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COMPARISON OF LIFE CYCLE IMPACTS OF JAWS SURFACE CLEANERS AND CONVENTIONAL SURFACE CLEANER BOTTLES

BY

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ABSTRACT

COMPARISON OF LIFE CYCLE IMPACTS OF JAWS SURFACE CLEANERS AND CONVENTIONAL SUFACE CLEANER BOTTLES

By

Sunil Bhutani

The life cycle impacts of JAWS surface cleaners were compared with the life cycle impacts of conventional surface cleaner bottles. The study compared the life cycle impacts of glass cleaners in conventional 32 oz. capacity PET spray bottles and glass cleaner in the JAWS (Just Add Water System) using refill cartridges. Averages of 10 fills and of 20 fills per bottle in the JAWS system were compared with standard non-refillable bottles. The package system compared included the primary package (bottle, sprayer, labels, etc.) and the distribution packaging (corrugated boxes, pallets, stretch wrap).

A modified life cycle approach was used to tabulate the inputs and outputs associated with the alternative package systems. All the data was obtained from published sources. The evaluation of life cycle impacts comprises both life cycle inventory information, which is simply a tabulation of the inputs and outputs associated with the package systems being compared, and an evaluation of selected environmental impacts of those inputs and outputs. Often, comparison of environmental costs and benefits of competitive package systems is difficult because tradeoffs are involved, with one system providing benefits in some areas, and the other system benefits in different areas. In this case, however analysis is simple. The JAWS system provides benefits across the board: in material use, energy use, energy consumption, greenhouse gas emissions, air pollutions, water pollutants, and solid waste.

To my brother (Munish Bhutani) and my friends (Ria and Pankaj)

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I am indebted to my family for their love and encouragement throughout my life. Such love from my parents, brother and sisters makes me one of the luckiest people on earth.

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1. Introduction

1.1. Packaging

For centuries, packaging has always been an essential need for human kind in its own way. In ancient times, people used bamboo baskets and animal skins to stock up their provisions. Though our ancestor's packaging styles were basic and not always sanitary, they were the predecessors of our current packaging and containers. The word "packaging" refers to the container or wrapper used to enclose or hold a product [1] and it is an essential part of the product supply chain. Packaging can be categorized in three different types: Primary, Secondary and Tertiary Packaging. [2]

1.1.1. Primary Packaging

Primary packaging is the material that is in direct contact with a product or products. It is the material that encloses the product and holds it. For example, a plastic bottle containing Coca-Cola™ drink is the primary packaging for a coca-cola drink.

1.1.2. Secondary Packaging

Secondary packaging is the material used to hold a number of primary packages together. It is outside of the primary packaging and does not come in contact with the product. For example, a box containing 6 bottles of Coca-Cola™ is the secondary packaging.

1.1.3. Tertiary Packaging

The packaging used to hold secondary packages during transportation or storage or bulk handling is called tertiary packaging. For example, a large pallet of shrink-wrapped boxes of Coca-Cola™ is called tertiary packaging.

1.2. Functions of packaging

For ages, packaging has had a significant relationship with product. There are a number of functions of packaging including the following four basic functions:

1.2.1. Containment

One of the basic functions of a package is to provide containment to a product. There are many physical forms of product like gas, liquid, powder, paste, granules etc. that cannot be transported without a package. Packaging makes a consumer's life easy when it comes to the usage of products. [3, 4]

1.2.2. Protection

Packaging should provide protection to the contents of the package from the atmosphere and vice versa. Most products, whether they are food, medicine or electronic, require protection from temperature and humidity, and packaging should serve well in providing protection from the environment. Packaging should also extend the shelf life of a product. Packaging should also protect the product from mechanical shock, vibration, crushing, piercing, tearing, and electrostatic discharge during transportation or handling. In the case of transportation of hazardous materials, where the safety of human beings is of prime concern, packaging must not only protect human beings but also prevent any contamination or damage of the environment and other substances. [3, 4]

1.2.3. Communication

The shapes of a package and its designing, labeling, and printing serves as a communication function of packaging. For example; a warning (fragile) sign on a package enclosing a glass product or a tracking barcode on a shipping box can easily communicate a message to the person who is holding/shipping the product. Designing and printing can be a major factor in terms of product sale and it can make the sale process more efficient. However, labeling, printing, etc should meet all the legal requirements. Important information printed on the packaging can provide a customer all the details about the product and its usage. [3, 4]

1.2.4. Convenience

Shape, weight and size of packaging can affect the performance or utility including stacking, ease of opening, safe handling, filling, sealing, etc. Packaging is one of the crucial factors when it comes to the efficiency of transport, handling and storage of goods, especially when the handling is to be entirely or partially manual. A package should be easy to open, close, reopen and store safely and appropriately. The design of a package should be in such a way that it may not only be held, lifted and stowed efficiently and safely, but also could lead to space-saving storage. [3, 4]

1.3. Life cycle assessment

Nowadays, modern packaging is not only about protection, storage, communication, ease of transport, sales, promotions, etc. but it must also have minimum impact on the environment. The environmental impact of a product does not start when you possess it, rather it starts a way before and ends after you own it. Every product goes through a cycle throughout its life time, from extraction and processing of raw materials to manufacturing to packaging to use and to disposal. Figure 1 below illustrates the possible life cycle stages, which can be considered in this cradle-to-grave approach of life cycle analysis. The storage and transportation of a product are also important stages that make an impact on the environment.

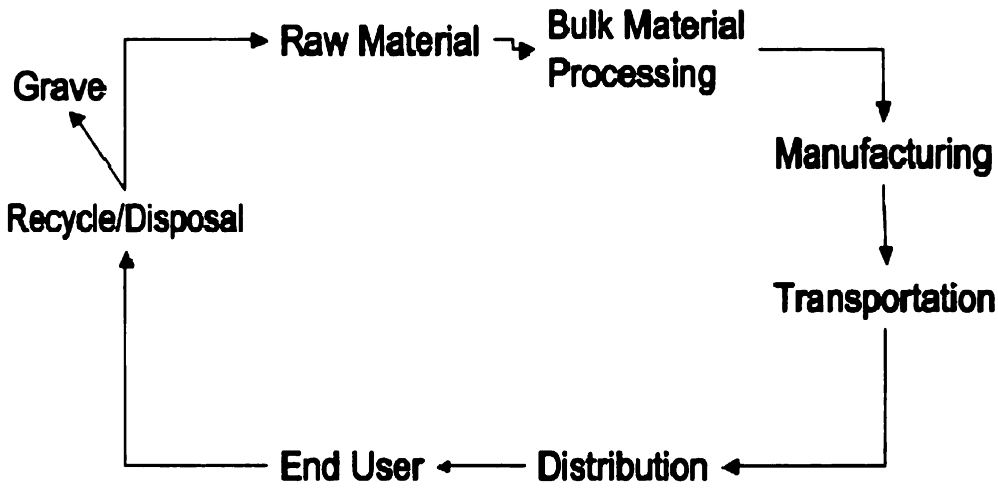

Figure 1 Life Cycle Analysis

There are a number of factors including the production, filling, distribution, consumption and recyclability that can influence the environmental impacts. Though the environmental performance is a broad and complex topic, there are tools that can be used to assess the environmental impacts of a product or service.

Life Cycle Analysis is a technique that is used to analyze the environmental impacts of a packaging system throughout its life cycle. It is also known as the 'Cradle to Grave' technique that signifies the detail assessment of the life cycle of the packaging, i.e. the raw material production, container/package manufacturing, filling, distribution, product consumption and final disposal/recycling. It also includes the prevailing transportation in between the material production and the disposal/recycling. Not only can we evaluate the environmental loads and impact of these loads but also we can compare the two different systems and assess the options available. [5-7]

2. Literature Review

2.1. Introduction

Packaging has always played an important part in our lives. Being an integral part of our daily life, it has become a need for the society. For example, one can purchase milk from the farmer, but a carton/bottle is required to bring it home. From a consumer point of view, the package should fulfill its function of protection, containment and convenience all the time. When a consumer buys a product, s/he buys the product, not the package and once the product is consumed, the same package becomes a waste. Continuing with the above example, a carton/bottle can be used to bring milk from the farmer to home but this package will go into the waste bin once the product is consumed, which can create a burden to the environment. This unfriendly side of packaging has led us to think about the ways to minimize the environmental impacts of the packaging.

Knowing 'how to measure the environmental impacts of packaging' is very essential before one starts looking for the ways to minimize it, and life cycle assessment is a tool that can be used to measure the different environmental impacts of a product/service throughout its life cycle. The life cycle of a product includes extraction of raw material, processing, manufacturing, transportation, distribution, usage, resue, recycling, and final disposal. All the environmental burdens related to every unit process are quantified and can be used in making some important decisions related to environmental outcomes; for example how to develop and improve the product, or how to design environmental policies, etc. LCA can work as a communicator within or outside companies to resolve disputes on environmental impacts.

The Society of Environmental Toxicology and Chemistry defines life cycle assessment as:

> .....an objective process to evaluate the environmental burdens associated with a product process or activity by identifying and quantifying energy and materials used and wastes released to the environment, to assess the impact of those energy and materials uses and releases on the environment, and to evaluate and implement opportunities to effect environmental improvements" [8].

LCA is a very complex tool but since it is based on scientific data, it can provide necessary information to solve the environmental issues. To understand all the features of LCA, this chapter has been divided into different sections. The first few sections present an overview of the basic life cycle assessment, different approaches to life cycle assessment, and needs for LCA. However the last section covers one of the important topics - different phases of LCA.

2.2. Approaches

Packaging interactions in packaging systems start from the moment the packaging material and the product come in contact with each other and the external environment during its production, processing, packaging and storage. These interactions extend throughout the life cycle of a package. There are a number of approaches that can be taken into consideration to assess the life cycle of a product.

2.2.1. Cradle to Gate

The cradle to gate approach represents the assessment of environmental burdens by a product from the manufacturing to delivery to seller. The word "Cradle" represents the beginning of a product and the word "Gate" represents the market for a product. In other words we can say that it includes the measurements of environmental impacts of a product until it is produced or delivered. The end of life scenario and the usage is not included in this approach. [9, 10]

2.2.2. Cradle to Grave

The cradle to grave approach signifies the detailed assessment of the whole life cycle, i.e. the raw material production, container/package manufacturing, filling, distribution, product consumption and final disposal/recycling. It also includes the prevailing transportation in between the material production and the disposal/recycling. [6, 11, 12]

2.2.3. Cradle to Cradle

The cradle to cradle approach signifies the intelligent design of a product/system, where the grave of one product can be the cradle for some other product. In other words, we can say that the end of a product can be a start for an other product. It includes the use of renewable energy sources, use of environmentally safe materials, material re-usage like recycling, etc., and considers the social responsibilities also. [10, 12]

2.3. Need for LCA

Solid waste has been an important issue for many years. The increasing volume of solid waste generation has always taken the attention of everyone to study the effect of packaging on the environment. One of the most primitive applications of LCA was for packaging.

Americans generate million of tons of waste every year. The total annual generation of MSW (Municipal Solid Waste) of the United States in 1960 was 88.1

million tons, which increased to 245.7 million tons in 2005. Containers and packaging made up 31.2% of the waste generated, about 77 million tons [13]. As shown in Figure 2 below, the total municipal solid waste generated in 2006 was 251 million tons (before recycling) and containers and packaging made up 31.7 percent of the waste generated [14].

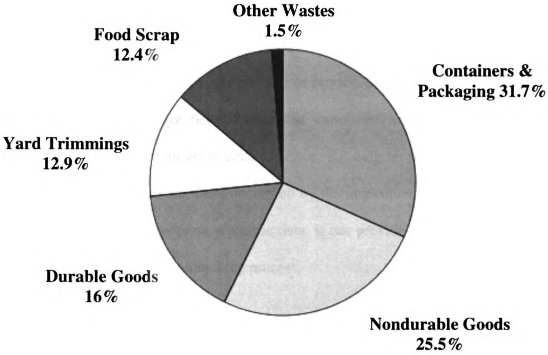

Figure 2 Total MSW Generation (by Category), 2006

These alarming figures have driven the industry to approach "Green" strategies. Nowadays 'Environmentally Friendly' packaging systems has become a trend/crucial need for the industry sector and life cycle analysis can be used as a successful tool by the companies to be competent in the business market. LCA is a decision-support tool which can be used in quantifying the environmental impacts related to products, processes, and activities [15, 16]. It can help in deciding between different choices related to a product or system [17]. LCA can help the industry people to spot the areas where environmental progress can be done [17].

There are a number of tools available to provide information on the environmental burdens but LCA focuses on products/functions, which are an integral part of every business. Thus LCA can be worked as an effective tool when it comes to the changing of environmental policies on products or services. Also life cycle assessment takes an integrative approach considering all the environmental burdens produced during every unit process throughout the life cycle of a product or service. Sometimes a change in one stage of a life cycle can induce new problems in some other stage. Therefore while making a decision relating to an environmental issue, the long term strategy should be used based on the information and facts quantified by the assessment tools. Since LCA is a quantitative tool which works on scientific data, it can provide credible information which helps in an efficient decision making process.

2.4. History

LCA started in the late 1960s and early 1970s. Harold Smith presented one of the studies on LCA at the World Energy Conference in 1963. One of the early life cycle analysis studies was conducted in 1969 for the Coca Cola Company [15]. This Life Cycle Analysis started by the Midwest Research Institute (MRI) focused on analysis of different beverage packaging systems to find out which packaging system had the minimum effect on the resource utilization and on the environment [18]. The early methodology in similar life cycle analyses, building an approach called Resource and Environment Profile Analysis (REPAs) paid attention to issues like energy efficiency, raw material utilization, and waste flow. In Europe, it was known as Econobalance. In the early 1970s the global oil crises happened, which shifted the focus of life cycle analysis onto 'net energy analysis' rather than waste flow and emissions. In the late 1970s and early 1980s, once the oil crisis settled down, life cycle analysis studies focused on issues such as hazardous waste management. [15, 16, 19]

In the late 1980s, because of the shortage of landfill space, there was a demand for alternative disposal methods that led to use of life cycle analysis as a tool to analyze the solid waste problem. Also, the 'Green Movement' in Europe, which made companies want to prove their products greener than their competitor's products, led to a number of comparative life cycle analysis studies. In 1990, for the Council for Solid Waste Solutions, a life cycle assessment was done comparing the environmental burdens of paper to that of plastic grocery bags [20].

