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RESOURCE AND ENVIRONMENTAL PROFILE ANALYSIS OF NINE BEVERAGE CONTAINER ALTERNATIVES

Final Report

U.S. ENVIRONMENTAL PROTECTION AGENCY

RESOURCE AND ENVIRONMENTAL PROFILE ANALYSIS

OF NINE BEVERAGE CONTAINER ALTERNATIVES

Final Report

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FOREWORD

Under the Solid Waste Disposal Act of 1970 as amended, the U.S. Environmental Protection Agency is charged with the study of "changes in product characteristics and production and packaging practices which would reduce the amount of solid waste." Beverage containers represent a significant and rapidly growing fraction of post-consumer municipal solid waste. The shift from the use of refillable to single-use beverage containers in the past two decades, has resulted in a significant effect upon the use of material and energy resources and the generation of solid wastes and other pollutants. This study identifies the magnitude of these impacts as they relate to alternative beverage container types.

The report analyzes seven different impact categories: virgin raw materials use, energy use, industrial solid waste, post-consumer solid waste, air pollution emissions, and water pollutant effluents. These impacts were assessed for each manufacturing and transportation step in the life cycle of a container, beginning with the extraction of raw materials from the earth, through the fabrication of the product, use and final disposal.

To assure the accuracy of the analysis, a draft of the report was carefully reviewed by industrial and other technical experts. Many valuable comments were received, and these comments have been incorporated into the report in its current and final form.

One basic conclusion that may be drawn from this analysis is that a wide-scale shift from the current "one-way," "throw-away" container system to a returnable system which maximized reuse and recycling of containers would result in a significant reduction in raw material and energy use, and a decrease in environmental pollution.

We hope that this study will provide a significant exploration of the resource and environmental impacts of using alternative beverage containers, and we hope it will assist those seeking to minimize these impacts as they relate to beverage container consumption.

--ARSEN J. DARNAY
Deputy Assistant Administrator
for Solid Waste Management

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CHAPTER I

SUMMARY

This study is a resource and environmental profile analysis (REPA) of nine beverage container options. The analysis encompassed seven different parameters: virgin raw materials use, energy use, water use, industrial solid wastes, post-consumer solid wastes, air pollutant emissions and water pollutant effluents. These parameters were assessed for each manufacturing and transportation step in the life cycle of a container, beginning with extraction of the raw materials from the earth, continuing through the materials processing steps, product fabrication, use and final disposal.

The nine container systems encompass four basic raw materials--glass, steel, aluminum and plastic. A fifth basic material is also included in packaging of the containers; this material is paper.

The analysis encompasses only the relative environmental effects for the seven categories listed. We have not included environmental categories which we judged to be redundant, or for which entirely inadequate quantitative data existed. Some of the factors excluded were: aesthetic blight, litter, waste heat and carbon dioxide. Since this is a relative comparison of beverage containers, no attempt is made to determine actual environmental damage arising from beverage container usage as compared to other product systems or to national or worldwide industrial activity.

The basic assumptions used in this study are detailed in Chapter II. These assumptions are quite important and the reader is urged to examine them carefully. Other environmental studies are presently being made available for public scrutiny, and the basic assumptions of any two studies should be examined before comparisons between results are made. In addition, we emphasize that the results contained in this study pertain to comparative impacts of specific types of beverage containers only. Extrapolation of these results to other products will likely be invalid, even if the other products are made of the same materials. For example, the results contained in this study pertaining to glass and steel beverage containers cannot be applied directly to compare other products made from glass and steel because of differences in amounts of materials required, different material compositions and different manufacturing subsystems employed.

The specific package selected for study was beer containers, and the nine container alternatives are given in Table 1. The primary reason that beer was selected rather than soft drink packages, is that a 12-ounce package is standard for beer containers. This selection simplified the comparison of various container systems. However, resource and environmental profiles of soft drink containers were also made on a basis of 1,000 liters of beverage delivered; although in the case of soft drinks, 16-ounce glass bottles were compared with 12-ounce cans and plastic bottles.

TABLE 1

NINE BEER CONTAINER ALTERNATIVES

Material and Package Description	Code	Degree of Occurrence
Glass		
Returnable 19-trip on-premise	19-RET	Widespread
Returnable 10-trip off-premise	10-RET	Widespread
Returnable five-trip off-premise	5-RET	Regional
One-way conventional glass	OWG	Widespread
Plastic coated glass	PCG	Regional
Steel		
Conventional three-piece steel can--aluminum closure	CSTL	Widespread
All steel can	ALSTL	Little Used
Aluminum		
Two-piece all-aluminum can (15 percent of cans recycled)	ALUM	Widespread
Plastic		
Plastic bottle[a]	ABS	Test market

a/ The plastic resin was defined in terms of data available in the open literature. The profile resulting from the production and use of proprietary plastics may be somewhat different.

