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JAWS Concentrated Cartridge —— Packaging Technology —— Environmental Impact Study

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05-31-06

Comparison of Life Cycle Impacts of JAWS Glass Cleaner and Conventional Glass Cleaner Packaging Systems

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May 31, 2006

Executive Summary

This study compared the life cycle impacts of glass cleaner in conventional 32-oz. capacity PET spray bottles and glass cleaner in the JAWS 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. In both cases, the JAWS system provided a variety of environmental benefits. As would be expected, these benefits increased with more fills per bottle. However, they were quite large even at the conservative 10 fill per bottle level.

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 consumption, greenhouse gas emissions, air pollutants, water pollutants, and solid wastes.

Figure ES1 illustrates the savings in total material use, energy, and greenhouse gas emissions provided by the JAWS system. Figure ES2 shows the decrease in selected air and water emissions.

Figure ES-1 Proportional values of material use, energy for manufacture of packaging systems, and greenhouse gas emissions for conventional window cleaner systems, JAWS system averaging 10 fills per bottle, and JAWS system averaging 20 fills per bottle.

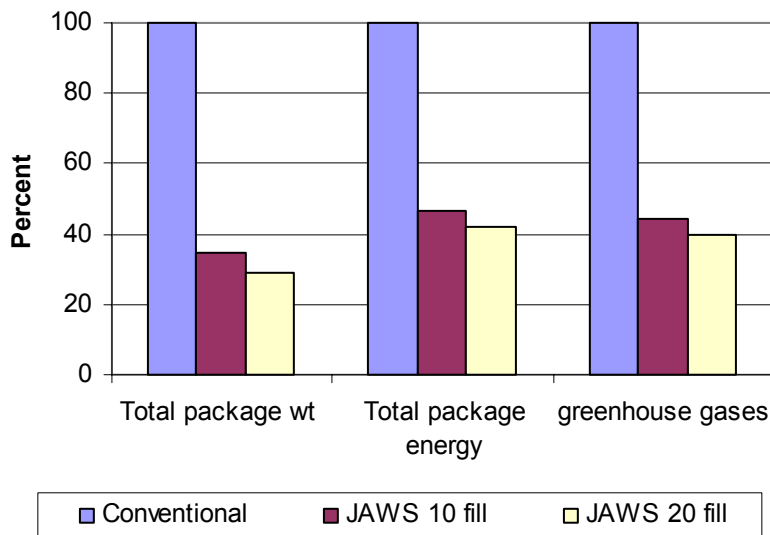
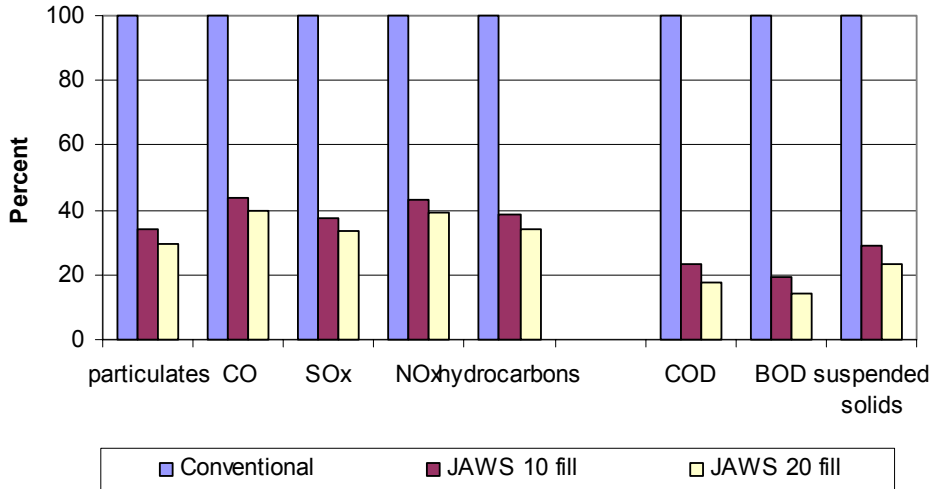