Battle between cloth and disposable diapers

In the early nineties, a number of comparative life cycle assessment studies between cloth and disposable diapers were conducted which showed us a battle of "who is better than who". In 1990, Franklin Associates conducted an LCA study for the American Forest and Paper Association, which compared cloth and paper diapers. They concluded that all diapering options had several ecological and energy effects and specifically, that "cloth diapers produce seven times as much waterborne waste and consume four times as much water volume as paper diapers". This study favored the disposable diapers over cloth diapers [21].

In 1991, another study done by Lehrberger & Jones for the National Association of Diaper Services (NADS) concluded the opposite of what Franklin Associates study concluded. They stated that the disposable diapers use 70% more energy than reusable cloth diapers [22]. Basically the study favored the cloth diapers over disposable diapers.

In 1992, A. D. Little conducted another study for Procter and Gamble, which favored the paper diapers over cloth diapers [23]. In the same year Franklin Associate did a new study that concluded the battle between cloth and disposable diapers. This study showed that the answer of 'which diaper is better than the other' depends on how you look at the results [23]. It depends on the factors that you are concentrating on - whether it is energy or water or solid waste.

This diaper controversy demonstrated the importance of the boundaries placed for life cycle analysis. Most of the initial studies did not use similar methodologies and put up some extensive marketing claims to promote products. These actions demonstrated the inappropriate use of LCA that led to the development of LCA standards.

The Society of Environmental Toxicology and Chemistry (SETAC) took the first step towards an international LCA standard. SETAC published a report "A Technical Framework for Life Cycle Assessments," which provided the standard guidelines for a life cycle analysis [24]. These guidelines included the various components of an LCA: goal definition, inventory assessment, impact assessment, and improvement analysis. This approach of SETAC took LCA to another level where the studies do not focus on merely inventory quantification but consider the environmental impacts also. In the late 1990's, the International Organization for Standardization (ISO) published the ISO 14040 series, which included the standard principles and framework for Life Cycle Analysis. Since then the International Organization for Standardization (ISO) has been publishing and updating the standards in its 14000 series.

According to ISO/EN 14040, the life cycle analysis

"...involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system. These inputs and outputs may include the use of resources and release to air, water and land associated with the system".

Table 1 represents relevant international standards and drafts of the ISO 14000 series, in general, accepted as a framework for life cycle assessment:

Table 1 ISO Standards

ISO – 14000 Series	**Year**	**Detail**
ISO 14040	1997	Principles and Framework
ISO 14041	1998	Goal and Scope Definition and Inventory Analysis
ISO 14042	2000	Life Cycle Impact Assessment
ISO 14043	2000	Life Cycle Interpretation
ISO/TR 14047		Examples of application of ISO 14042
ISO/TS 14048	2002	Data documentation format
ISO/TR 14049	2000	Examples of Application of ISO 14041 to Goal and Scope Definition and Inventory Analysis

Even though we have standard methodology, there are still arguments about whether the impact assessment techniques application to inventory data of LCA is based on science. With the progress of LCA, the growth of software tools and databases for executing LCA was happening. This software was emerging to make the complex calculations of LCA effortless. The software works as a tool, which helps in collecting and evaluating the environmental performances of products or services. Typical LCA software contains various life cycle inventory databases from which one can quantify the inputs and outputs related to all the unit processes of the LCA study. Though this software is developed to make the quantification and calculations for LCA easier, there are a few issues that limit its usage. Following are few benefits and limitations related to the usage of LCA software [17].

Benefits:

1. Software can work as a support tool in quantifying the inputs and outputs related to every unit process. It can help in creating an inventory of all the resources and emissions.

2. It can help in evaluating all the results and decision making.

3. In case of any mistake, it could be easier to trace back the whole process with the help of software. This transparency feature of software can be very beneficial to find any mistake that happened throughout the assessment.

4. There are a number of features in the software that can used to present the results. Depending upon the target audience, different presentation styles can be chosen to display the results.

5. The data is usually taken from the database or library in the software. These databases can be updated which can make sure that the user gets good quality data.

6. Some software comes with a number of uncertainty analysis tools, which can help in assessing the affect of uncertainty on the outputs.

Limitations:

1. Sometimes it can be hard to find software that includes all the information relating to every unit process that you are considering in your LCA study.

2. Some software is compatible to one operating system. (e.g. SimaPro works with Microsoft windows not with Mac OS) which limits its usage.

3. Though working on LCA software can be an easy process, it might require some training sessions for first time users.

4. Purchasing or licensing the software can be quite expensive sometimes.

A number of life cycle assessment tools are commercially available all around the world, which can either be purchased or licensed for a time period. Table 2 represents the 37 major LCA software tools which are offered in the market except for four software tools (EcoSys, EDIP, LCAD and SimaTool) that are still under development [25].

Table 2 Comprehensive list of Life-Cycle Assessment Tools

Sl. No.	Name	Vendor	Version	Cost, $K	Data Location
1	Boustead	Boustead	2	24	Europe
2	CLEAN	EPRI	2	14	U.S.
3	CUMPAN	Univ. of Hohenheim	Unknown	Unknown	Germany
4	EcoAssessor	PIRA	Unknown	Unknown	UK
5	EcoManager	Franklin Associates, Ltd.	1	10	Europe/U.S.
6	ECONTROL	Oekoscience	Unknown	Unknown	Switzerland
7	EcoPack2000	Max Bolliger	2.2	5.8	Switzerland
8	EcoPro	EMPA	1	Unknown	Switzerland
9	EcoSys	Sadia/DOE	Prototype	Unknown	U.S.

Table 2 Contd.

10	EDIP	Inst. For Prod. Devel.	Prototype	Unknown	Denmark
11	EMIS	Carbotech	Unknown	Unknown	Switzerland
12	EPS	IVL	1	Unknown	Sweden
13	GaBi	IPTS	2	10	Germany
14	Heraklit	Fraunhofer Inst.	Unknown	Unknown	Germany
15	IDEA	IIASA	Unknown	Unknown	Europe
16	KCL-ECO	Finnish Paper Inst.	1	3.6	Finland
17	LCAI	P&G/ETH	1	Not Avail.	Europe
18	LCAD	Battelle/DOE	Prototype	<1	U.S.
19	LCAiT	Chalmers Industriteknik	2.0	3.5	Sweden
20	LCASys	Philips/ORIGIN	Unknown	Unknown	Netherlands
21	LIMS	Chem Systems	1	25	U.S.
22	LMS Eco-Inv. Tool	Christopher Machner	1	Unknown	Austria
23	Oeko-Base	Peter Meier	Unknown	Unknown	Switzerland
24	PEMS	PIRA	3.1	9.1	Ave. European
25	PIA	BMI/TME	1.2	1.4	Europe
26	PIUSSOECOS	PSI AG	Unknown	Unknown	Germany

Table 2 Contd.

27	PLA	Visionik ApS	Unknown	Unknown	Denmark
28	REGIS	Simum Gmbh	Unknown	Unknown	Switzerland
29	REPAQ	Franklin Associates, Ltd.	2	10	U.S.
30	SimaPro	Pre' Consulting	3.1	3	Netherlands
31	SimTool	Leiden Univ.	Prototype	Unknown	Netherlands
32	Simbox	EAWAG	Unknown	Unknown	Switzerland
33	TEAM	Ecobalance	1.15 & 2.0	10	Europe/US
34	TEMIS	Oko-Institute	2	Unknown	Europe
35	TetraSolver	TetraPak	Unknown	Unknown	Europe
36	Umberto	IFEU	Unknown	Unknown	Germany
37	Umcon	Particip Gmbh	Unknown	Unknown	Germany

An evaluation study of Life-Cycle Assessment tools was done by Dean M. Menke and Gary A. Davis in 1996. In this study, 14 software packages were evaluated and 5 were selected for in-depth evaluation. It was concluded that "there are a number of unique features/capabilities not found in every LCA software tool". Table 3 represents the comparative evaluation of five software systems focusing on unique software features. [25]

Table 3 Comparison of Unique Software Features

	KCL-ECO	LCAiT	PEMS	SimaPro	TEAM
Graphical Interface	√	√	√		√
Data Protection			√	√	√
Unit Flexibility	√				√
Use of Formulas	√				√
Uncertainty Analysis	√		√		√
Impact Assessment		√	√	√	√
Comparison of Results			√	√	√
Graphical Display of Results		√	√	√	

2.5. Phases of LCA

To get a logical understanding of LCA, all processes have been structured in four main components. According to the understanding of the International Organization for Standardization (ISO 14040, 1997), there are four phases in LCA methodology as shown in Figure 3:

1. Goal and Scope Definition
2. Life Cycle Inventory Analysis
3. Life Cycle Impact Assessment
4. Interpretation of Results

Each phase is divided into many sub-parts explaining the necessary steps required for the LCA process. The first phase is to define the goal and scope of the study in which the product/s, main aim and range of the study are explained. The second phase is life cycle inventory analysis, which is divided into four different subcategories explaining the different necessary steps to quantify the inputs (energy, raw materials used) and the outputs (hazardous and non hazardous emissions) for each process. The third phase is life cycle impact assessment in which impacts of all the emissions are characterized and quantified. The final phase of LCA methodology is interpretation of results in which all the results are quantified and interpreted in the most instructive way possible.

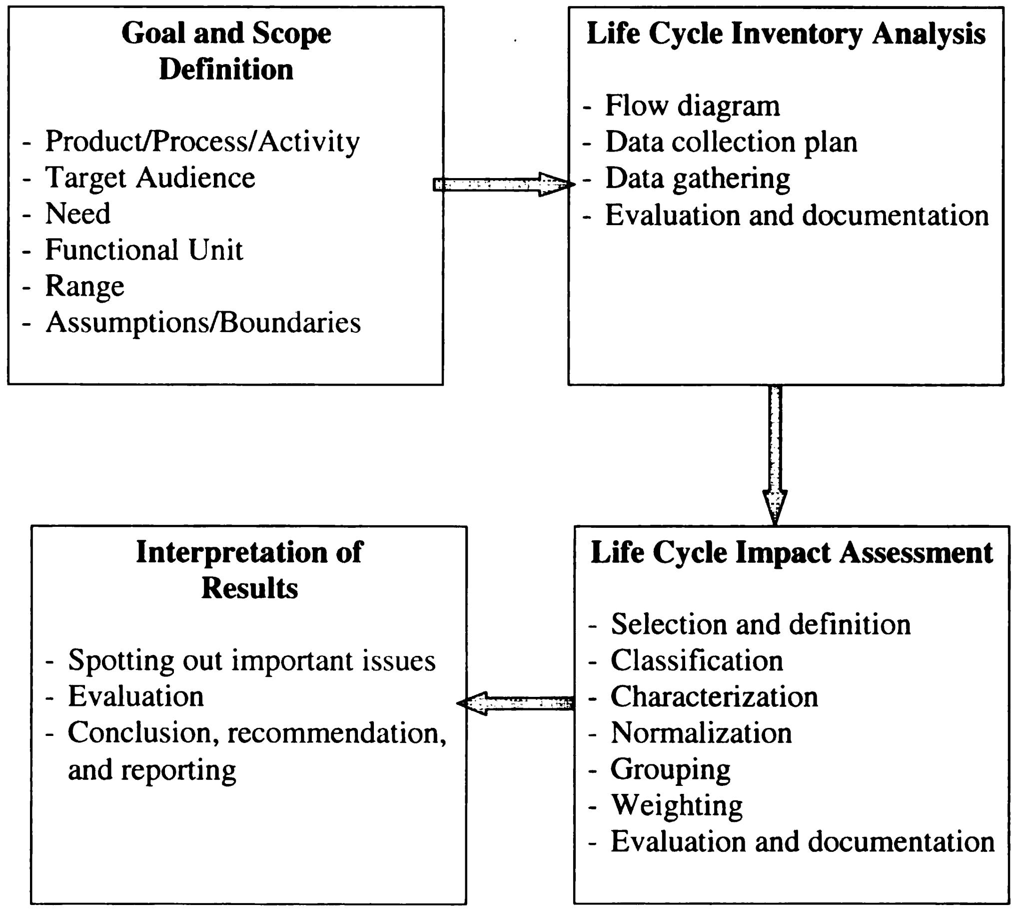

Figure 3 LCA Framework

2.5.1. Goal and Scope Definition

In this first phase of the LCA process, the goal and the scope of the study are defined, which establishes the time and resources needed for a particular project. In other words, the main purpose and range of the study are defined in this phase that provides guidance to finish the project with meaningful results. This stage explains what goals are to be achieved and how they will be carried out. The following are the sub-parts of this phase that are included in Goal and Scope Definition.

1. Subject: It is important to describe and define the subject of the study in detail. The following are a few questions which should be answered in this step –
    a. What kind of a product/process/activity is it?
    b. What amount of it should be considered in the study?
    c. Up to what level should the study extend?
2. Need: In this step, one should be able to answer questions like –
    a. Why do we need to do this study?
    b. Is this study for an existing product or to develop a new product?
    c. Is the purpose of the study to compare products?
    d. Is this study to get information only or to prove something (which product is superior, etc.)?
3. Initiator and Target audience: The following questions are important issues that should be considered in this step of goal and scope definition.
    a. Who has initiated the study?
    b. Is the target audience internal or public or governmental?

c. Is the main aim of this study to provide data/results to an organization internally? Or to compare products publicly?

d. Or are the results for both internal and external use?

4. Functional unit: The functional unit is a quantifying value, which can explain the function of the product or service. In case of a comparative study between different products/services serving the same function, it is very hard to compare one product/service to another product/service because each may have some distinctive characteristics. Thus to keep a comparison criterion identical, a functional unit is defined in this phase. For example; in case of a comparative LCA study of two cordless phones that use different sizes of batteries, the functional unit would not be the same number of batteries used in both phones. The functional unit would refer to the overall function, e.g. the number of batteries required for 500 hours of communication.