Source: Midwest Research Institute

A. REPA Summary Results

The results of the resource and environmental profile analysis of beer containers is given in terms of the rank of each system for each impact category in relation to the other eight containers (Table 2). The system ranked "one" produces the least overall impact in that category, while the one ranked "nine" produces the greatest comparative impact. Thus, a rank of "one" is the most favorable from a resource use or environmental effluent standpoint.

The 19-RET ranks first in five of the seven categories, and is the highest ranked container overall. However, deriving comparative relationships for the other systems is a more complex task.

In order to provide a more meaningful comparison, we have compared returnables to conventional one-way containers. The 10-RET container is the most representative returnable system for trippage today, whereas 19-RET and 5-RET represent outer bounds of returnable trippage which are found in some localities or regions. Thus, the 10-RET was selected as the basic container

TABLE 2

SUMMARY OF COMPARITIVE RANKING OF CONTAINER SYSTEMS FOR 1,000 LITERS (AND 1,000 GALLONS) BEER

	19-RET	10-RET	5-RET	ABS[a/]	ALSTL[a/]	PCG[a/]	OWG	CSTL	ALUM
Raw Materials - kg	1	3	7	1	5	8	9	5	4
Energy - 10^9 joule	1	2	4	6	3	6	6	5	9
Water - 10^3 liter	1	2	4	9	4	4	4	4	2
Industrial Solid Waste - cu m	1	3	4	1	9	5	6	8	6
Atmospheric Emissions - kg	1	2	4	6	3	6	6	5	9
Waterborne Wastes - kg	2	3	8	8	1	5	5	3	5
Post-consumer Solid Wastes - cu m	4	5	6	6	2	8	9	2	1

a/ Little used or hypothetical containers.

Note: Underlined values represent a tie for that rank. That is, less than a 10 percent difference separated the values.

for comparison with the one-way systems. If 10-RET is compared only to the three conventional one-way containers, it ranks first in six of the seven categories in this four-way comparison. Furthermore, the magnitude of the difference between 10-RET and single use containers is quite impressive (Table 3). In the areas of energy, industrial solid waste and air pollution, the second place system in each category has more than double the quantitative value of each category compared to 10-RET. However, in post-consumer solid waste, 10-RET produces about 4.5 times as much waste as either ALUM or CSTL because of the large weight and volume difference in the containers. However, this one category alone is not as important as the combined effect of the others. Hence, we conclude that the returnable system has lower overall resource and environmental effects than conventional one-way containers.

Comparing 10-RET to the three hypothetical or little used containers, gives somewhat different results--the diferences are not as great. However, 10-RET still ranks first or second in all categories (except for post-consumer waste where it ranks third) when compared to the three other container alternatives. Thus, we conclude that the returnable system still has the lowest overall effects, but not by an impressive margin as in the previous case.

Because of the narrower margin of difference, the possibility exists that technological innovation, changes in design or other alterations in the systems could bring about changes in the rankings. The 10-RET is compared to each of its next lowest ranked competitors in each category for 10-RET vs. the three hypothetical or little used containers (Table 4). Substantial improvements in one-way containers would be needed to increase their ranks to a tie with 10-RET; on the average, the impacts of the second ranked container would have to be cut in half to equal 10-RET. It is unlikely that the overall impact profile of any container will be improved to match or surpass that of 10-RET in the near future.

B. Soft Drink Containers

Calculations were also carried out for soft drink containers delivering a "standard unit" of 1,000 liters of beverage. As shown in Table 5, the results are quite similar to those for beer containers. That is, the returnable glass container ranks higher than the one-way systems.

An important aspect of the soft drink systems is the fact that a wide range of glass bottle sizes and weights are in common use. Thus, the impacts of the container system per 1,000 liters of beverage vary with the particular container used. In Table 5, a 16-ounce returnable bottle is compared with 12-ounce one-way containers because the most complete data were available for these sizes. However, calculations using a wide range of glass bottle configurations show that no matter which available container is chosen, the conclusions of this study are not altered.