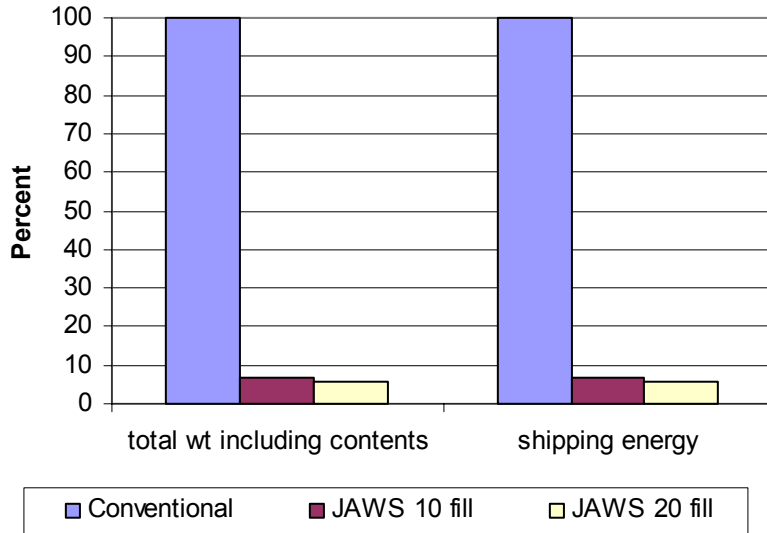
Figure ES-2 Proportional values of selected air emissions (particulates, carbon monoxide, sulfur oxides, nitrogen oxides and hydrocarbons) and in selected water emissions (chemical oxygen demand, biological oxygen demand and suspended solids) for manufacture of packaging systems for conventional window cleaner systems, JAWS system averaging 10 fills per bottle, and JAWS system averaging 20 fills per bottle.



Reductions in other air and water emissions associated with package system manufacture are similar, and are reported in detail in Appendix 1.

There are also significant savings in energy and emissions associated with transport of the filled packages to the retailer (and smaller savings associated with transport from the retailer to the end use location). Figure ES3 illustrates the reduction in weight and in shipping energy associated with distribution by truck from the filler to the retailer, assuming energy use is proportional to weight of the load.

Figure ES-3 Proportional values of energy associated with transport of filled packages to retailer for conventional window cleaner systems, JAWS system averaging 10 fills per bottle, and JAWS system averaging 20 fills per bottle.



I. Objective:

The objective of this project was to compare the life cycle impacts of conventional packaging of surface cleaners for home use with the packaging of surface cleaners based on the JAWS (Just Add Water) system. In this system, the cleaner is distributed in concentrated form, in cartridges. The product is diluted at home through a simple process of adding water to the empty bottle, placing the cartridge in the bottle neck, applying the spray fixture, and shaking. Following initial purchase of the empty bottle plus two cartridges, consumers can purchase refill cartridges and do not need to acquire a new bottle. Cartridges are packaged in PET blisters.

The specific system chosen for analysis was glass cleaner in 32-oz PET spray bottles. The package systems compared include the primary package (bottle, sprayer, labels, etc.) and the distribution packaging (corrugated boxes, pallets, stretch wrap). Additional details are provided in the methodology section.

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.

In any study of this type, assumptions must be made. We have attempted to clearly indicate all significant assumptions, throughout the report. Our guiding principle in making assumptions was to be conservative – meaning that if the assumptions might “favor” either the JAWS or the conventional system, the assumption chosen would favor the conventional system. Therefore, conclusions drawn from the data presented are robust; in most cases, the differences found in favor of the JAWS system are likely even larger than those presented here.

II. Description of Package Systems and Functional Unit

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).

The systems to be compared consist of:

Conventional packaging

Primary: stretch blow molded polyethylene terephthalate (PET) bottles (32 oz), polypropylene (PP) film labels, injection molded PP spray attachments.

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

JAWS packaging

Primary:

- (a) Bottle system: PET bottles (32 oz), PP cartridges, PET blisters, PP labels, paper inserts, PP spray attachments, LDPE shrink wrap.
- (b) Cartridge refill system: PP cartridges, PET blisters, PP labels, paper inserts.

Distribution: corrugated boxes, LDPE stretch wrap, wood pallets.