5. Assumption/boundaries/range: Any assumptions or project boundaries, whether related to location, material, transportation, equipment, etc., are defined in this Goal and Scope definition stage of LCA. All the stages of a product/process: raw material acquisition, manufacturing, use/reuse/maintenance, and recycle/waste management, are defined in detail in this phase. Up to what extent these stages should be involved, and how detailed a study is required, are defined in this phase.

2.5.2. Life Cycle Inventory Analysis

A life cycle inventory is a process in which energy and raw material requirements, air emissions, water emissions, solid waste generation and other environmental releases encountered throughout the life cycle of a product/process/service are collected and organized. This quantification of the input and output data can be very useful when comparing products or processes. Life cycle inventory is a complex and time consuming process that includes the construction of a flow diagram, making of a data collection plan, gathering of data and, finally, evaluation of the data. Any incomplete data or variations in the way data were collected add to the complexity of this process. Construction of a flow chart is a crucial step in this phase. An ideal flow chart should start with extraction of materials and raw products and end with environmental releases and waste, including all the in-between processes. The following are the key steps of the life cycle inventory phase:

1. Constructing a flow diagram of the process: A flow diagram is a qualitative means to represent the inputs (material, energy, etc.) and the outputs (hazardous material, non-hazardous material, etc.) of all the unit processes throughout the life cycle of a product system. In this step, all unit processes are linked together to form a complete life cycle picture keeping pre-determined system boundaries in mind. Constructing a flow diagram of all unit processes helps in keeping the study transparent. The following approach can be used to construct a process flow chart.

    a. Start with the manufacturing process.
    b. Classify all the necessary processing steps.
    c. Connect all the 'before manufacturing' processes (extraction, manufacturing and processing of raw materials etc.) and 'after manufacturing' processes (recycling, waste treatment etc.) respectively.
    d. Designate a separate box for by-products wherever it is applicable.
    e. Mark unfamiliar processes.

The main purpose of this step is to get a big picture of the study without going into small details of every unit process.

2. Data collection plan: In this demanding part of an LCA, a data-collecting plan is made to structure all the data quality needs for the assessment. A plan is made to collect all the input and output flow relating to every process explained in the flow chart. All the data sources and methods of data collection are also defined in this step. There are a number of sources and methods available which can help to collect the data required for life cycle assessment. Some of the examples are written below.

   a. Scientific Journals;
   b. Reference books;
   c. Surveys;
   d. Laboratory test results;
   e. Interviews;
   f. Technical encyclopedias;
   g. Theoretical calculations, etc.

A data collection plan is an important step in the life cycle inventory phase because the required data is not always available. Thus a plan made earlier can work things out easily and clearly.

3. Data gathering and documentation: Keeping the data flow chart (constructed in step 1) in mind, all the required input and output data is gathered using the data collection sources and methods (explained in step 2) and documented in a presentable format. Collecting the input/output data related to all the processes can be a time consuming and complex procedure, and the slightest error could lead to severe setbacks. A standard sheet

can be used to record all the data in a systematic way so that the tracking of data could be easier. Once the data related to inputs (material, energy etc) and outputs (hazardous material, non-hazardous material etc) is collected, it is documented on standard sheets.

4. Evaluation: In this final step of life cycle inventory phase, keeping the aim of the study in mind, all the collected data is evaluated. There are a number of tools available to make the necessary calculations. To make more sense of all the outcomes, it is always advised that calculations should be done with the same unit. For example, all the emissions of CO are quantified and added up together showing as the total CO released by the system.

2.5.3. Life Cycle Impact Assessment

Life cycle impact assessment is a procedure to categorize and characterize the impact of the system on human health, plants, and animals, or the future availability of natural resources. Life cycle impact assessment provides an understandable basis to differentiate between impacts of environmental releases that are mentioned in the inventory tables to environmental burdens. The following are the key steps of a Life Cycle Impact Assessment.

1. Selection and Definition: In this step, different impact categories are selected and defined. This step works as a part of the goal and scope definition phase of life cycle assessment. All the impact categories that are relevant to the study are acknowledged in this step.

2. Grouping: In this step, depending on different types of emissions (e.g. air, water) or location (e.g. local, global) or priority (high, low, medium etc.), impact indicators are assigned into groups.

3. Classification and Characterization: In this step, Life Cycle Impact (LCI) results are organized and assigned to impact categories. Using science-based conversion factors, the LCI results are converted into comparable impact indicators, which if added, can give us a total score for each environmental burden. For example, using CO_2 equivalency conversion factors, LCI results can be expressed as an overall indicator of global warming potential.

4. Normalization: This is an optional step, which can be used to relate the environmental impacts to the local or global emissions. Using a selected reference value, the impact indicators are standardized so that they could be matched among different impact categories. For example: the reference may be selected as an average yearly environmental burden in a country or continent divided by the population. Impact category divided by the reference will make the same unit for all impact category indicators.

5. Weighting: In this step, different impact categories are assigned relative values. In other words, some impact categories are highlighted as an important class in comparison to other categories.

6. Evaluation and Documentation: To check accuracy and reliability of the outcomes, all the results are evaluated and documented in this step.

2.5.4. Interpretation of results

In this last phase of the life cycle assessment process, all the results of LCI and LCIA are quantified and the information obtained from these results is evaluated. The main objectives of the life cycle interpretation are to assess results, draw conclusions, explain boundaries, provide recommendations, and report in an understandable and satisfactory manner. The following are the key steps of this phase.

1. Spotting important issues: In this step, all the information obtained from LCI and LCIA is reviewed in detail and important categories that contributed significantly to the outcomes of LCI and LCIA are presented.

2. Evaluation: To keep the consistency of the results of the life cycle assessment study, all the relevant data and information is completely examined and checked.

3. Conclusion, Recommendations and Reporting: In this final step of the life cycle interpretation phase, the results are interpreted and conclusions regarding the significant impacts of different processes/products are drawn. Keeping the goals and scope of the study in mind, several recommendations are also made in this step. Once the study is completed, a comprehensive report including the results, methods, data, assumptions, and limitations, is generated in an understandable, complete, clear and presentable manner.

2.6. Comparative LCA

Life cycle assessment is a technique for assessing the environmental impacts associated with a product over its life cycle, such as climate change, greenhouse effect, ozone depletion, acidification, heavy metals, winter and summer smog, eutrophication, carcinogens, toxicological impact on human health, depletion of resources – and others. One of the most important applications of Life Cycle Assessment is to characterize the environmental burdens with an aim to prioritize improvements in products or processes. LCA can also be used in making decisions among choices of different systems delivering a common purpose, making sure that assumptions and classifications are transparent and explained effectively. Instead of making temporary decisions that can lead to environmental degradation, LCA can help in making a choice of the best alternative among different choices. On the basis of comparative life cycle assessment between two products delivering the same function, environmental claims relating to the dominance of one product against a challenging product can be stated.

2.7. Case Studies

Numerous LCA based comparative studies between different packaging systems have been done in the past. Some examples of comparative life cycle assessment studies are discussed in this section.

2.7.1. Egg packaging

A study done at the Aristotle University of Thessaloniki, Greece, presents the application of Life Cycle Assessment for comparative analysis of two egg packaging products, polystyrene and recycled paper. By quantifying all the energy and material uses and releases, the environmental performances of two packages were characterized and their impacts were assessed throughout the life cycle including extracting and processing raw materials, manufacturing, transportation, and distribution, use, reuse, maintenance, recycling and final disposal. The landfill disposal was taken into account for both egg packaging products. Unlike recycled paper egg cups, the production cycle for polystyrene was traced back to the extraction of raw materials from the earth and data for polystyrene production was taken from Life Cycle Assessment Software developed by Pré Consultants - SimaPro 4.0 (demo version) databases. The Eco-Indicator'95 method was used to measure the environmental impacts associated with the two egg packaging products. [26]

Considering the ambiguity of the findings, the study concluded that the polystyrene (PS) package has a bigger environmental impact then the recycled package.

2.7.2. Reusable and single use bulk transit packaging

A comparative Life Cycle Assessment was conducted involving the comparison of re-usable and single-use bulk transit packaging used in the transportation of empty yoghurt containers in New Zealand. This study is a great source of help for the reader who needs to attain more knowledge about the comparative life cycle assessment of different packaging systems. In this study, using surrogate/proxy data from the Environmental Priorities Strategy (EPS) 2000 Default Method, a simplified life cycle analysis of a conventional single-use wooden pallet packaging system and a re-usable high-density polyethylene (HDPE) packaging system was conducted.

The requisite data was taken mainly from Simapro 5.1 and partially from the Association of Plastic Manufacturers in Europe (APME) and the Life Cycle Assessment Data Inventory of the Centre for Design at RMIT University, Melbourne, Australia. The author made an effort to ensure to keep the system limitations and data value and sources as parallel as possible. A statistical analysis was followed by the life cycle analysis and the result showed that the impact of the reusable plastic packaging system was four times less severe than conventional wooden pallet packaging system at a confidence level of 96.5%. The reusability and recyclability of the plastic packaging system made it a most likely superior choice over the conventional wooden pallet. [27]

2.7.3. Yogurt container

A life cycle assessment was conducted on the yogurt product delivery system (4,6,8 and 32 oz polypropylene cups and 2 oz linear low density polyethylene tubes) used by Stonyfield Farm, New Hampshire. The delivery of 1000 lb yogurt to market (distributor/retailer) was considered as the functional unit for the yogurt product delivery system. Data was collected and calculations on the inputs (material, water, energy) and outputs (water pollutant emission, air pollutant emission, solid waste) associated with different process units – material production, distribution, manufacturing, filling, yogurt consumption and end-of-life were performed to characterize the importance of two impact categories: global warming potential (GWP) and ozone depletion potential (ODP).

The results of life cycle assessment on the yogurt product delivery system indicated that the environmental burdens are inversely proportional to container size. Among the 6 oz, 8 oz and 32 oz containers, the 32 oz yogurt cups were indicated as the best option in every class. The total energy consumption for 32 oz containers was the lowest among the whole product delivery system. The overall solid waste generation was the highest for smaller containers (2 oz, 4 oz) and the water emissions were also inversely related to the container sizes. [28]

To improve the environmental performance of these systems, ten strategies were investigated and their impacts on the environmental burdens at each phase of the life cycle were quantified. It was proposed that changing the cup manufacturing process from injection-molding to thermoforming would result in a decrease in energy consumption for the composite product delivery system (PDS), solid waste and life cycle global warming potential (GWP). Also eliminating the lids on the 6 and 8 oz size containers would result in a reduction of energy consumption and solid waste. [28]

2.7.4. Single-use and reusable cups

A computer-based life cycle assessment study was done to determine the environmental performances of the reusable cup and single-use cup of the same composition (polypropylene). The environmental assessment of reusable cups used during an event that took place in Barcelona, Universal Forum of Cultures, 2004 was compared with that of single-use cups. The main aim of this study was to find the minimum number of times the reusable cup has to be reused so that its environmental impact is less than that of the single-use cup. SimaPro software (which was developed by Pré Consultants) was used to evaluate and compare the environmental assessment of both types of cups. A serving of 1000 liters of beverage was considered as the functional unit and different reuse scenarios (2, 9, 10, and 14 uses) were studied. This study considered the washing of reusable cups also. However the quantity of soap used and the amount of soap emissions into the water were not considered at all. [29]

The study concluded that the environmental impacts of the reusable cups would be smaller than that of single-use cups if the minimum number of reuses of the reusable cup was 10 and the impacts will be decreased if the number of reuses increases.

Since the main reason for this kind of result was the higher weight of the reusable cup, it was proposed that the environmental impact associated with the reusable cup would have been decreased if the weight of the reusable cup was lowered by introducing LCA methodology during the design of the reusable cup. This would have resulted in a smaller number of uses of the reusable cup. [29]

2.7.5. Alternate coffee packaging

A life cycle analysis study done in Trieste, Italy included a comparison between the environmental impacts associated with different packaging systems for coffee trade. In this life cycle assessment study, the following five packaging systems were considered with respect to the functional unit of 1 kg of packed coffee.

1. Cans with a capacity of 3 kg.
2. Cans with a capacity of 250 g.
3. Cans with a capacity of 125 g.
4. Cans with a capacity of 36 single-use coffee servings (250 g).
5. Poly-laminate bags with a capacity of 40 single-use coffee servings (280g).

SimaPro 5.0 (life cycle analysis software, which was developed by Pré Consultants) was used to evaluate and compare the environmental impacts of alternative coffee packaging systems. Since the factors related to coffee cultivation, transportation and processing until the end of roasting process were constant for every packaging system, they were not included in this study. Regarding the energy production, life cycle assessment was localized to Italy only. However in respect to raw materials, Europe was integrated as the geographical region of interest. A mass and energy balance was generated relating to the various processes involved in coffee packaging and specific data about material, emissions, and energy consumption etc. were taken from the company. [30]

Various impacts related to different effects – greenhouse effect, ozone depletion, acidification, heavy metals, winter and summer smog, eutrophication and carcinogens were assessed and final comparisons were studied with respect to different alternative coffee packaging. Results concluded that if the final disposal is not considered, the bigger packaging alternative (3 kg can) has the smallest impacts and the smallest packaging alternative (250 g can with a capacity of 36 single-use coffee servings) shows the biggest impact. Consideration of final disposal for all packaging systems resulted in a common rise in the impact values. [30]

2.8. Life Cycle Assessment applications and challenges

Life cycle assessment is a technique that is used to evaluate the environmental burdens associated with a product, process or service. The process includes:

- The assemblage of all the inventory of resources (materials, energy used etc.) and output (hazardous and non-hazardous emissions) related to every unit process.
- Assessment of possible environmental impacts related to the inputs and outputs.
- Interpretation of results.

LCA has a wide variety of applications in relation to a product or process. It can help in:

1. Quantifying the environmental burdens
2. Evaluating the specific environmental impacts
3. Selecting the product/process that would have less environmental burdens
4. Identifying the opportunities for improvements
5. Comparing two or more different products or systems
6. Designing new environmentally friendly products
7. Marketing

There can be some challenges related to LCA.