TABLE 3

COMPARISON OF 10-RET WITH SECOND RANKED COMPETITION (Conventional Containers)

	Nearest Competitor	Percent Difference [a]
Raw materials	ALUM	27
Energy	CSTL	150
Water	ALUM	Tie
Industrial solid wastes	OWG	273
Atmospheric emissions	CSTL	135
Waterborne wastes	CSTL	Tie
Post consumer waste [b]		

a/ Percent Difference = $\frac{\text{(Second Ranked Competitor) - (10-RET)}}{\text{10-RET}} \times 100$

b/ 10-RET ranks third in this category, behind ALUM and CSTL. There is a 78 percent difference between ALUM and 10-RET.

TABLE 4

COMPARISON OF 10-RET TO NEXT LOWEST COMPETITOR (Hypothetical or little used containers)

	Next Lowest Competitor	Percent Difference
Raw Materials	ALSTL	75
Energy	ALSTL	79
Water	ALSTL PCG	153
Industrial Solid Wastes	PCG	231
Atmospheric Emissions	ALSTL	55
Waterborne Wastes	PCG	56
Post-consumer Solid Wastes	ABS	127

TABLE 5

SUMMARY OF COMPOSITE DATA FOR SOFT DRINK CONTAINER SYSTEMS
FOR 1,000 LITERS (AND 1,000 GALLONS)

	15-RET	ABS	ALSTL	PCG	CSTL	OWG	ALUM
Raw Materials - kg (lb)	2	1	4	6	4	7	3
Energy - 10^9 joule (10^6 Btu)	1	4	2	4	3	6	6
Water - 10^3 liter (1,000 gal)	1	4	7	3	6	4	2
Industrial Solid Water - cu m (cu ft)	2	1	7	3	6	5	3
Atmospheric Emissions - kg (lb)	1	3	2	3	3	6	7
Waterborne Wastes - kg	2	5	1	3	3	4	6
Post-consumer Solid Wastes - cu m (cu ft)	4	5	3	6	2	6	1

Source: Table 12, Volume II.

C. Recycle and Reuse

Considerable potential exists for improving the resource and environmental profile of any container system through reuse and recycle. As has been shown in the primary results for containers presently in use, the reusable glass bottles have lower overall impacts on resources and the environment than the other conventional containers. However, the one-trip containers have potential for reuse or recycling.

It is possible that plastic or glass bottles can be both recycled and reused. Plastic and glass can be recycled if clean scrap is available. A plastic returnable bottle may soon be viable. In that event, both reuse and recycling options will be available to both plastic and glass. A returnable bottle made from recycled material would have a highly favorable environmental profile compared to other beverage packaging options.

The greatest improvement for any of the material systems as a result of recycling is for aluminum. The energy use drops from 23.6×10^9 joules per 1,000 liters at current recycling rates for aluminum to 5.25×10^9 joules for 100 percent recycled aluminum, a decrease of 78 percent. Steel and plastic show improvements of 39 and 62 percent for 100 percent recycling.

At 100 percent recycling, steel, aluminum and plastic achieve energy use comparable to the 10-trip glass returnable. However, this is an unrealistic recycling rate and would not be achievable on a widespread basis. Even at 50 percent recycling, none of the systems require less energy than that of a 10- or 19-trip returnable container. However, 50 percent recycling of any of these materials on a regional or nationwide basis is a very high rate of recycling and while recycling possesses distinct resource and environmental advantages over one trip containers, they are unlikely to match the returnable container achieving at least 10-trips.

