herbicides			4.1E-10			6.3E-10		6.9E-09	8.0E-09

Source: Franklin Associates, Ltd.

Chapter 3 SENSITIVITY ANALYSIS OF LAUNDERING OPERATIONS

OVERVIEW

The consumer use aspect of this analysis proved to be one of the largest impacts from a life cycle perspective. Consumer use accounted for 82 percent of the total energy requirements and 66 percent of the solid waste volume created. The two operations included in the consumer use category are laundering (washer, dryer, and water heater) and detergent manufacture. Of the two operations, the laundering process dwarfs the detergent manufacturing in terms of both energy consumption and environmental releases.
This chapter focuses on both defining the impacts from the baseline laundering operations as well as investigates several variations to the laundering assumptions. The first section discusses the baseline laundering operation, while energy comparisons for the various sensitivity analyses are discussed later in the chapter.

BASELINE LAUNDERING DATA

Table 3-1 describes the energy requirements and environmental emissions associated with the home laundering process. The data in this table indicate impacts per one wash load. The data are described in terms of source: washer, dryer, and water heater. Assumptions associated with these operations include a warm wash cycle and all products being machine dried for 15 minutes.
As Table 3-1 indicates, electricity usage occurs at all three operations with most of the electricity being consumed by drying and water heating operations. The only process-related laundering waste is from waste-water being discharged from the washing operation (producing both solid and waterborne process wastes). As indicated in Table 3-2, fuel-related emissions from the generation of power are associated with each operation.

LAUNDERING SENSITIVITY ANALYSES

In addition to the baseline laundering analysis performed for this study, several sensitivity analyses including various laundering operations were also performed. The changes in energy consumption for each of these variations is described in Table 3-2.

Wash Temperature

The baseline wash temperature assumption used in this study was a warm wash cycle (approximately 94*F) and a cold rinse cycle. Two variations of this assumption were analyzed. The first variation substituted a cold wash cycle for the warm wash cycle. The second variation reflected changing the wash temperature 10 degrees. As Table 3-2 indicates, the only operation that these changes affected was the water heater. The use of a cold wash cycle eliminated the need for heating of water and resulted in an overall reduction in laundering energy consumption by over 60 percent. Changing the wash water temperature by 10 degrees resulted in approximately a 14 percent change in overall laundering energy needs. Similar changes in fuel-related air, water, and solid waste emissions would also be expected.

Table 3-1
DATA FOR ONE LAUNDRY LOAD

	Washer	Dryer	Water Heater
ENERGY			
Electricity (kwh)	0.35	1.42	1.84
Natural Gas (cu. ft.)	-	0.46	10.26
SOLID WASTE (cu. ft.)			
Process	0.0030	-	-
Fuel-Related	0.0013	0.0052	0.0071
AIR EMISSIONS (pounds fuel-related)			
Particulates	0.0018	0.0072	0.0094
Nitrogen Oxides	0.0025	0.010	0.018

Hydrocarbons	4.3E-04	0.0022	0.013
Sulfur Oxides	0.0046	0.019	0.024
Carbon Monoxide	5AE-04	0.0023	0.0043
Aldehydes	3.6E-07	1.5E-06	1.9E-06
Methane	3.2E-06	1.5E-05	4.8E-05
Other Organics	4.5E-07	1.SE-06	2AE-06
Kerosene	1.6E-07	6.5E-07	8AE-07
Anunonia	3.6E-07	1.5E-06	1.9E-06
Lead	2.7E-09	LIE-08	1AE-08
WATERBORNE EMISSIONS (pounds) (process)			
Dissolved Solids	0.13	-	-
Suspended Solids	0.0021	-	--
BOD	0.013	-	-
COD	0.020	-	-
Phosphates(fuel-related)	0.0023	-	-
Acid	3.9E-04	0.0016	0.0020
Metal Ion	9.7E-05	3.9E-04	5.1E-0-4
Dissolved Solids	1AE-04	6.8E-04	0.0028
Suspended Solids	5.5E-07	2.2E-06	2.9E-06
BOD	3.6E-07	1.5E-06	1.9E-06
COD	I.0E-06	4JE-06	5.3E-06
Phenol	9.1E-08	3.7E-07	4.8E-07
Sulfide	9.1E-08	3.7E-07	4.8E-07
Oil	1.8E-07	7AE-07	9.6E-07
Sulfuric Acid	3AE-06	1AE-05	1.8E-05
Iron	2.9E-04	0.0012	0.0015

Source: Franklin Associates, Ltd. 3-2

Table 3-2
ENERGY REQUIREMENTS FOR VARIOUS SENSITIVITY ANALYSES

	Baseline Case One Load Per 1MM Wearings(25,000 loads)		**Changes in Wash Water Temperature**		**Changes In Machine Dryer Use**	
Assumptions						
Wash Temp.	Warm (94°)	Warm (94°)	Cold	+/- 10°	n/c	n/c
Dryer Time	15 min.	15 min.	n/c	n/c	0 min. (e.g. line dry)	+/- 10 min.
Energy Consumption (mil btu)						
Washer	0.004	107.1	n/c	n/c	n/c	n/c
Dryer	0.016	387.9	n/c	n/c	-100.0%	66.7%
Water Heater	0.032	778.0	-100.0%	22.3%	n/c	n/c
Total	0.051	1,273.0	-61.9%	13.8%	-30.8%	20.5%

Note: Values below indicate percent change from baseline data
Note: n/c indicates that no change occured from baseline values.
Source: Franklin Associates, Ltd.

Machine Dryer Use

The baseline assumption for this analysis was that all laundered blouses would be dried in mechanical dryers for a period of 15 minutes. Two variations of this assumption are examined in Table 3-2. The first variation assumes that all blouses are dried outside on a line. The second variation changes the required drying time by 10 minutes. As indicated in Table 3-2, the elimination of mechanical drying reduces the overall laundering energy consumption by approximately 31 percent. A 10 minute variation in drying time accounts for nearly a 21 percent change in the overall laundering energy consumption. Because both of these variations involved changes in fuel consumption, similar changes in fuel-related emissions can also be expected.