1. Data collection can be intensive and time consuming.
2. Availability of data can affect the accuracy of results.

3. Does not point out the impacts related to a product or process in a particular region.
4. Does not incorporate market analysis.
5. It involves a number of assumptions.
6. It does not concentrate on social and economical aspects.
7. It does not determine the cost effectiveness of a product or process.
8. Lack of a widely accepted methodology for conducting LCA

[6, 11, 17, 19]

2.9. Approach to current study

For this study, a cradle to grave approach was used for the Life Cycle Assessment. All the inputs and outputs related to unit processes throughout the life cycle of two packaging systems were organized and evaluated. The environmental burdens related to both packaging systems were compared and the least burdensome packaging system was chosen as a favorable system.

3. Comparative LCA of two 'glass cleaner' packaging systems

3.1. Introduction

This chapter presents information relating to a comparative life cycle assessment of two different packaging systems for glass cleaners:

1. JAWS glass cleaner packaging system
2. Conventional glass cleaner [ackaging system

Keeping ISO's LCA steps in mind, a comparative study between these two packaging system is explained in this chapter. In the first section of this chapter, both packaging systems are described in detail so that the reader can draw a clear mental picture of the systems. The main objective and functional unit of this comparative LCA study is explained in the second and third section. Finally, the life cycle inventory and impacts related to both packaging systems are quantified and compared in the last section of this chapter.

3.2. Description of packaging system and functional unit

1. JAWS Glass Cleaner System: J.A.W.S. Just Add Water System. This is an innovative refillable system that is ideal for glass and other hard surface cleaning. This "Just Add Water" concept was introduced by **JAWS® International, Ltd. Holland Sylvania Road, Toledo, OH 43615.** This system can be very easy and simple to use. This glass and other hard surface cleaning system required us to just add water to the empty 32-oz. bottle, drop a cleaner cartridge into the bottle's neck, then tighten the spray handle on. The concentrated cleaner inside the cartridge is released into the water, creating an excellent formula for cleaning tasks.

This system comes with refill cartridges, which means that when a consumer finishes the glass cleaner solution, all s/he has to do is to remove the old cartridge, add water and then add the new cartridge, and the system is ready to clean glasses and other hard surfaces. The details of the packaging system are described below:

a) Primary:

   i. Bottle system: PET bottles (32 oz), PP cartridges, PET blisters, PP labels, paper insert, PP spray attachment, LDPE shrink wrap.

   ii. Cartridge refill system: PP cartridges, PET blisters, PP labels, paper inserts.

b) Distribution: Kraft corrugated boxes, low density polyethylene (LDPE) stretch wrap, wood pallets.

2. Conventional Glass Cleaner System: The Conventional Glass Cleaner System includes a 32-oz. bottle and a spray handle connected to the bottle. In this system, there is no need to add water because the system comes with glass cleaning solution. The details of the packaging system are described below:

a) Primary: PET bottles (32 oz), polypropylene (PP) film labels, and injection molded PP spray attachments.

b) Distribution: kraft corrugated boxes, low density polyethylene (LDPE) stretch wrap, wood pallets.

Functional Unit

Since this is a comparative life cycle assessment study between two package systems, the basis of comparison should be equivalent. This can be related to weight or volume. The basic unit of comparison used in this study is 32,000 ounces (equivalent to

1000 32-oz bottles) of glass cleaner. This will be referred to as the functional unit (FU). Details of the package systems are shown in Table 4.

Table 4 Individual components of the JAWS and conventional package systems

Component weight (g)	JAWS	Conventional
PET bottle	48.1226	52.2470
PP oriented film labels for bottles (front and back)	2.0612	2.0612
PP injection-molded cartridge	13.0625	
PP oriented film label for cartridge	0.4191	
Paper insert for cartridge	0.7114	
PET blister	6.2687	
PP injection molded spray system	33.9565	25.1600
Shrink wrap for bottle-cartridge system	7.2091	
Corrugated shipper	635	451
Stretch wrap for 1 pallet load	200	200
Pallet	27216	27216

Weights for the JAWS primary package components are based on sample components provided by the company. It is assumed that the primary package is shipped with two cartridges, providing an initial filling plus one refill. The first cartridge is snapped onto the bottle using the molded-in feature. Shrink wrap is used to bundle the bottle and attached cartridge to the second cartridge. The amount of shrink wrap required was calculated based on experiments run at the School of Packaging. (A picture of the shrink- wrapped bottle with two cartridges can be found in Appendix D.) Additional refill cartridges are packaged individually in PET blisters. Since the average number of refills is uncertain, as it will reflect consumer behavior and product success, comparisons are provided for averages of 10 and 20 fills per bottle. Both these values are well under the measured lifetime of the spray attachment, according to the company.

Weights for the components of the conventional package are based on bottles purchased at retail. A local store had 4 brands of glass (or glass and surface) cleaner for sale in 32 oz. bottles. Two bottles of each brand were purchased and weighed. Details are presented in Table A1 in Appendix A. It was assumed that the average label weights for the bottles were identical to those in the JAWS system. Therefore the average weight of the PET bottles was obtained by subtracting the label weight from the average weight of the labeled bottles.

It should be noted that the weight of the JAWS bottles was nearly 8% less than that of the average of the conventional bottles. Conventional bottle weights, after subtracting for labels, ranged from a low of 49.9888 g to a high of 56.0860 g (averages of 2 bottles per brand). The lower weight of the individual JAWS bottles provides additional environmental advantages, across the board, including reductions in energy use, reductions in air and water pollutants, etc. These advantages are real, and therefore were included in the analysis.

The weight of the corrugated boxes for the JAWS system is based on a sample provided by the company, designed to contain 12 bottles. It is assumed that the same size and style of box is used for shipping of the cartridge refills, with a total of 200 cartridges per box. The weight of the corrugated boxes for the conventional system is based on the assumption that the same board configuration is used, but the size of the boxes is somewhat smaller since the two refill cartridges in each JAWS system require extra space. Therefore, a corrugated box obtained at a retail store (containing 12 bottles) was used to determine the box size, and the weight from the JAWS box was adjusted proportionally. Details of the calculations are presented in Appendix B.

The weight of pallet stretch wrap was calculated based on experiments carried out at the School of Packaging (Appendix B). The weight of a pallet is based on average weight of grocery pallets [31]. Weights of pallets and stretch wrap per load were assumed to be identical for the JAWS and conventional systems.

From the basic information presented in Table 4, the weights of materials required to deliver one functional unit (32,000 ounces of glass cleaner) can be obtained, and are presented in Table 5. For the conventional packaging system, delivery of 32,000 ounces of glass cleaner requires delivery of 1,000 PET bottles with labels, sprayers, etc. For the JAWS system, the requirements for delivery of 32,000 ounces of glass cleaner depend on the average number of fills per bottles. If 10 fills per bottle are assumed, then delivery of 32,000 ounces of cleaner requires 100 of the bottle-plus-two-cartridge package systems, plus an additional 800 cartridge/blister refill packages. If 20 fills per bottle are assumed, then 50 bottle-plus-two-cartridge systems and 900 cartridge/blister refills are required. Calculations for the weight of pallets and stretch wrap required per functional unit are shown in Appendix B.

In Table 6, like materials are combined, to indicate the total amount of the various materials required to deliver one functional unit of glass cleaner, hence facilitating comparisons. Note that PET bottles and PET blisters remain separate from each other, reflecting the difference in processing between stretch-blow-molded bottles and thermoformed sheet. Similarly, injection molded PP spray attachments and cartridges remain separate from PP film.

Table 5 Weight of packaging components per functional unit

Component weight (g)	Conventional	JAWS 10 fill	JAWS 20 fill
Bottle system			
Bottle	52,247	4,812	2,406
Spray Attachment	25,160	3,396	1,698
Bottle Labels	2,061	206	103
Shrink Wrap		721	360
Blister		1,254	627
Cartridge		2,613	1,306
Insert		142	71
Label for cartridge		84	42
Box	37,613	4,233	2,117
Pallet	68,726	12,095	6,048
Stretch Wrap	505	89	44
Refill system			
Blister		5,015	5,642
Cartridge		19,030	21,408
Insert		569	640
Label for cartridge		335	377
Box		2,540	2,858
Pallet		7,257	8,165
Stretch Wrap		53	60
Total*	186,312	64,444	53,972

*Entries may not add to total due to rounding

Table 6 Weight of packaging materials per functional unit, by material type

Material weight (g)	Conventional	JAWS 10 fill	JAWS 20 fill
PET bottle	52,247	4,812	2,406
PET blister	0	6,269	6,269
PP film (labels)	2,061	625	522
PP injection molded	25,160	25,039	24,412
LDPE film	505	863	464
Bleached kraft paper	0	711	711
Corrugated box	37,613	6,773	4,975
Pallet	68,726	19,352	14,213
Total*	186,312	64,444	53,972

*Entries may not add to total due to rounding

3.3. Package System Life Cycle Inventory and Impacts

3.3.1. Overview

A modified life cycle approach was used to tabulate the inputs and outputs (the inventory) associated with the alternative package systems. The general framework for the life cycle inventory is shown in Figure 4. As indicated by the dashed lines, the filling, retailer, and product consumption components were not included in the quantitative analysis, due to lack of data, although they will be discussed qualitatively. Distribution between the filler and the retailer was included in the analysis, but distribution between container manufacturing and the filler was not, again due to lack of data. In the disposal/recycling component, only the solid waste aspects were included. The use of recycled content in container manufacture was not considered. The shaded area indicates that material production, container production, and distribution between these segments were all included as Container Manufacturing.

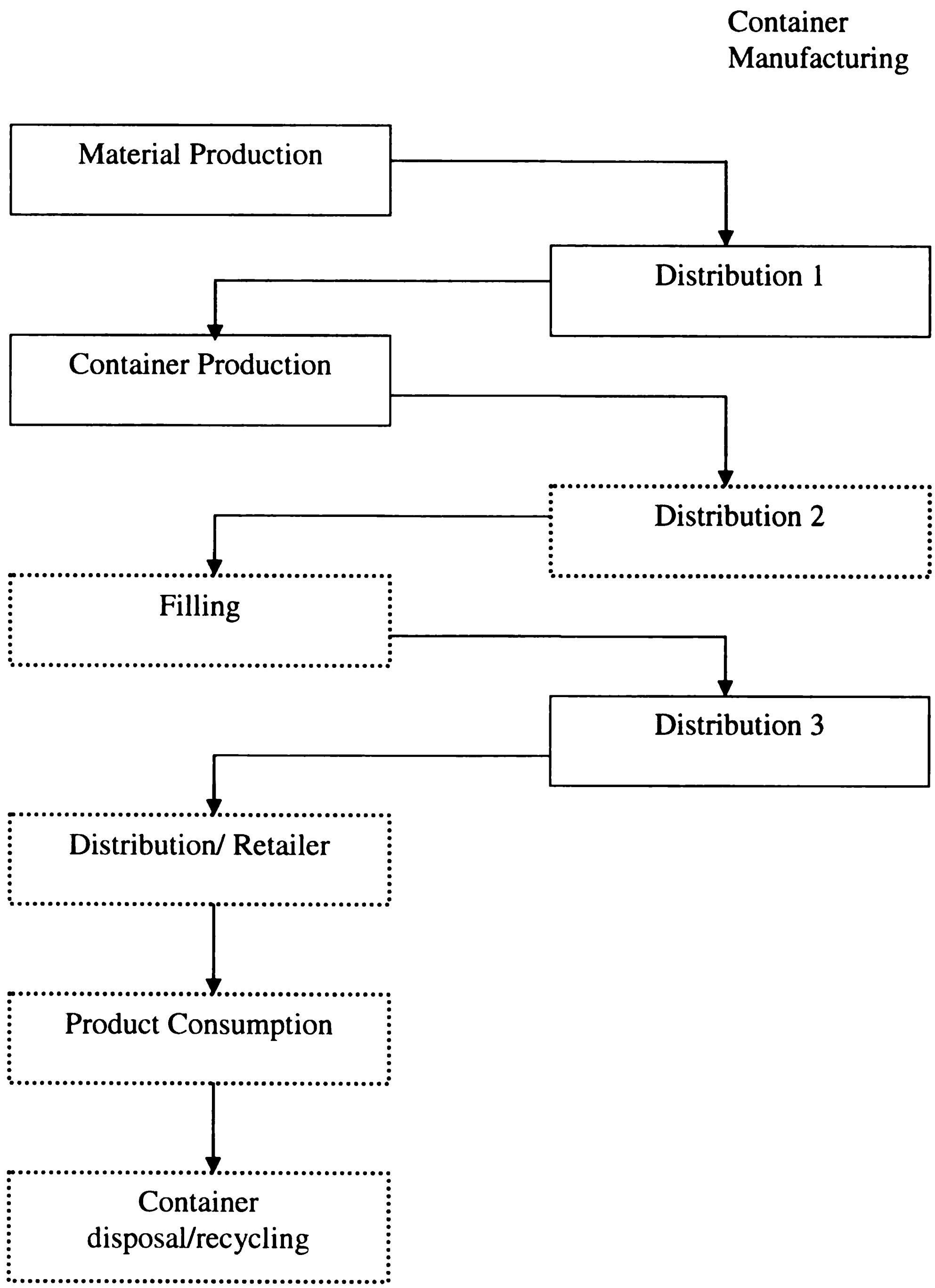

Figure 4 Schematic of Life Cycle.

All inventory data was obtained from published sources, which are described below. Inventory data reported includes the following:

a) Total energy

i. Electricity

ii. Oil

iii. Other

b) Greenhouse gas emissions

c) Air pollutant emissions

d) Water pollutant emissions

e) Solid wastes

A variety of raw materials are used in manufacture of the container systems. A complete tabulation of these materials is not included. Since the types of materials used in the systems being compared are very similar, the differences in total mass between the systems provide a reasonable indication of the differences in total raw materials used. Alternatively, total energy can be used as a surrogate measure for raw materials. This is particularly appropriate in this case since all the major materials in the packaging systems are based on oil, natural gas, and wood. Therefore, only minor components (e.g. some catalysts, processing aids, etc.) which have no fuel value are not represented through their energy values.