CHAPTER II

STUDY APPROACH AND METHODOLOGY

A. Introduction

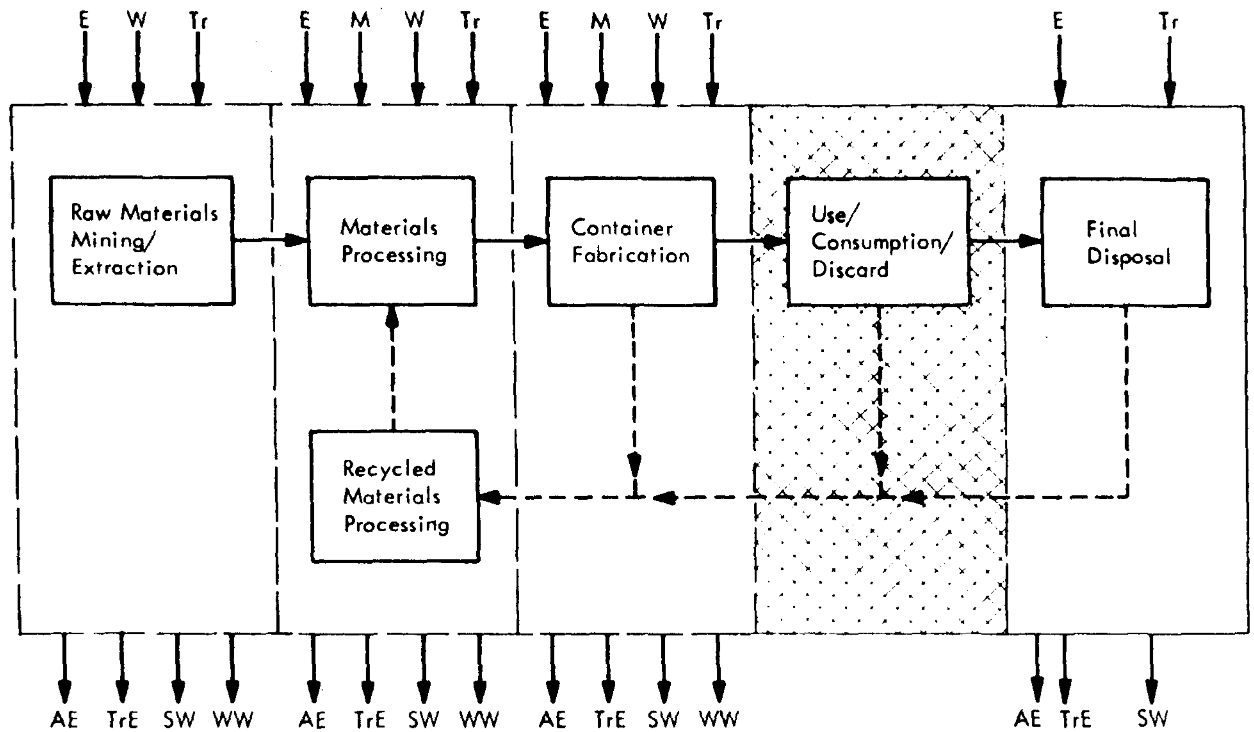
The purpose of resource and environmental profile analysis is to determine the comparative effects that alternative or competing products have on environmental degradation. Environmental degradation may take any or all of four forms: (1) aesthetic blight; (2) alteration of food chains; (3) creation of health hazards; (4) depletion of resources; or (5) degradation of the quality of air, water, and land. The seriousness of an impact is dependent on the type and amount of environmental damage that takes place.

It would be ideal if an objective analysis would reveal a quantitative measure of environmental degradation. However, this is not the case. For example, a manufacturing plant may discharge "x" pounds of sulfur oxides to the air and "y" pounds of oil to a nearby river. But the precise extent to which these two pollutants contribute to environmental degradation cannot be readily determined (although there is general agreement that degradation has occurred). The point of view taken in this study is that even though the true environmental damage cannot be determined, it is useful to establish reliable estimates of the relative impact of competitive products. Thus, even if the true effect of energy use or air pollution is not known, we can conclude that a product responsible for more energy use or more air pollution produces more environmental degradation than an alternative product.

B. Basic Approach

The effort expended in the study went into determining quantifiable impacts of manufacture. The term "manufacture" is used throughout this report in a general sense--it includes those activities associated with materials from the time they are severed from the earth to the point where the finished container has been finally disposed of, including all transportation links in the processing sequence. The manufacturing activities which intervene are designated processes or subprocesses. A summary of the impacts documented is shown in Figure 1.

The nine container options considered in this report are derived from four basic raw materials. These materials are: glass, plastic, steel, and aluminum. For each material system, the manufacturing cycle was broken into its component processes and subprocesses for the purpose of identifying environmental effects. For some systems, this task is relatively simple and for some, it is quite complex. For example, glass container manufacture



SUMMARY OF INPUT/OUTPUT CATEGORIES

INPUT	OUTPUT
E = Energy (in all forms)	AE = Atmospheric Emissions
M = Virgin Materials (consumed and unconsumed)	TrE = Transportation Effluents (for each fuel type)
W = Water	SW = Solid Wastes
Tr = Transportation to Next Operation (including all modes, all fuels in each mode)	WW = Waterborne Wastes

Figure 1 - General overview of resources and environmental effects of container manufacture and use.

is divided into ten basic processes, with many of the processes not requiring more detailed analysis of subprocesses. At the other extreme is the ABS polymer which is manufactured by utilizing 15 basic processes. In several instances, a detailed analysis of several subprocesses was required. In one case (petroleum refining) it was necessary to determine completely the manufacturing parameters for seven such subprocesses.