Details of the package systems are shown in Table 1.

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 4.) 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 1. 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.

Table 1 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

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 2.

The weight of pallet stretch wrap was calculated based on experiments carried out at the School of Packaging (see Appendix 2). The weight of a pallet is based on average weight of grocery pallets (Twede et al, 2006). 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 1, the weights of materials required to deliver one functional unit (32,000 ounces of glass cleaner) can be obtained, and are presented in Table 2. 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 2.

In Table 3, 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 2 Weight of packaging components per functional unit (32,000 oz. of glass cleaner).

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 3 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

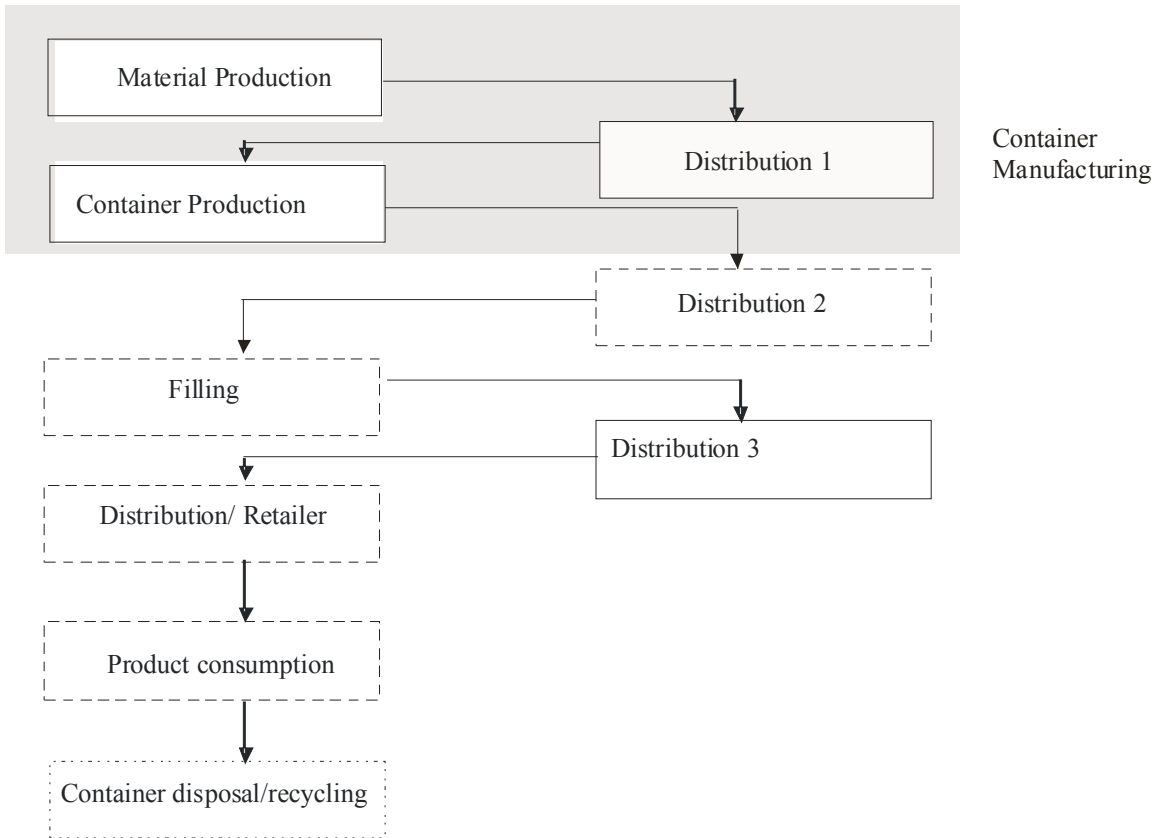
*Entries may not add to total due to rounding

III. Package System Life Cycle Inventory and Impacts

A. 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 1. 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 1. Schematic of Life Cycle. Dashed lines indicate components not included in analysis. Dotted line indicates only solid waste disposal included.



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

- Total energy
 - Electricity
 - Oil
 - Other
- Greenhouse gas emissions
- Air pollutant emissions
- Water pollutant emissions
- 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. 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 (Franklin Assoc., 2004). 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.