Information for plastics was obtained from "Eco-profiles" published by the Association of Plastics Manufacturers in Europe (APME), updated in March 2005. While the precise values in these profiles to some extent reflect practices and conditions in Europe, the general comparisons are valid for the United States. Up to date U.S. data was available for LDPE, but not for PET and PP. Rather than combine data from different sources obtained using somewhat different assumptions, for consistency all the plastics data was obtained from a single source, APME (2005). Generic LDPE was used to represent both stretch and shrink film. These eco-profiles include production of raw materials, transportation of materials to the manufacturing point, and associated events and operations. Eco-profiles used were those for stretch blow molded PET bottles, injection molded polypropylene, polypropylene film, and LDPE film [32]. No profile was available for thermoformed PET, so some data for PET film was used and adjusted as explained in the sections that follow.

Information for energy requirements and air and water emissions for bleached kraft paper for the cartridge inserts, corrugated boxes, and truck transport of containers from the filler to the retailer was taken from a 2004 report published by the Oregon Department of Environmental Quality [33]. Corrugated boxes were assumed to have an average of 38% post-consumer recycled content, which was determined to be typical for the United States. Greenhouse gas emissions were not available from this source, so were taken from the Office of the Federal Environmental Executive (2006), assuming the same recycled content (38%) for corrugated, and using office paper with a recycled content of 38% as a surrogate for bleached kraft packaging paper, as information for bleached kraft packaging paper was not available. As is the case for plastics, these values include production of raw materials, transportation of materials to the manufacturing point, and associated events and operations.

Pallets were assumed to be made of softwood. They were included in calculating the weight of the load for the Distribution 3 segment and in estimating solid waste contributions, but energy consumption and emissions associated with pallet manufacture and distribution were not otherwise included, due to lack of reliable data. Since pallets may or may not be reusable (and may also be made of plastic or other materials), this further complicates their inclusion in the analysis.

3.3.2. Energy consumption for package manufacture

Energy used was divided into 3 categories: electricity, oil fuels, and other fuels. Figure 4 shows the energy required for the manufacturing of conventional packaging, JAWS 10 fill, and JAWS 20 fill, MJ per functional unit.

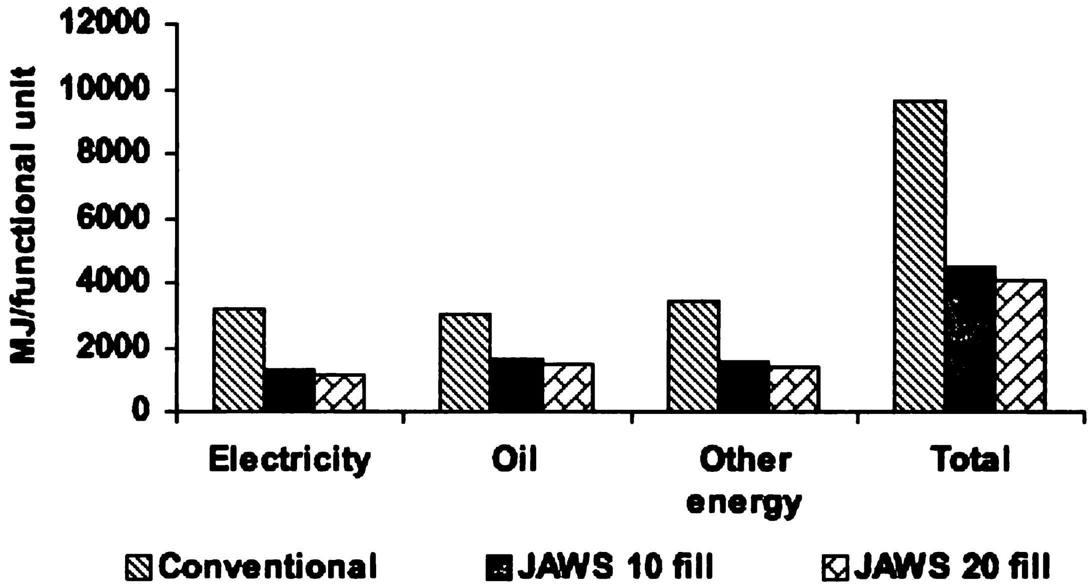

Figure 5 Comparison of the energy required for the manufacturing.

Overall energy consumption for manufacture of the packaging involved in the three systems being compared is shown in the above figure. This does not include transportation energy for the filled product to the retailer. The 10 fill JAWS system requires less than 47% of the total energy of the conventional packaging, at this point in the system; the 20 fill system requires less than 43%. Savings are significant in all 3 categories: electricity, oil fuels, and other fuels. Details showing the breakdown of the energy use by product component can be found in Table A2 in Appendix A. Note that pallets are not included in this tabulation, due to lack of reliable data.

It should be noted that information for energy requirements for thermoformed PET sheet was not available; therefore values for PET film were used. These values were increased by 10% as a conservatively high estimate of the energy requirements for thermoformed PET blisters.

Because of the likely overestimation of the energy required for manufacture of the PET blisters and the omission of the energy requirement for the additional pallets used in the conventional system, the actual energy comparison will even more strongly favor the JAWS system than is indicated here.

3.3.3. Transportation energy

Transportation energy requirements provide a further advantage for the JAWS systems. The weight of filled containers transported to the retail store for the 3 systems being compared is shown in Table 7. It is assumed that energy consumption by the trucks is proportional to the weight being hauled [33].

Energy requirements (and emissions) for shipping depend on the transportation distance. Table 8 presents results for shipping from the filler to the retailer, by truck, for average distances of 500 and 1000 miles. A combination (tractor trailer) truck is assumed, running on gasoline. Energy required for diesel trucks would be 12% higher; energy required for single unit trucks running on gasoline would be 182% higher, and for diesel 216% higher. Therefore, this is a conservative estimate.

Table 7 Total weights of filled package systems shipped to retailers, g per functional unit

Weights, g	Conventional	JAWS 10 fill	JAWS 20 fill
Packaging	186,313	64,445	53,972
Contents	908,000	10,725	10,725
Total weight	1,094,313	75,170	64,697

Table 8 Energy requirements for shipping filled package systems to retailers, MJ per functional unit

System	Total wt, kg	Energy for 500 miles, MJ	Energy for 1000 miles, MJ
Conventional	1094	832	1664
JAWS 10 fill	75	57	114
JAWS 20 fill	65	49	98

As can be seen, the longer the average transportation distance, the greater is the energy savings using the JAWS systems. The 10 fill JAWS system uses less than 8% of the shipping energy used by the conventional system, and the 20 fill system less than 7%. This reflects the large mass of water shipped in the conventional system. It could be argued that the actual savings is somewhat less, since the water must be added at some point. However, transportation of water to the home by pipeline, as is the case in the JAWS system, requires only a miniscule amount of energy compared to transportation of the water to the retail store by truck, so these comparisons are valid. Further, there is additional energy savings associated with transport of the containers to the home, which would compensate for the pipeline energy use for water.

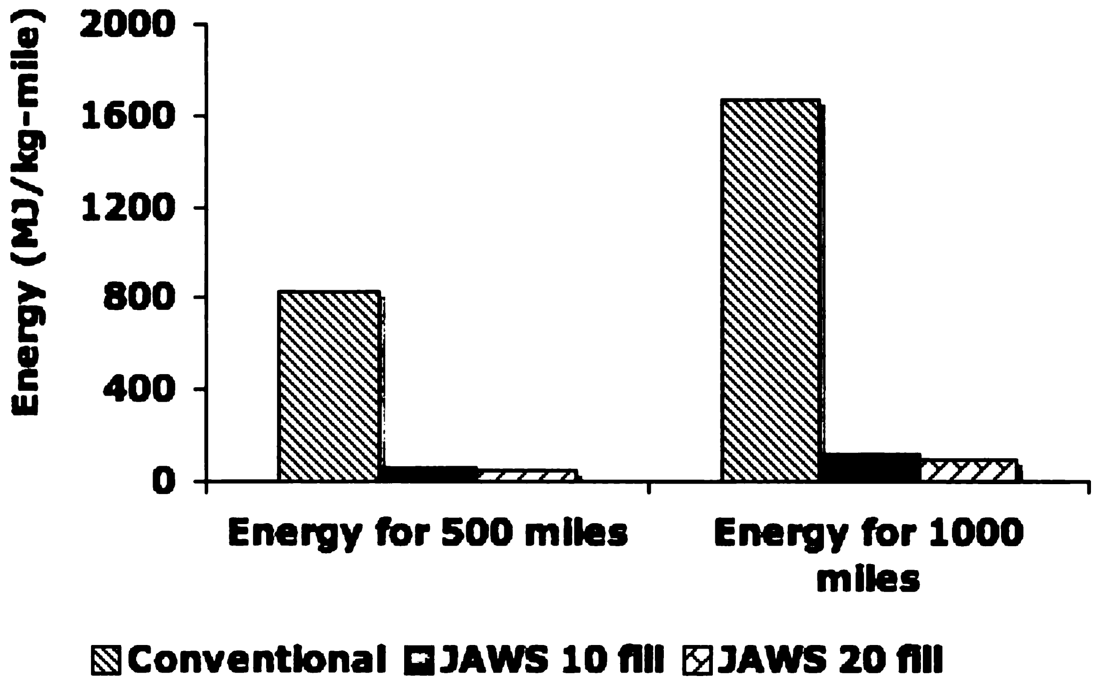

Figure 6 Comparison of energy used in transportation

Overall transportation energy for 500 miles and 1000 miles for both packaging systems is presented graphically in figure 6.

3.3.4. Greenhouse gas emissions

Greenhouse gas emissions were calculated for manufacture of the conventional, JAWS 10 fill, and JAWS 20 fill package systems. Results are shown in Table 9, as carbon dioxide equivalents. Pallets and distribution from the filler to the retailer are not included. Greenhouse gas emissions associated with container manufacture for the 10 fill JAWS system are less than 45% of those for the conventional system, and for the 20 fill JAWS system are less than 40% of those for the conventional system.

Table 9 Greenhouse gas emissions in kg CO_2 equivalents per functional unit

Component	Conventional	JAWS 10 fill	JAWS 20 fill
PET bottle	293	27	13
PET blister	0	48	48
PP film (labels)	7	2	2
PP inj mold	133	133	129
LDPE film	2	3	1
Bleached kraft paper	0	2	2
Corrugated box	87	16	11
Total	521	230	207

Because of the omission of greenhouse gas emissions associated with pallet manufacture and with transportation from the filler to the retailer, actual greenhouse gas emission reductions for the JAWS systems will be even greater than is presented here.

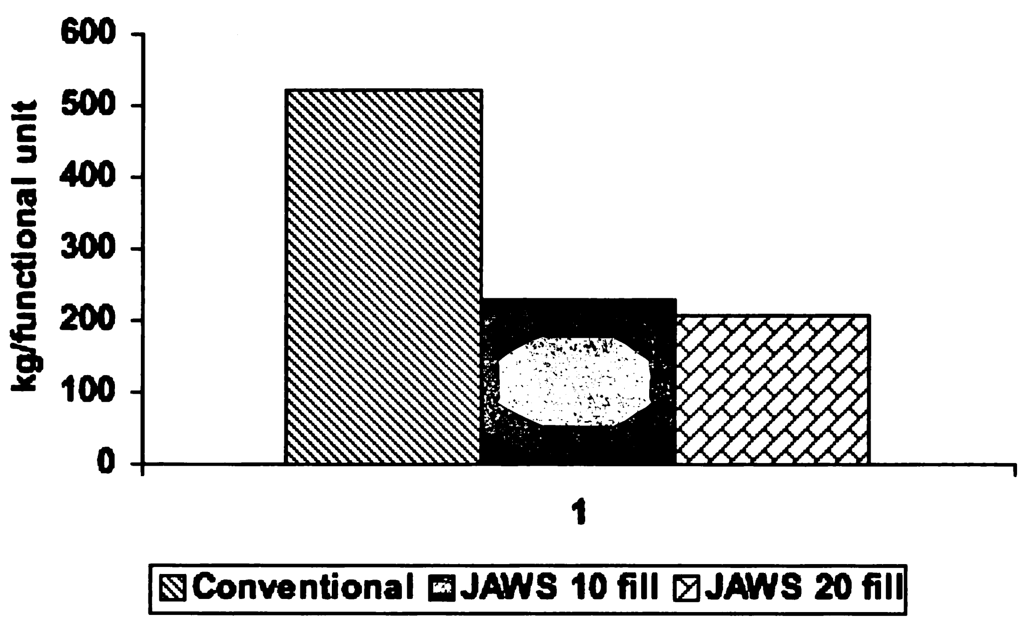

Figure 7 Comparison of greenhouse gases

Overall greenhouse gas emissions for the systems being compared are presented graphically in Figure 7 above.

3.3.5. Air pollutant emission

Emissions of air pollutants from the conventional and JAWS systems are compared in the following tables. Table 10 details the major emissions from production of the plastics materials in the packaging systems (details by component are in tables A3 to A7 in Appendix A). Table 11 shows the emissions from the paper components (details are in tables A8 and A9 in Appendix A). Since, as discussed, no information was available specifically for thermoformed PET, emissions for PET film were used. These values were increased by 10% as a conservatively high estimate of the emissions associated with thermoformed PET blisters. As before, pallets are not included due to lack of reliable data.

It is generally agreed that summing of various types of emissions in a life cycle analysis is an unwise practice; therefore no sums are provided here. It can easily be noted that emissions for the JAWS systems are lower than those for the conventional systems in all cases. Comparisons for the major air emissions (particulates, carbon monoxide, sulfur oxides, nitrogen oxides, and hydrocarbons) are presented in Figure 8. Reductions in air emissions for these components range from 56 to 66% for the 10 fill JAWS system, and are even larger for the 20 fill system. Data is provided in Table A10 in Appendix A.