For each process and subprocess, seven parameters are determined:

1. Raw materials: The quantity in kilograms and the type of virgin raw materials input to each operation were determined in terms of a given product output. Materials not intended to become part of the finished product, such as cooling water and fuels, were excluded from raw materials. Other raw materials, such as additives, which aggregate to less than 5 percent of the total weight of the finished container were included in this category by reporting their weight in the finished product. This provides an estimate of the virgin raw materials which should be allocated to materials used in low quantities in the finished product.

2. Energy: The energy in million joules and the source of energy (oil, gas, electricity, etc.) used by each operation, including transportation, for a given product output was determined. Process energy used by the actual manufacturing operations was included. That used for space heating of buildings and other miscellaneous categories was excluded wherever possible. The energy content of certain organic raw materials was also included in energy summations. (See the discussion on page 12.) The second-order energy necessary to extract, process and transport fuels are included as well as the heat of combustion of the specific fuels used in a system. The energy value assigned to electricity use was the energy associated with the consumption of fuels necessary to deliver electricity to the customer (see Volume II, Chapter I, for more details).

3. Wastewater volume: The volume of process water in thousand liters discharged per unit of product output from each operation was reported. An alternative measure of water is the actual volume consumed or removed from natural water cycles. However, such data are not available for every system. This category considers water discharged only, not what is discharged from a process into the water in the form of pollutants. (This factor is covered separately.)

4. Industrial solid wastes: The volume in cubic meters of solid waste per unit of product output which must be landfilled, or disposed of in some other way, was determined also. Three categories were measured: process losses, fuel combustion residues (ashes) and mining wastes. The first category--process discards--includes wastewater treatment sludges, solids resulting from air pollution control and trim and waste materials from manufacturing operations which are not recycled. Fuel combustion residues are ash generated by coal combustion. Mining wastes are primarily materials discarded due to raw ore processing and do not include overburden removed to expose ore.

5. Post-consumer solid wastes: The volume in cubic meters of solid wastes generated by disposal of the container and its associated packaging was determined. This is solid waste which most likely would be discarded into municipal solid waste streams. It was assumed that 9 percent would be incinerated and 91 percent would be landfilled, and that the amount of material recycled directly from municipal waste is at present less than 1 percent of the total volume.

6. Atmospheric emissions: The emissions in kilograms of substances classified as pollutants were determined per unit of product output. Eleven identifiable pollutants were considered for each operation--particulates, nitrogen oxides, hydrocarbons, sulfur oxides, carbon monoxide, aldehydes, other organics, lead, odorous sulfur compounds, ammonia and hydrogen fluoride. The amounts reported represent actual discharges into the atmosphere after existing emission controls have been applied. All atmospheric emissions were considered on an equal basis; no attempt was made to determine the relative environmental effects of each of these pollutants. However, we do acknowledge that there are differences in the relative damage caused by air pollutants, but there is not sufficient documentation available to weight them with respect to each other.

7. Waterborne wastes: This category includes the water pollutants in kilograms from each operation per unit of product output. The effluent values are those after wastewater treatment has been applied and represent discharges into receiving waters. Thirteen specific pollutants are included--BOD, COD, suspended solids, dissolved solids (oil field brine), oil, fluorides, phenol, sulfides, acid, alkalinity, metal ions, chemicals and cyanide. Other factors such as turbidity and heat, were not included because usable data were not available.

C. Organic Raw Materials--Unique Considerations

A unique situation exists for products utilizing organic raw materials, such as wood, crude oil and natural gas. These materials have alternative uses as feedstocks for material goods such as paper or plastic products or as fuels for energy. In assessing resource depletion, then, the use of organic materials can be considered as depleting either material resources or energy resources.

It is our opinion that viewing organic materials either as a material resource or as an energy resource is justifiable from an environmental point of view. In given sets of circumstances, either view may be desirable. For example, in certain cases MRI's calculations show that some plastic products not only require less process energy, but also use less hydrocarbon energy resources (including energy content of the basic physical materials) than some alternative materials.

Thus, situations exist where the manufacture of plastic materials--even when using natural gas and petroleum as a material feedstock--conserves natural gas and petroleum as compared to competitive products.

The treatment given organic materials in a resource and environmental profile analysis must be considered carefully. There are two options available: (1) organic materials used as a material to be converted into a product may be considered as material resources; or (2) they may be considered as energy resources.