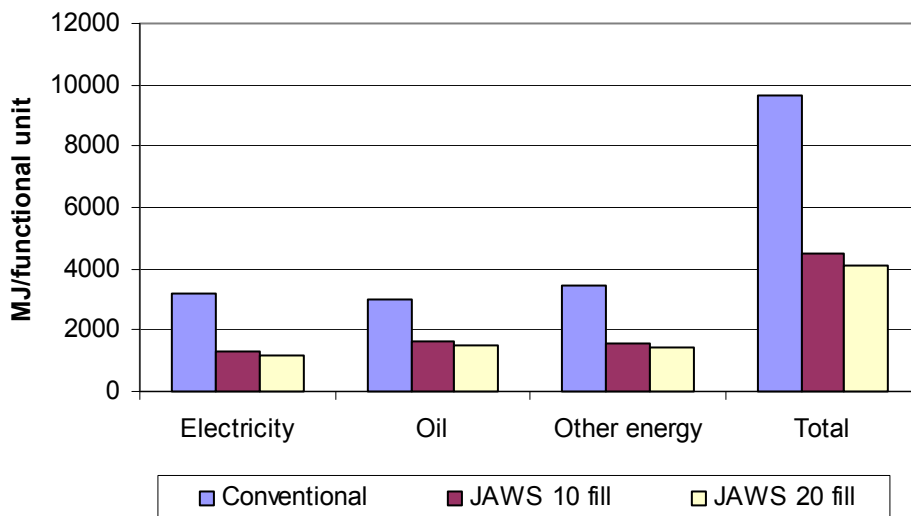
Pallets were assumed to be made of softwood. They were included in calculating the weight of the load for the Distribution 3 segment and in estimating solid waste contributions, but energy consumption and emissions associated with pallet manufacture and distribution were not otherwise included, due to 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.

B. Energy Consumption for Package Manufacture

Energy used was divided into 3 categories: electricity, oil fuels, and other fuels. Initially we planned to distinguish between fossil fuels and non-fossil fuels, and between feedstock and other types of energy. However, due to differences in the types of data available from various sources, this could not be done.

Overall energy consumption for manufacture of the packaging involved in the three systems being compared is shown in Figure 2. 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 1. Note that pallets are not included in this tabulation, due to lack of reliable data.

Figure 2. Energy required for manufacture of conventional packaging, JAWS 10 fill, and JAWS 20 fill (using a high estimate for PET blisters and omitting pallets), MJ per functional unit.



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.

C. 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 4. It is assumed that energy consumption by the trucks is proportional to the weight being hauled (Franklin Assoc., 2004).

Energy requirements (and emissions) for shipping depend on the transportation distance. Table 5 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 4 Total weights of filled package systems shipped to retailer, 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 5 Energy requirements for shipping filled package systems to retailer, MJ per functional unit.

	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.

D. 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 6, 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.

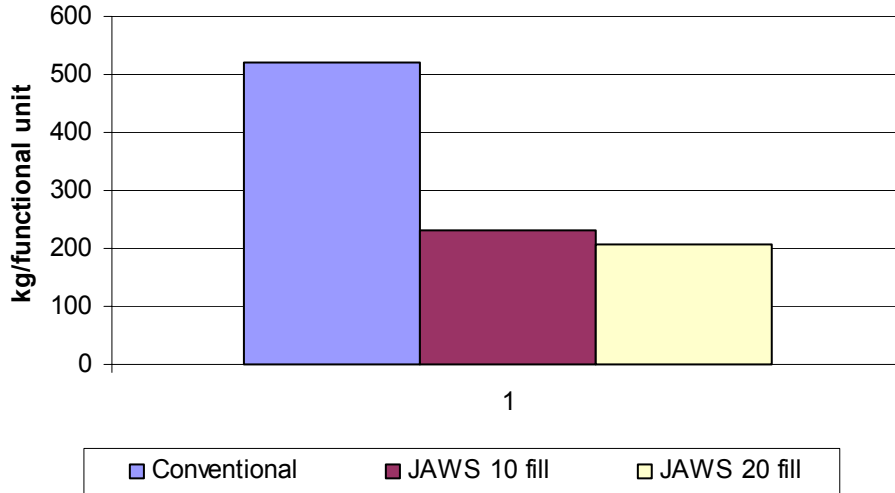
Table 6 Greenhouse gas emissions for manufacture of the conventional and JAWS systems, in kg CO₂ equivalents per functional unit (omitting pallets).