Table 10 Major air emissions from production of plastics materials in packaging systems, g per functional unit

Total emissions (g/functional unit)	**Conventional**	**Jaws 10 fill**	**Jaws 20 fill**
particulates (PM10)	187.02	73.78	65.68
CO	872.25	420.25	384.36
SOx as SO_2	1137.21	468.75	419.26
NOx as NO_2	754.38	356.74	324.85
HCl	22.14	9.13	8.19
HF	0.79	0.33	0.30
hydrocarbons not specified	587.37	226.88	200.57
organics	17.86	5.20	4.34
metals	0.24	0.13	0.12
H2	27.37	11.10	9.96
aromatic HC not specified	21.55	6.26	5.31
NMVOC*	63.52	12.88	9.78
ethylene C_2H_4	0.16	0.07	0.07
propylene	0.08	0.04	0.03

Table 11 Major air emissions from production of paper material in packaging systems, g per functional unit.

Total emissions (g/functional unit)	**Conventional**	**Jaws 10 fill**	**Jaws 20 fill**
particulates	73.35	14.39	10.89
CO	151.96	28.06	20.80
SOx	221.54	43.72	33.13
NOx	130.52	27.65	21.41
HCl	0.00	0.00	0.00
hydrocarbons not specified	0.75	0.14	0.11
organics	0.00	0.07	0.07
metals	0.00	0.00	0.00
aldehydes	0.23	0.04	0.03
odorous sulfur	1.09	0.21	0.16
reduced sulfur	0.00	0.03	0.03
ammonia	1.69	0.33	0.25
chlorine	0.00	0.01	0.01

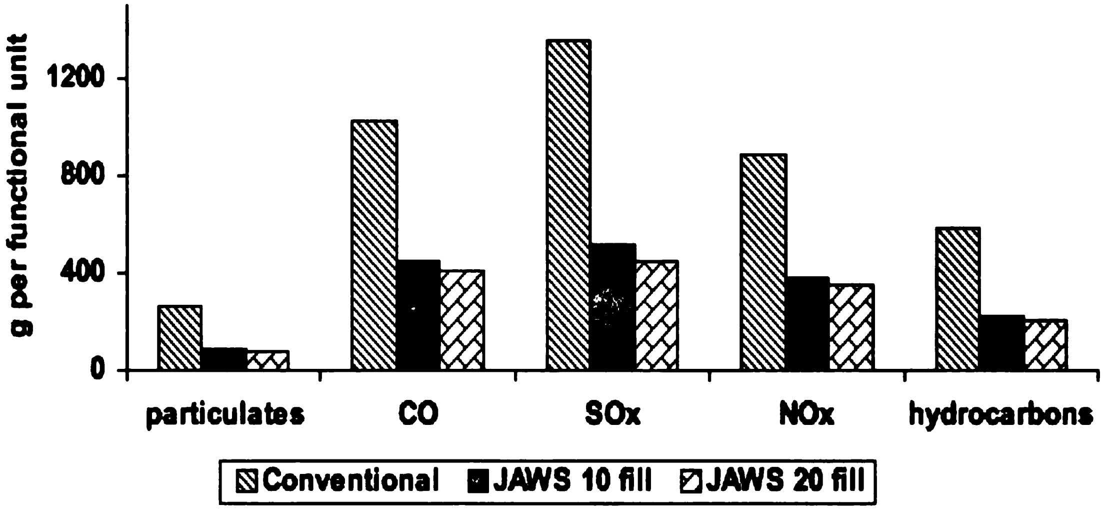

Figure 8 Comparisons of major air emissions

Further reductions in air emissions for the JAWS systems compared to the conventional system would arise from the reduction in transportation requirements. Reductions in air emissions would generally be proportional to reductions in energy consumption, and are not detailed here, but are included in Appendix C for both gasoline and diesel.

3.3.6. Water emission

Emissions of water pollutants from the conventional and JAWS systems are compared in the following tables. Table 12 details the major emissions from production of the plastics materials in the packaging systems (details by component are in tables A11 to A15 in Appendix A). Table 13 shows the emissions from the paper components (details are in tables A16 and A17 in Appendix A). As was done for air emissions, water emissions for thermoformed PET were conservatively estimated (high estimate) by increasing the emissions for PET film manufacture by 10%. Estimates for pallets are not included due to lack of data.

Table 12 Major water emissions from production of plastics materials in packaging systems, g per functional unit.

Total emissions (g/functional unit)	Conventional	Jaws 10 fill	Jaws 20 fill
COD (chemical oxygen demand)	70.40	22.48	19.17
BOD (biological oxygen demand)	105.38	17.33	12.47
Na+ compounds as Na	13.15	4.17	3.56
acid as H+	0.42	0.49	0.47
NO3-	3.42	3.18	3.08
metals not specified elsewhere	1.30	0.48	0.42
ammonium compounds as NH4+	0.35	0.18	0.16
Cl-	15.67	6.56	5.86
dissolved organic not specified	1.19	0.47	0.41
suspended solids	33.34	14.47	12.97
detergent/oil	1.46	0.62	0.56
hydrocarbons not specified	5.89	1.17	0.89
phenols	0.11	0.06	0.06
dissolved solids not specified	8.49	2.24	1.85
other nitrogen as N	0.15	0.06	0.05
other organics not specified	18.32	6.28	5.49
SO4--	44.13	28.66	26.93
TOC (toxic organic compounds)	2.39	0.60	0.49
CO3--	5.04	1.72	1.48

Table 13 Major water emissions from production of paper materials in packaging systems, g per functional unit.

Total emissions (g/functional unit)	**Conventional**	**Jaws 10 fill**	**Jaws 20 fill**
COD (chemical oxygen demand)	345.66	75.08	53.68
BOD (biological oxygen demand)	92.15	21.20	15.50
phosphorus	1.20	0.32	0.25
phosphates	2.82	0.63	0.45
acid	0.53	0.11	0.08
metals not specified elsewhere	6.13	1.28	0.90
ammonia	0.87	0.38	0.33
nitrogen	1.28	0.29	0.21
phenols	0.03	0.01	0.00
suspended solids	114.34	28.20	21.12
dissolved solids	5.64	1.37	1.02
oil	2.71	0.56	0.40
sulfides	2.71	0.56	0.40
cyanide	0.00	0.00	0.00
sodium dichromate	0.00	0.00	0.00
nitrates	0.05	0.01	0.01

Again emissions for the JAWS systems are lower than those for the conventional systems in all cases. Comparisons for the major water emissions (chemical oxygen demand, biological oxygen demand, and suspended solids) for conventional and JAWS systems (omitting pallets) are presented in Figure 9. Reductions in emissions for these components are over 70% in all cases. Data is provided in Table A18 in Appendix A.

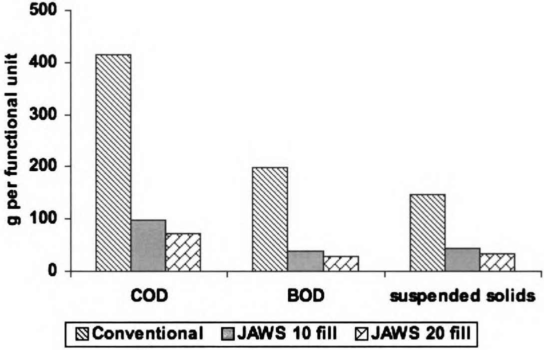

Figure 9 Comparisons of major water emissions

Further reductions in water emissions for the JAWS systems compared to the conventional system would arise from the reduction in transportation requirements. Reductions in water emissions would generally be proportional to reductions in energy consumption, and are not detailed here, but are included in Appendix C for both gasoline and diesel.

3.3.7. Solid waste

The effects of solid waste reductions for the JAWS system are strongly dependent on the prevailing recycling habits and rates. The recycling rates for the relevant materials used for purposes of estimation are shown in Table 14. The rates for PET bottles and for corrugated boxes represent the current average recycling rates in the U.S. [34, 35]

Table 14 Recovery/recycling rates used for estimation of solid waste contributions

Recovery/recycling rates used for estimation	Percent
PET bottles	23.5
PET blisters	0
Corrugated Box	78.3
LDPE Stretch Wrap	78.3
PP sprayers, labels, cartridges	0
LDPE shrink wrap	0
Wood pallets	78.3

The recycling rate for wooden pallets was 15.4% in 2003, according to the EPA. However, this does not include reuse of pallets, which can be substantial, but is also highly variable, depending on the type of pallet used and the system employed. Because of this lack of data, a combined recovery and recycling rate equal to that for corrugated was used for pallets. No specific data was found on stretch wrap recycling. Pallet stretch wrap is recycled much more than other types of film.

The overall recycling rate for plastic film in 2003 was less than 6%. Since this significantly underestimates recycling of pallet stretch wrap, a recycling rate equal to that for corrugated boxes was assumed, as had been done for the wood pallets. This overestimates the actual recycling rate. For LDPE shrink wrap, on the other hand, there are almost no recycling opportunities in the U.S. Therefore, a recycling rate of 0 was assumed for this material. Similarly, there are virtually no recycling opportunities for the PP sprayers or for the PP cartridges, so recycling rates were also estimated at 0 for these materials. The bottle labels will be collected and processed at the same rate as the PET bottles to which they are attached. However, the labels become a waste material at the processing facility, so a recycling rate of 0 was also used for the PP labels. PET blisters are potentially recoverable, but they are generally not accepted in PET bottle recycling collection systems, so a recycling rate of 0 was also used for the PET blisters.

Table 15 Estimated solid waste contributions after recycling, g per functional unit

Solid waste after recycling/recovery (g/functional unit)	**Conventional**	**Jaws 10 fill**	**Jaws 20 fill**
PET bottle	39969	3681	1841
PET blister	0	6269	6269
PP film (labels)	2061	625	522
PP inj mold	25160	25039	24412
LDPE stretch wrap	110	31	23
LDPE shrink film	0	721	360
Bleached kraft paper	0	711	711
Corrugated box	8162	1470	1164
Pallet	14914	4199	3084
Total	90375	42746	38301

Using these recycling rates, the estimated solid waste contributions per functional units were calculated, and are presented in Table 15. Recovery amounts are presented in Table A21 in Appendix A. Figure 10 shows the overall solid waste contribution after recycling and recovery for all systems.

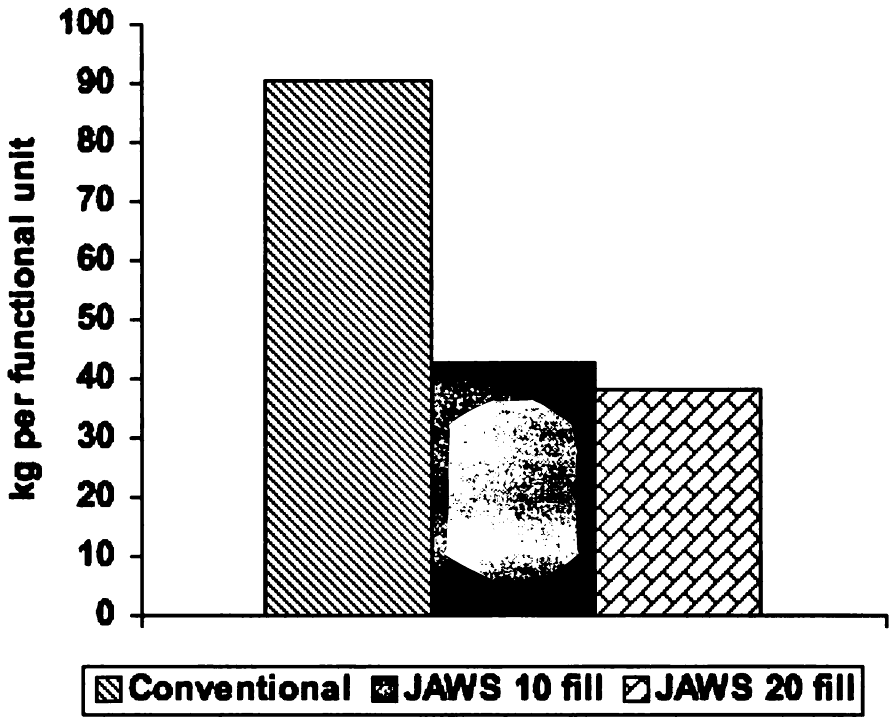

Figure 10 Comparisons of overall estimated solid waste

As can be seen, the JAWS system provides a significant reduction in solid waste going to landfill, even with the conservative assumptions used. Reduction in solid wastes is more than 52% for the 10 fill JAWS system, and more than 57% for the 20 fill system. Reductions in waste would be even larger if a return and refill or recycle system were implemented for the JAWS cartridges. In addition, packaging the refill cartridges in multi-packs of 2 or more cartridges would significantly cut down on solid wastes, as the PET blisters do not double or triple in size if the number of cartridges doubles or triples.

4. Limitations and Qualitative Discussions

As is common in analyses of this type, this study does not include resource use and emissions associated with manufacture of processing equipment and other ancillary operations. Such contributions are generally very small, contributing less to the overall impacts than the magnitude of the uncertainty in the main data.

More significantly, this study does not include impacts associated with the filling operation, with handling of materials, or with warehousing of packaging materials and finished products. Transportation of such materials is included only to a limited extent. Most impacts associated with the manufacture and use of pallets are also not included, as discussed earlier. It is expected that all of these factors, if included, would further favor the JAWS systems. For example, for the filling operation, it is expected that the energy requirements for putting the much smaller amount of liquid into the cartridges will be less than that required for putting the much larger amount of liquid into the conventional bottles. Certainly less space will be required for warehousing the cartridges than the bottles, and less energy will be consumed by forklifts, heating and cooling of warehouses and other storage space, etc. Any savings in energy consumption will bring with it savings in emissions of greenhouse gases and of air and water pollutants. Similarly, less solid waste going to disposal from the JAWS system means less transport energy and emissions associated with disposal.

It is assumed that plastics used are virgin resin. If recycled resins were used, this would likely save energy and reduce emissions. We did not attempt to quantify these potential effects, which could apply both to the conventional and to the JAWS systems. (The effect of recycled content in corrugated boxes is included, as indicated earlier.)

As discussed, refill of the cartridges would reduce solid waste impacts. If such a system were implemented, it would also likely result in savings in energy use and greenhouse gas emissions. These potential effects are not included in the analysis presented here.