In the first case, the organic materials intended to become part of a finished product are simply measured in kilograms and treated as any mineral resource, with one exception. A unique consideration for organic materials is the inherent fuel value of the material. As natural gas and petroleum undergo chemical processing, losses in chemical potential energy occur. That is, a pound of petrochemical made from natural gas has less fuel value than a pound of natural gas. Thus, a loss in the fuel value of the material has occurred and should be counted as a loss to the world's energy reserve. (The energy loss is given up in chemical reactions when hydrocarbon feedstock is converted to a new compound.)

In the second case, organic materials are simply counted in terms of their energy content. The amounts of wood, natural gas, and petroleum severed from the land are measured in terms of joules of energy, rather than in kilograms. Thus, they are considered as energy resources.

Another point of consideration regarding the fuel value of organic materials is that finished products are a potential fuel even after they have been used and discarded. Thus, if the solid waste stream is incinerated and energy recovered, part of the original fuel value is reclaimed. However, this point is largely academic at present because, in actual fact, products are typically landfilled, burned in open dumps or incinerated with no heat recovery. Virtually no energy is recovered from solid waste streams, even though the potential does exist.* In addition, the energy content of all waste products will never be available for recovery. Some portion of the products will become litter or will be discarded into waste streams too small for economic heat recovery operations. Even in the distant future, full recovery of the residual energy inherent in organic products will probably not be achieved.

Because of these considerations, a strong case can be made for treating plastic materials as an energy resource rather than as a material resource, which reflects accurately the primary environmental concern of the plastics industry--the consumption of energy reserves in the form of natural

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* We recognize that several resource recovery installations which recover energy from solid wastes exist today and that there is an emerging technology under development. However, at present the actual useful recovery of the residual energy content of organic wastes is negligible in comparison to the amount disposed.

gas and petroleum. These fuels are at present, and in the near future will be, in short supply to a greater extent than any other major natural resource. As mentioned earlier, the material resources considered in this study such as limestone and iron ore are much more abundant than natural gas and petroleum. Petroleum and natural gas feedstock use is not equivalent on a kilogram-for-kilogram basis with, for example, limestone and a better resource use picture is conveyed if the energy value of feedstocks is the basis of evaluation. Since essentially no recovery of the intrinsic fuel value of finished plastic products is practiced at present, the impact on the nation's energy reserves as a result of plastics manufacture is the sum of the process energy required for plastics manufacture and the inherent fuel value of the organic materials consumed. Thus, our conclusion is that treating organic materials as an energy input rather than as a physical quantity of material is a more accurate statement of environmental impact and places the comparison of competitive container systems on a more logical basis.

On the other hand, we have treated wood fiber as both a material resource and as an energy resource. On a worldwide basis, slightly less than half of the wood harvested is used as a fuel, with the remainder used as a material resource. Thus, wood serves for either use. It is difficult to judge the present and future aspects of wood fiber depletion because of its renewable character. If wood is viewed as a material resource, then projections for its future use indicate that adequate amounts of wood can be grown to maintain world reserves. On the other hand, if significant conversion from present fossil fuel use patterns to use of wood as a fuel takes place, the annual harvest of wood would greatly exceed the annual growth and depletion of wood resources would take place. Thus, it seems reasonable to classify wood used as a material resource with minerals such as sand and limestone for which long-term supplies exist. On the other hand, it is also reasonable to classify wood harvested to be used as an energy source with hydrocarbon fuels or other energy sources. We divided the pulpwood harvested for paper manufacture such that the portion which is intended for use in paper is measured in kilograms of fiber, and the portion burned for process energy is measured in joules.

D. Methodology

The general approach used to carry out the calculations for the quantitative comparison was straightforward. All processes and subprocesses were first considered to be separate, independent systems. For each system a standard unit such as 1,000 kilograms of output was used as a basis for calculations. A complete materials balance was first determined. If marketable coproducts or by-products were produced, the materials inputs were adusted to reflect only the input attributable to the output product of interest.

To illustrate this point, consider a hypothetical manufacturing process that produces 1,000 kilograms of product 'A.' At the same time, it produces 500 kilograms of a coproduct 'B' and 100 kilograms of waste in the form of air and water pollutants and solid waste. The total input of raw materials is 1,600 kilograms as shown in Figure 2. An energy input of 3×10^9 joules is assumed for this example. The output is 1,000 kilograms of product 'A' and 500 kilograms of product 'B.'

A 500-kilogram credit has been applied to the input materials because we are not interested in product 'B.' This reduces the input from 1,600 kilograms to 1,100 kilograms. In addition, because product 'B' is one-third of the product output of the process by weight, one-third of the wastes, or 33 kilograms, is attributed to product 'B'; a new waste figure of 67 kilograms (100 kilograms - 33 kilograms = 67 kilograms) results. Thus the raw material input value for product 'A' is 1,067 kilograms (1,100 kilograms - 33 kilograms = 1,067 kilograms).