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

Overall greenhouse gas emissions for the systems being compared are presented graphically in Figure 3.

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 3 Comparison of greenhouse gas emissions for conventional and JAWS systems, kg CO₂ equivalents per functional unit (omitting pallets).



E. Air Pollutant Emissions

Emissions of air pollutants from the conventional and JAWS systems are compared in the following tables. Table 7 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 1). Table 8 shows the emissions from the paper components (details are in tables A8 and A9 in Appendix 1). 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 4. 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 1.

Table 7 Major air emissions from production of plastics materials in packaging systems, g per functional unit.

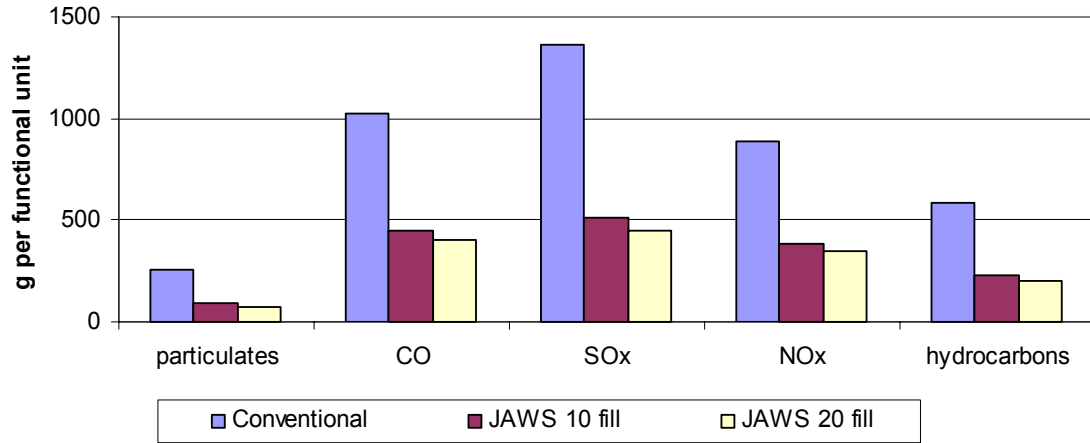
Total emissions (g/functional unit)	Conventional	Jaws 10 fill	Jaws 20 fill
particulates (PM10)	187.02	73.78	65.68
CO	872.25	420.25	384.36
SOx as SO ₂	1137.21	468.75	419.26
NOx as NO ₂	754.38	356.74	324.85
HCl	22.14	9.13	8.19
HF	0.79	0.33	0.30
hydrocarbons not specified	587.37	226.88	200.57
organics	17.86	5.20	4.34
metals	0.24	0.13	0.12
H ₂	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 ₂ H ₄	0.16	0.07	0.07
propylene	0.08	0.04	0.03

* Non-methane volatile organic compounds

Table 8 Major air 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
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 4 Comparisons of major air emissions for conventional and JAWS systems (omitting pallets).



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 3 for both gasoline and diesel.

F. Water Emissions

Emissions of water pollutants from the conventional and JAWS systems are compared in the following tables. Table 9 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 1). Table 10 shows the emissions from the paper components (details are in tables A16 and A17 in Appendix 1). 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 9 Major water emissions from production of plastics materials in packaging systems, g per functional unit.