It should be noted that information for energy requirements, air emissions and water for thermoformed PET sheet was not available; therefore values for PET film were used. These values were increased by 10% as a conservatively high estimate of the energy requirements, air emission and water emission for thermoformed PET blisters. Because of the likely overestimation of the energy required for manufacture of the PET blisters, air emission and water emission, the actual comparisons will even more strongly favor the JAWS system than is indicated here.

We did not examine JAWS systems averaging greater than 20 fills, although the trigger spray is robust enough to handle a significantly larger number, and the bottle should also be able to do so. An indication of the effects of a larger number of refills is provided by the comparison between the 10 fill and 20 fill systems. As the average number of refills increases, the differences between the conventional and the JAWS system also increase, further favoring JAWS.

5. Conclusion and Recommendation for future work

Based on the limitations discussed above, following is the summary of results obtained from the comparative life cycle analysis done between conventional packaging system and JAWS packaging system.

Summary:

1. The 10 fill JAWS system requires less than 47% of the total energy of conventional packaging and the 20 fill system requires less than 43%.
2. The 10 fill JAWS system uses less than 8% of the shipping energy used by the conventional system, and the 20 fill system less than 7%, reflecting the large mass of water shipped in the conventional system.
3. Greenhouse gas emissions associated with container manufacture for the 10 fill JAWS system are less than 45% of those for the conventional system, and for the 20 fill JAWS system are less than 40% of those for the conventional system.
4. Reduction in major air emissions (particulate, carbon monoxide, sulfur oxides, nitrogen oxides, and hydrocarbons) ranges from 56 to 66% for the 10 fill JAWS system, and even larger for the 20 fill system.
5. Reductions in major water emissions (chemical oxygen demand, biological oxygen demand, and suspended solids) are over 70% in both JAWS system.
6. Reduction in solid waste is more than 52% for the 10 fill JAWS system, and more than 57% for the 20 fill system.

Despite some limitations of the study, the message is clear. The JAWS system provides significant environmental benefits across an array of categories, compared to conventional packaging for window cleaner. The assumptions used in this analysis were chosen to minimize, rather than to add to, the differences between the systems. Therefore, actual differences are even larger than those presented here. This analysis was done specifically for window cleaner. However, the results are applicable, with only minor modification, to a variety of types of cleaners sold in similar packages.

Whether it is the energy use or the emissions, the JAWS packaging system comes out as a favorable choice compared with the conventional packaging system.

Recommendations for future work:

Though this study showed that the JAWS glass cleaner packaging system is a preferred choice in comparison to the conventional packaging system, there is additional useful research that can be done.

1. Since most of the omitted segments were not taken into consideration because of the lack of appropriate data, it is recommended to do this study using LCA software. The quality data can be taken from the databases/libraries of LCA software, which would help in quantifying detailed inventory, impacts and results.
2. Comparisons of bottles in other sizes were not included in this analysis. Therefore another opportunity of future work could be a similar LCA study between bottles of different sizes.
3. People also reuse the conventional packaging system by refilling it with the glass cleaner solution bought in bulk bottles without sprayers. So, a similar study; comparing the JAWS packaging system to the conventional packaging system with the refill option would be an interesting approach.

4. Since consumer behavior is an important factor for the success of any product, a study focusing on consumer's acceptance of the JAWS packaging system can really support the potential of the JAWS concept.
5. The JAWS concept requires use of concentrated cleaning solution, which may be harmful for a consumer in case of leakage. Thus a study considering the safety aspects related to the JAWS packaging system can ensure the protective function of this JAWS high performance packaging technology.

Appendices

6.1. Appendix A – Data Tables

Table A 1 Weights of Glass Cleaner Bottles

Brand	**Bottle weight (g) (including labels)**	**Sprayer weight (g)**
Brand 1 – 1	53.9592	28.9699
Brand 1 – 2	53.0484	29.1215
Brand 2 – 1	53.4054	28.7894
Brand 2 – 2	53.6573	28.9087
Brand 3 – 1	58.1779	21.1991
Brand 3 – 2	58.1165	21.2200
Brand 4 – 1	52.0254	21.6632
Brand 4 – 2	52.0746	21.4083
Average	54.3081	25.1600

Brands 1,2 and 4 are national brands; brand 3 is a store brand.

Table A 2 Energy Requirements for Packaging Manufacture - Electricity

Electricity per functional unit, MJ	**Conventional**	**JAWS 10 fill**	**JAWS 20 fill**
PET bottle	2056	189	95
PET blister*	0	228	228
PP oriented film labels	48	15	12
PP inj.mold.	809	805	785
LDPE film	10	17	9
Paper	0	8	8
Corrugated boxes	249	45	33
Total	**3172**	**1307**	**1170**

Table A 3 Energy Requirements for Packaging Manufacture – Oil fuels

Oil fuels per functional unit, MJ	**Conventional**	**JAWS 10 fill**	**JAWS 20 fill**
PET bottle	1707	157	79
PET blister*	0	225	225
PP oriented film labels	98	30	25
PP inj.mold.	1188	1183	1153
LDPE film	419	33	18
Paper	0	5	5
Corrugated boxes	18	3	2
Total	**3032**	**1637**	**1508**

Table A 4 Energy Requirements for Packaging Manufacture – Other fuels

Other fuels per functional unit, MJ	**Conventional**	**JAWS 10 fill**	**JAWS 20 fill**
PET bottle	1667	154	77
PET blister*	0	299	299
PP oriented film labels	58	18	15
PP inj.mold.	898	894	871
LDPE film	16	27	15
Paper	0	26	26
Corrugated boxes	819	147	108
Total	**3458**	**1564**	**1410**

* Values obtained by multiplying amounts for PET film by 1.1

Table A 5 Air emissions per functional unit, for PET bottles

G per functional unit	Conventional	JAWS 10 fill	JAWS 20 fill
particulates (PM10)	141.0669	12.9924	6.4962
CO	574.717	52.932	26.466
SO_x as SO_2	835.952	76.992	38.496
NO_x as NO_2	512.0206	47.1576	23.5788
HCl	16.19657	1.49172	0.74586
HF	0.574717	0.052932	0.026466
hydrocarbons not specified	449.3242	41.3832	20.6916
Organics	16.19657	1.49172	0.74586
metals not specified elsewhere	0.156741	0.014436	0.007218
H2	19.33139	1.78044	0.89022
aromatic HC not specified	18.80892	1.73232	0.86616
NMVOC (non-methane volatile organic compounds)	62.6964	5.7744	2.8872
ethylene (C2H4)	0.104494	0.009624	0.004812
Propylene	0.052247	0.004812	0.002406

Table A 6 Air emissions per functional unit, for PET bliseters

G per functional unit	Conventional	JAWS 10 fill	JAWS 20 fill
particulates (PM10)	0	16.55016	16.55016
CO	0	82.7508	82.7508
SO_x as SO_2	0	103.4385	103.4385
NO_x as NO_2	0	75.8549	75.8549
HCl	0	1.930852	1.930852
HF	0	0.068959	0.068959
hydrocarbons not specified	0	58.61515	58.61515
Organics	0	2.06877	2.06877
metals not specified elsewhere	0	0.0344795	0.0344795
H2	0	1.586057	1.586057
aromatic HC not specified	0	1.930852	1.930852
NMVOC (non-methane volatile organic compounds)	0	6.137351	6.137351
ethylene (C_2H_4)	0	0.012538	0.012538
Propylene	0	0.006269	0.006269

* Estimated by increasing values for PET film by 10%

Table A 7 Air emissions per functional unit, for PP film

G per functional unit	Conventional	JAWS 10 fill	JAWS 20 fill
particulates (PM10)	2.6793	0.8125	0.6786
CO	18.7551	5.6875	4.7502
SO_x as SO_2	20.61	6.25	5.22
NO_x as NO_2	13.3965	4.0625	3.393
HCl	0.35037	0.10625	0.08874
HF	0.012366	0.00375	0.003132
hydrocarbons not specified	8.8623	2.6875	2.2446
Organics	0.119538	0.03625	0.030276
metals not specified elsewhere	0.008244	0.0025	0.002088
H2	0.43281	0.13125	0.10962
aromatic HC not specified	0.2061	0.0625	0.0522
NMVOC (non-methane volatile organic compounds)	0.039159	0.011875	0.009918
ethylene (C_2H_4)	0.004122	0.00125	0.001044
Propylene	0.002061	0.000625	0.000522

Table A 8 Air emissions per functional unit, for PP injection molded (sprayers and cartridges)

G per functional unit	**Conventional**	**JAWS 10 fill**	**JAWS 20 fill**
particulates (PM10)	42.772	42.5663	41.5004
CO	276.76	275.429	268.532
SO_x as SO_2	276.76	275.429	268.532
NO_x as NO_2	226.44	225.351	219.708
HCl	5.5352	5.50858	5.37064
HF	0.20128	0.200312	0.195296
hydrocarbons not specified	118.252	117.6833	114.7364
Organics	1.45928	1.452262	1.415896
metals not specified elsewhere	0.07548	0.075117	0.073236
H2	7.548	7.5117	7.3236
aromatic HC not specified	2.516	2.5039	2.4412
NMVOC (non-methane volatile organic compounds)	0.52836	0.525819	0.512652
ethylene (C_2H_4)	0.05032	0.050078	0.048824
Propylene	0.02516	0.025039	0.024412

Table A 9 Air emissions per functional unit, for LLDPE film

G per functional unit	Conventional	JAWS 10 fill	JAWS 20 fill
particulates (PM10)	0.49995	0.85437	0.45936
CO	2.02	3.452	1.856
SO_x as SO_2	3.8885	6.6451	3.5728
NO_x as NO_2	2.525	4.315	2.32
HCl	0.05555	0.09493	0.05104
HF	0.00202	0.003452	0.001856
hydrocarbons not specified	2.2725	3.8835	2.088
Organics	0.08585	0.14671	0.07888
metals not specified elsewhere	0.00101	0.001726	0.000928
H2	0.05555	0.09493	0.05104
aromatic HC not specified	0.01919	0.032794	0.017632
NMVOC (non-methane volatile organic compounds)	0.2525	0.4315	0.232
ethylene (C_2H_4)	0.000505	0.000863	0.000464
Propylene	0.000505	0.000863	0.000464

Table A 10 Air emissions per functional unit, for corrugated boxes

G per functional unit	Conventional	JAWS 10 fill	JAWS 20 fill
Particulates	73.34535	13.20735	9.70125
CO	151.95652	27.36292	20.099
SO_x	221.54057	39.89297	29.30275
NO_x	130.51711	23.50231	17.26325
HCl	1.88065E-06	3.3865E-07	2.4875E-07
hydrocarbons not specified	0.75226	0.13546	0.0995
Organics	0.000349801	6.29889E-05	4.62675E-05
metals not specified elsewhere	0.00188065	0.00033865	0.00024875
Aldehydes	0.225678	0.040638	0.02985
odorous sulfur	1.090777	0.196417	0.144275
reduced sulfur	0	0	0
Ammonia	1.692585	0.304785	0.223875
Chlorine	1.76781E-05	3.18331E-06	2.33825E-06

Table A 11 Air emissions per functional unit, for paper inserts

G per functional unit	Conventional	JAWS 10 fill	JAWS 20 fill
Particulates	0	1.18737	1.18737
CO	0	0.69678	0.69678
SO_x	0	3.82518	3.82518
NO_x	0	4.14513	4.14513
HCl	0	0	0
hydrocarbons not specified	0	0.007821	0.007821
Organics	0	0.066834	0.066834
metals not specified elsewhere	0	0.000013509	0.000013509
Aldehydes	0	2.6307E-06	2.6307E-06
odorous sulfur	0	0.01422	0.01422
reduced sulfur	0	0.02844	0.02844
Ammonia	0	0.02844	0.02844
Chlorine	0	0.010665	0.010665

Table A 12 Comparison of major air emissions per functional unit.

G per functional unit	Conventional	JAWS 10 fill	JAWS 20 fill
Particulates	260.36	88.17	76.57
CO	1024.21	448.31	405.15
SO_x	1358.75	512.47	452.39
NO_x	884.90	384.39	346.26
hydrocarbons	588.12	227.02	200.68

Table A 13 Water emissions per functional unit, for PET bottles

G per functional unit	Conventional	JAWS 10 fill	JAWS 20 fill
COD (chemical oxygen demand)	62.6964	5.7744	2.8872
BOD (biological oxygen demand)	104.494	9.624	4.812
Na+compounds as Na	11.49434	1.05864	0.52932
acid as H+	0.313482	0.028872	0.014436
NO3-	0.156741	0.014436	0.007218
metals not specified elsewhere	1.04494	0.09624	0.04812
ammonium compounds as NH4+	0.208988	0.019248	0.009624
Cl-	11.49434	1.05864	0.52932
dissoved organic not specified	0.888199	0.081804	0.040902
suspended solids	22.98868	2.11728	1.05864
detergent/oil	1.04494	0.09624	0.04812
hydrocarbons not specified	5.74717	0.52932	0.26466
Phenols	0.052247	0.004812	0.002406
dissolved solids not specified	7.83705	0.7218	0.3609
other nitrogen as N	0.104494	0.009624	0.004812
other organics not specified	15.6741	1.4436	0.7218
SO4--	18.28645	1.6842	0.8421
TOC (toxic organic compounds)	2.142127	0.197292	0.098646
CO3--	4.232007	0.389772	0.194886

Table A 14 Water emissions per functional unit, for PET blisters

G per functional unit	Conventional	JAWS 10 fill	JAWS 20 fill
COD (chemical oxygen demand)	0	9.65426	9.65426
BOD (biological oxygen demand)	0	6.8959	6.8959
Na+compounds as Na	0	1.517098	1.517098
acid as H+	0	0.357333	0.357333
NO3-	0	0.081497	0.081497
metals not specified elsewhere	0	0.137918	0.137918
ammonium compounds as NH4+	0	0.025076	0.025076
Cl-	0	1.517098	1.517098
dissoved organic not specified	0	0.094035	0.094035
suspended solids	0	2.482524	2.482524
detergent/oil	0	0.131649	0.131649
hydrocarbons not specified	0	0.50152	0.50152
Phenols	0	0.006269	0.006269
dissolved solids not specified	0	0.896467	0.896467
other nitrogen as N	0	0.012538	0.012538
other organics not specified	0	2.344606	2.344606
SO4--	0	2.413565	2.413565
TOC (toxic organic compounds)	0	0.156725	0.156725
CO3--	0	0.545403	0.545403