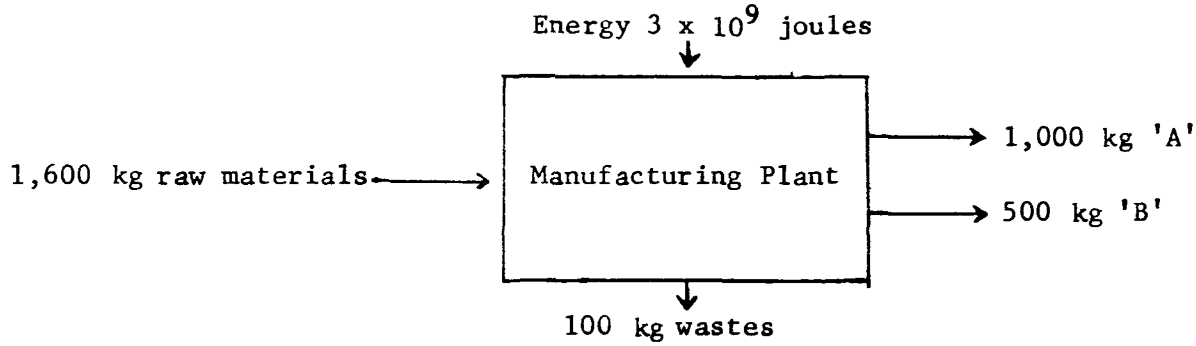
Once the detailed material and energy balance information had been determined for 1,000 kilograms or 1 metric ton of output from each subprocess, a master flow chart was established for the manufacture of containers. Using known process yield rates, the output of each subprocess necessary to produce 1,000 kilograms or 1 metric ton of finished containers were determined. Summary tables for the manufacture of 1,000 kilograms or 1 metric ton of containers were then constructed. (Details of calculations, summary tables and data sources are included in Volume II.)

For purposes of comparing the nine container systems, another adjustment of the raw numbers was necessary. The purchase and consumption of containers (their ultimate utility) depends not on the number of kilograms of containers, but on the number of units necessary to deliver a given quantity of the beverage to the customer. Hence, the values based on container weight were converted so that containers were considered on a unit-by-unit basis. A standard unit of 1,000 liters of beer delivered in 12-ounce containers to the customer was selected as the unit of comparison.

Up to this point, data gathering and calculations for each system were kept entirely independent of each other. After converting the data to a 1,000 liter basis, the nine systems were then compared to each other for the first time.

E. Assumptions and Limitations

Some assumptions are always necessary to limit a study to reasonable scope, and it is important for the reader to know what assumptions have been made in order for him to understand fully the scope and applicability of the study. The principal assumptions and limitations were:



For analysis purposes, a new flow diagram would be established as shown here.

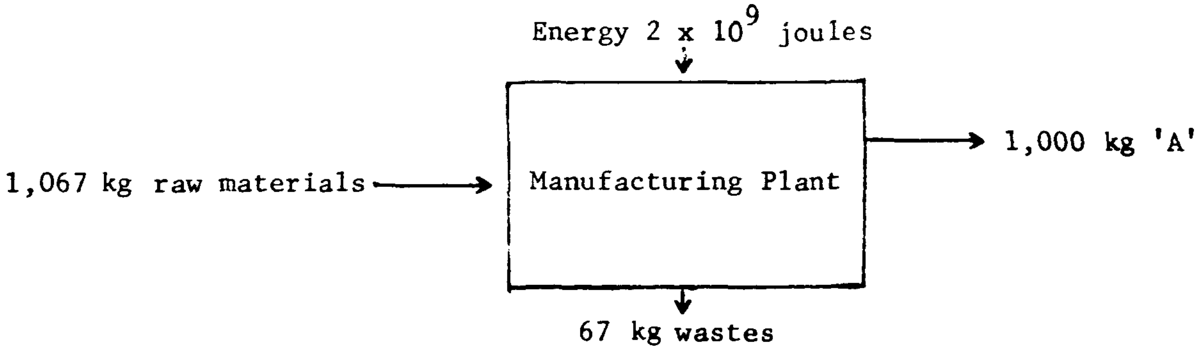


Figure III-1 - Diagram Illustrating Co-Product Credits

1. Data sources: An attempt was made in every case to obtain data which were "typical" and which could be verified in the open literature. Extensive use was made of government agencies and publications, technical associations and open literature sources. National average data were used where possible. Certain sets of data involved proprietary processes so that information was submitted to us on a confidential basis. However, data in the public domain were used whenever possible.