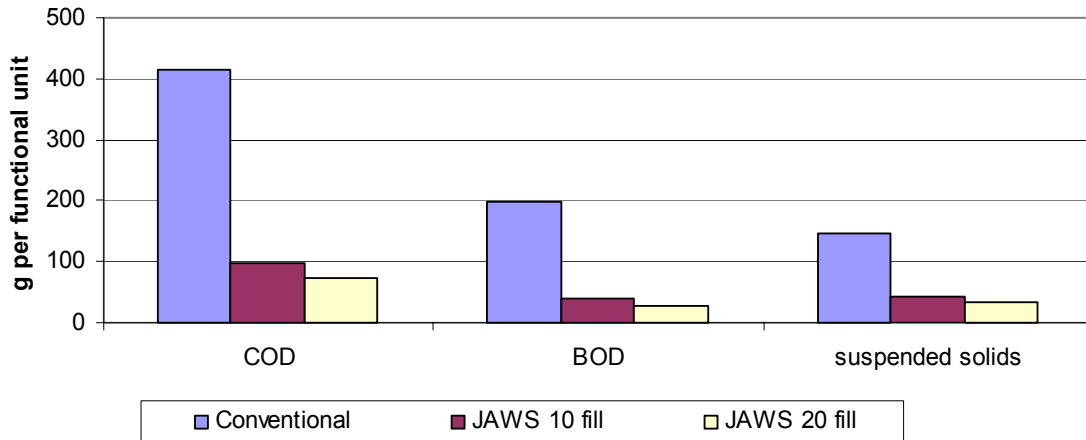
Total emissions (g/functional unit)	Conventional	Jaws 10 fill	Jaws 20 fill
COD (chemical oxygen demand)	70.40	22.48	19.17
BOD (biological oxygen demand)	105.38	17.33	12.47
Na+ compounds as Na acid as H+	13.15	4.17	3.56
	0.42	0.49	0.47
NO3-	3.42	3.18	3.08
metals not specified elsewhere	1.30	0.48	0.42
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 10 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 (COD, BOD, and suspended solids) are presented in Figure 5. Reductions in emissions for these components are over 70% in all cases. Data is provided in Table A18 in Appendix 1.

Figure 5 Comparisons of major water emissions (chemical oxygen demand, biological oxygen demand, and suspended solids) for conventional and JAWS systems (omitting pallets).



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 3 for both gasoline and diesel.

G. Solid Wastes

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 11. The rates for PET bottles and for corrugated boxes represent the current average recycling rates in the U.S (APC, 2006; AF&PA, 2006).

The recycling rate for wooden pallets was 15.4% in 2003, according to the EPA (US EPA, 2005). 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% (US EPA, 2005). 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 11 Recovery/recycling rates used for estimation of solid waste contributions

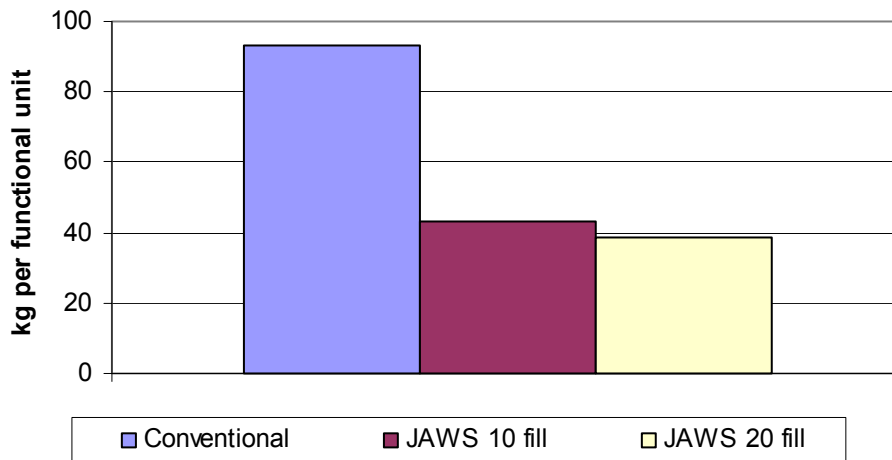
Recovery/recycling rates used for estimation	Percent
PET bottles	21.6
PET blisters	0
Corrugated Box	76.6
LDPE Stretch Wrap	76.6
PP sprayers, labels, cartridges	0
LDPE shrink wrap	0
Wood pallets	76.6

Using these recycling rates, the estimated solid waste contributions per functional unit were calculated, and are presented in Table 12. Recovery amounts are presented in Table A21 in Appendix 1. Figure 6 shows the overall solid waste contribution after recycling and recovery.