* Estimated by increasing values for PET film by 10%

Table A 15 Water emissions per functional unit, for PP labels

G per functional unit	Conventional	JAWS 10 fill	JAWS 20 fill
COD (chemical oxygen demand)	1.15416	0.35	0.29232
BOD (biological oxygen demand)	0.121599	0.036875	0.030798
Na+compounds as Na	0.127782	0.03875	0.032364
acid as H+	0.006183	0.001875	0.001566
NO3-	0.24732	0.075	0.06264
metals not specified elsewhere	0.022671	0.006875	0.005742
ammonium compounds as NH4+	0.010305	0.003125	0.00261
Cl-	0.32976	0.1	0.08352
dissoved organic not specified	0.022671	0.006875	0.005742
suspended solids	0.84501	0.25625	0.21402
detergent/oil	0.030915	0.009375	0.00783
hydrocarbons not specified	0.010305	0.003125	0.00261
Phenols	0.004122	0.00125	0.001044
dissolved solids not specified	0.051525	0.015625	0.01305
other nitrogen as N	0.012366	0.00375	0.003132
other organics not specified	0.201978	0.06125	0.051156
SO4--	1.93734	0.5875	0.49068
TOC (toxic organic compounds)	0.018549	0.005625	0.004698
CO3--	0.059769	0.018125	0.015138

Table A 16 Water emissions per functional unit, for injection molded PP

G per functional unit	Conventional	JAWS 10 fill	JAWS 20 fill
COD (chemical oxygen demand)	6.29	6.25975	6.103
BOD (biological oxygen demand)	0.72964	0.726131	0.707948
Na+compounds as Na	1.48444	1.477301	1.440308
acid as H+	0.10064	0.100156	0.097648
NO3-	3.0192	3.00468	2.92944
metals not specified elsewhere	0.22644	0.225351	0.219708
ammonium compounds as NH4+	0.1258	0.125195	0.12206
Cl-	3.774	3.75585	3.6618
dissoved organic not specified	0.27676	0.275429	0.268532
suspended solids	9.3092	9.26443	9.03244
detergent/oil	0.3774	0.375585	0.36618
hydrocarbons not specified	0.1258	0.125195	0.12206
Phenols	0.05032	0.050078	0.048824
dissolved solids not specified	0.57868	0.575897	0.561476
other nitrogen as N	0.02516	0.025039	0.024412
other organics not specified	2.44052	2.428783	2.367964
SO4--	23.6504	23.53666	22.94728
TOC (toxic organic compounds)	0.22644	0.225351	0.219708
CO3--	0.72964	0.726131	0.707948

Table A 17 Water emissions per functional unit, for LDPE film

G per functional unit	Conventional	JAWS 10 fill	JAWS 20 fill
COD (chemical oxygen demand)	0.25755	0.44013	0.23664
BOD (biological oxygen demand)	0.029795	0.050917	0.027376
Na+compounds as Na	0.04545	0.07767	0.04176
acid as H+	0.002525	0.004315	0.00232
NO3-	0.001515	0.002589	0.001392
metals not specified elsewhere	0.00606	0.010356	0.005568
ammonium compounds as NH4+	0.001515	0.002589	0.001392
Cl-	0.07575	0.12945	0.0696
dissoved organic not specified	0.005555	0.009493	0.005104
suspended solids	0.202	0.3452	0.1856
detergent/oil	0.00606	0.010356	0.005568
hydrocarbons not specified	0.003535	0.006041	0.003248
Phenols	0.00101	0.001726	0.000928
dissolved solids not specified	0.018685	0.031931	0.017168
other nitrogen as N	0.00303	0.005178	0.002784
other organics not specified	0	0	0
SO4--	0.25755	0.44013	0.23664
TOC (toxic organic compounds)	0.00707	0.012082	0.006496
CO3--	0.02121	0.036246	0.019488

Table A 18 Water emissions per functional unit, for corrugated boxes

G per functional unit	Conventional	JAWS 10 fill	JAWS 20 fill
COD (chemical oxygen demand)	345.66347	71.97608	50.58176
BOD (biological oxygen demand)	92.15185	19.1884	13.4848
Phosphorus	1.203616	0.250624	0.176128
Phosphates	2.820975	0.5874	0.4128
Acid	0.526582	0.109648	0.077056
metals not specified elsewhere	6.130919	1.276616	0.897152
Ammonia	0.865099	0.180136	0.126592
Nitrogen	1.278842	0.266288	0.187136
Phenols	0.03234718	0.00673552	0.00473344
suspended solids	114.34352	23.80928	16.73216
dissolved solids	5.64195	1.1748	0.8256
Oil	2.708136	0.563904	0.396288
Sulfides	2.708136	0.563904	0.396288
Cyanide	3.7613E-06	7.832E-07	5.504E-07
sodium dichromate	0	0	0
Nitrates	0.0451356	0.0093984	0.0066048

Table A 19 Water emissions per functional unit, for paper inserts

G per functional unit	Conventional	JAWS 10 fill	JAWS 20 fill
COD (chemical oxygen demand)	0	3.09996	3.09996
BOD (biological oxygen demand)	0	2.01213	2.01213
phosphorus	0	0.0711	0.0711
phosphates	0	0.041949	0.041949
Acid	0	0.002133	0.002133
metals not specified elsewhere	0	0.00001422	0.00001422
Ammonia	0	0.19908	0.19908
Nitrogen	0	0.027729	0.027729
Phenols	0	3.9816E-08	3.9816E-08
suspended solids	0	4.38687	4.38687
dissolved solids	0	0.19908	0.19908
Oil	0	0.000036972	0.000036972
Sulfides	0	3.6972E-06	3.6972E-06
Cyanide	0	7.821E-08	7.821E-08
sodium dichromate	0	2.4174E-06	2.4174E-06
Nitrates	0	0	0

Table A 20 Comparison of major water emissions per functional unit.

G per functional unit	Conventional	JAWS 10 fill	JAWS 20 fill
COD (chemical oxygen demand)	416.06	97.55	72.86
BOD (biological oxygen demand)	197.53	38.53	27.97
suspended solids	147.69	42.66	34.09

Table A 21 Recovery and recycling of packaging materials

G per functional unit	Conventional	JAWS 10 fill	JAWS 20 fill
PET bottle	12278	1131	565
PET blister	0	0	0
PP film (labels)	0	0	0
PP inj mold	0	0	0
LDPE stretch wrap	395	111	81
LDPE shrink film	0	0	0
Bleached kraft paper	0	0	0
Corrugated box	29451	5303	3895
Pallet	53812	15153	15671
Total	**95937**	**21698**	**15671**

6.2. Appendix B – Corrugated Box, Pallet and Stretch Wrap Calculations

1. Corrugated Box

The corrugated box used for shipping the JAWS bottle plus two cartridge system weighed 635 g and contained 15 bottles. The perimeter of the box measured 21.5" x 14.375".

To arrive at a weight for the boxes for the conventional system, it was assumed that the same corrugated board would be used, and that the box height would be the same. The area is smaller due to the configuration (no space for blisters required). The measured length and width of a box for the conventional bottles was 13.875" x 11.625".

Therefore, the weight of the conventional box, containing 12 bottles, was calculated by multiplying the weight of the JAWS box by the ratio of the perimeters, giving a value of 451.359 g/box

2. Pallets

Pallets were assumed to weigh 27.2155 kg each.

For the conventional system, 12 bottles (or 200 cartridge refills) are packaged per corrugated box (13.875" x 11.625" in perimeter). 11 boxes per layer fit on a standard pallet, and are stacked 3 high, for a total of 33 boxes per pallet. This equals 396 bottles per pallet load.

Because the JAWS boxes are larger (21.5" x 14.375" perimeter), only 5 boxes fit per pallet layer, for a total of 15 boxes per pallet, or a total of 180 bottles or 3000 cartridges.

3. Stretch wrap

Experiments were performed at the School of Packaging. It was determined that the weight of stretch wrap for a 40" by 40" pallet was 0.4 lbs, 181 g. Since the distribution system uses 40" x 48" pallets, this amount was increased in proportion to the perimeter, for a total of 200 g stretch wrap per pallet

4. Weights per package system

Table A22 shows the weights of secondary packaging per bottle, for the conventional system, and per bottle-2-cartridge system and per refill cartridge for the JAWS system.

Table A 22 Weights of secondary packaging

Weight, g	Per bottle Conventional	Per bottle system JAWS	Per cartridge
corrugated box	37.61	42.33	3.18
stretch wrap	0.51	1.11	0.07
pallet	68.73	151.20	9.07

6.3. Appendix C – Truck Transport-Related Emissions

Calculation of fuel use per functional unit for 500 mile average distance from filler to retailer:

Table A 23 Shipping weights

	Conventional	JAWS 10 fill	JAWS 20 fill
Shipping wt, kg	1094.312617	75.16957001	64.69689204
Shipping wt, tons	1.203743879	0.082686527	0.071166581

Diesel or gasoline consumption: 9.4 gal/1,000 ton-miles (Franklin Assoc., 2004).

Table A 24 Fuel consumption per functional unit for 500-mile average distance from filler to retailer

Diesel or gasoline	Conventional	JAWS 10 fill	JAWS 20 fill
For 500 mile, gal	5.657596231	0.388626677	0.334482932

Following tables represents the emissions for semi-trailer trucks running on gasoline, 500 mile average distance from filler to retailer.

Table A 25 Air emissions

Air emissions g per FU	Conventional	JAWS 10 fill	JAWS 20 fill
Particulates	114.8141264	7.886712057	6.787929722
NO_x	168.2399391	11.55659149	9.946518944
Methane	8.861492976	0.608705964	0.523900616
hydrocarbons, other	162.589132	11.16843117	9.612437392
sulfur oxides	67.55283051	4.640280248	3.993793103
CO	988.8912452	67.92805686	58.46427166

Table A 25 Contd.

Aldehydes	1.027419476	0.070574605	0.0607421
organics, other	300.5201966	20.64307183	17.76706437
Ammonia	0.087330655	0.005998841	0.005163079
Lead	0.796250094	0.054695319	0.047075128
Nickel	0.003595968	0.000247011	0.000212597
Chlorine	0.003339113	0.000229367	0.000197412
HCl	0.053939522	0.003705167	0.00318896
HF	0.007191936	0.000494022	0.000425195
metals, other	0.005907662	0.000405804	0.000349267
nitrous oxide	0.006164517	0.000423448	0.000364453

Table A 26 Water emissions

Water emissions g/FU	Conventional	JAWS 10 fill	JAWS 20 fill
COD (chemical oxygen demand)	1.90072603	0.130563018	0.112372886
BOD (biological oxygen demand)	0.282540356	0.019408016	0.016704078
dissolved solids	76.28589606	5.240164387	4.510100956
suspended solids	1.746613108	0.119976828	0.103261571
Oil	1.772298595	0.121741193	0.104780123
sulfuric acid	0.015154437	0.001040975	0.000895946
Ammonia	0.030822584	0.002117238	0.001822263
Boron	0.061645169	0.004234476	0.003644526
Cadmium	0.002825404	0.00019408	0.000167041
Iron	0.041096779	0.002822984	0.002429684
Chromium	0.002825404	0.00019408	0.000167041
metal, other	0.41096779	0.028229842	0.02429684
Chlorides	2.799718071	0.192315797	0.165522224
Sulfates	2.260322846	0.15526413	0.133632621
Phosphates	0.007705646	0.00052931	0.000455566
other organics	0.184935506	0.012703429	0.010933578

Following tables represents the emissions for semi-trucks running on diesel, 500 mile average distance from filler to retailer.

Table A 27 Air emissions

Air emissions g per FU	Conventional	JAWS 10 fill	JAWS 20 fill
particulates	80.9092837	5.557750107	4.783440408
NOx	559.9436142	38.46315947	33.10444473
methane	10.40262219	0.714567871	0.615013767
hydrocarbons, other	225.7754297	15.50876935	13.34807657
sulfur oxides	159.2500187	10.9390637	9.415025565
CO	552.2379681	37.93384994	32.64887898
aldehydes	15.33423567	1.053325973	0.906575849
organics, other	297.9516479	20.46663531	17.61520912
ammonia	0.102741948	0.00705746	0.00607421
lead	0.000359597	2.47011E-05	2.12597E-05
nickel	0.004366533	0.000299942	0.000258154
chlorine	0.003852823	0.000264655	0.000227783
HCl	0.064213717	0.004410913	0.003796381
HF	0.008476211	0.00058224	0.000501122
metals, other	0.006935081	0.000476379	0.000410009
nitrous oxide	0.007191936	0.000494022	0.000425195

Table A 28 Water emissions

Water emissions g/FU	Conventional	JAWS 10 fill	JAWS 20 fill
COD	2.234637359	0.153499765	0.132114068
BOD	0.33391133	0.022936746	0.019741183
dissolved solids	89.38549437	6.139990594	5.284562737
suspended solids	2.029153464	0.139384844	0.119965648
oil	2.080524438	0.142913574	0.123002753
sulfuric acid	0.017722986	0.001217412	0.001047801
ammonia	0.035959682	0.002470111	0.002125974
boron	0.071919363	0.004940222	0.004251947
cadmium	0.003339113	0.000229367	0.000197412
iron	0.048802425	0.003352294	0.00288525
chromium	0.003339113	0.000229367	0.000197412
metal, other	0.488024251	0.033522937	0.028852498
chlorides	3.287742322	0.225838735	0.194374721
sulfates	2.645605149	0.181729607	0.156410909
phosphates	0.00898992	0.000617528	0.000531493
other organics	0.218326639	0.014997103	0.012907696

6.4. Appendix D – Shrink-wrapped JAWS bottle with two cartridges

Figure 11 Shrink-wrapped JAWS bottle with two cartridges.

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