Table 12 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	40962	3773	1886
PET blister	0	6269	6269
PP film (labels)	2061	625	522
PP inj mold	25160	25039	24412
LDPE stretch wrap	118	33	24
LDPE shrink film	0	721	360
Bleached kraft paper	0	711	711
Corrugated box	8801	1585	1164
Pallet	16082	4528	3326
Total	93184	43284	38675

Figure 6 Comparisons of overall estimated solid waste amounts after recycling and recovery for conventional and JAWS systems.



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 53% for the 10 fill JAWS system, and more than 58% 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 multipacks 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.

IV. 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 warehouse 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.

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.

Despite these 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. Comparisons of bottles in other sizes also are not included in this analysis. It can be expected that results would be similar, but not identical. These results cannot be extended, however, to products sold in containers other than PET bottles.

V. Market Information

Information about the size of the market for glass and similar cleaners would be helpful in estimating the overall potential environmental impact of adoption of the JAWS system. However, we were not able to obtain this information. According to the Global Market Information Database (2006), the average world retail value of sales of household surface cleaners of all types was \$8,307 (U.S.) per thousand households in 2004, continuing a steady rise from \$6,910 per thousand households in 2000. The total market in 2004 was \$13.9 billion (U.S.). It should be noted that this category includes items such as drain cleaner that would not be appropriate for the JAWS approach, as well as items such as multipurpose surface cleaner that likely would be adaptable.

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Appendix 1. Data Tables

Table A1. 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 A2 Energy Requirements for Packaging Manufacture

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

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

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 A3 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
H ₂	19.33139	1.78044	0.89022
aromatic HC not specified	18.80892	1.73232	0.86616
NM VOC (non-methane volatile organic compounds)	62.6964	5.7744	2.8872
ethylene (C ₂ H ₄)	0.104494	0.009624	0.004812
propylene	0.052247	0.004812	0.002406

Table A4 Air emissions per functional unit, for PET blisters*

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
H ₂	0	1.586057	1.586057
aromatic HC not specified	0	1.930852	1.930852
NM VOC (non-methane volatile organic compounds)	0	6.137351	6.137351
ethylene (C ₂ H ₄)	0	0.012538	0.012538
propylene	0	0.006269	0.006269

* estimated by increasing values for PET film by 10%

Table A5 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
H ₂	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 ₂ H ₄)	0.004122	0.00125	0.001044
propylene	0.002061	0.000625	0.000522

Table A6 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
H ₂	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 ₂ H ₄)	0.05032	0.050078	0.048824
propylene	0.02516	0.025039	0.024412

Table A7 Air emissions per functional unit, for LDPE 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
H ₂	0.05555	0.09493	0.05104
aromatic HC not specified	0.01919	0.032794	0.017632
NMVOOC (non-methane volatile organic compounds)	0.2525	0.4315	0.232
ethylene (C ₂ H ₄)	0.000505	0.000863	0.000464
propylene	0.000505	0.000863	0.000464

Table A8 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 A9 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 A10 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 A11 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 A12 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 A13 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 A14 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 A15 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 A16 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 A17 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 A18 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 A19 Recovery and recycling of packaging materials

G per functional unit	Conventional	JAWS 10 fill	JAWS 20 fill
PET bottle	11285	1039	520
PET blister	0	0	0
PP film (labels)	0	0	0
PP inj mold	0	0	0
LDPE stretch wrap	387	109	80
LDPE shrink film	0	0	0
Bleached kraft paper	0	0	0
Corrugated box	28812	5188	3811
Pallet	52644	14824	10887
Total	93128	21160	15297

Appendix 2 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 111.625".

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 111.625" 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 A22 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

Appendix 3 Truck Transport-Related Emissions

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

	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).

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

A. Emissions for semitrailer trucks running on gasoline, 500 mile average distance from filler to retailer:

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
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

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

B. Emissions for semitrailer trucks running on diesel, 500 mile average distance from filler to retailer:

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

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

Appendix 4 Shrink-wrapped JAWS bottle with two cartridges.