2. Geographic scope: The "environment" was defined as the environment of the world. However, impacts occurring outside this country are not well documented, so U.S. data was used to calculate foreign impacts. Thus, iron ore mined in Canada was assumed to produce the same impacts on a kilogram basis as domestic iron ore.

3. Secondary impacts: Impacts resulting from extraction, processing and transporting fuels are secondary impacts and were considered, as well as the primary impacts of the fuel combustion. However, secondary impacts resulting from effects such as manufacturing the capital equipment used in container manufacture are small per unit output, and can be excluded without significant error.

4. Small quantities of materials: The impacts associated with materials which aggregate to less than 5 percent by weight of the container were not included. The list of materials which comprise the "less than 5 percent" category was examined to insure that no known "high environmental impact" materials were excluded from the analysis. This inspection insures that the values from this assumption do not lead to an error of greater than 5 percent in the final results.

5. Electricity: Electrical energy is considered from the point of view of its impact on the total energy resources of the nation. A national average energy expenditure of 11,100 Btu of fossil fuels and hydropower is required for each kilowatt-hour of electricity made available to the public. Hence, this conversion factor is used rather than the direct use conversion factor of 3,413 Btu per kilowatt-hour. The impacts from mining or extraction of these fuels were included in the analysis.

6. Usage of scrap materials: Environmental impacts of scrap are considered to be only those impacts incurred after the scrap is discarded from the manufacturing site. Usually this includes only transportation and scrap processing steps. The environmental impacts of manufacture of the material which subsequently becomes scrap is allocated to the prime product. For example, suppose an idealized metal fabrication plant requires 1.2 metric tons of steel to produce 1.0 metric tons of prime product and 0.2 metric tons of steel scrap. The impacts associated with the manufacture of 1.2 metric tons of steel are all allocated to the prime product with none being allocated to the scrap.

7. Point sources of pollution: The burden on specific ecosystems was not considered--i.e., at specific point sources or geographic locations. It was assumed the operations took effect on the environment everywhere, not just where specific manufacturing operations are presently located.

8. Availability of data: Many industrial plants do not keep records in sufficient detail to determine the data in the desired form for a REPA study. For instance, if pollutant emission data are needed for a specific subprocess in a plant, that information may not be available. The plant may have data only for several combined processes or the entire plant. In this event, allocation must be used for data on the particular processes of interest. As the concept of resource and environmental profile studies gains acceptance, it is likely that more industries will make an effort to collect these types of data from their own operations and on a unit process basis. Engineering calculations of materials balances for subprocesses were used in some instances where actual operating data are not available.

9. Effluent data: Current actual conditions were assumed for air, water and solid waste discharges to the environment. We made no attempt to derive and apply effluent standards which may be in effect at some future date. However, the application of future standards has the effect of shifting effluents from one category into others. It does not usually add or substract from total amounts of effluents. For example, air pollution control usually removes air pollutants from air and they are then discharged to water bodies or become solid waste. Thus, reducing air pollution from a plant will usually increase the water pollutant and/or solid waste discharge. Thus, the analysis technique preserves the integrity of the laws of conservation of matter and energy.

10. Consumer impacts: Impacts related to consumer activities such as transporting the beverage home from the retail store were not included. We have assumed that trips to retail stores are necessary for other reasons, and should not be attributed to the container systems. Other consumer impacts (except disposal of the container) relate to the beverage, itself, not the container.

CHAPTER III

BEER CONTAINERS--THE RESOURCE AND ENVIRONMENTAL PROFILE

The comparative environmental impacts resulting from the manufacture, filling and delivery of nine container systems are discussed in this chapter, and are presented in numerical form. A data summary is presented first, followed by the ranking of the systems. A discussion of the systems then follows, with special consideration of energy factors concluding the chapter.

A. Data Summary

The resource and environmental profiles of the nine beer container systems were derived from a series of calculations and data analyses following the methodology outlined in the previous chapter. Thousands of calculations were involved, leading in a stepwise manner, for each impact category for each process and subprocess. All of the detail and supporting calculations are contained in Volume II of this report. A description of each system and the abbreviations used in this report are in Table 6.

Table 7 displays the quantitative summary of these calculations with the impacts reported in their appropriate units for the number of 12-ounce containers (2,817) which deliver 1,000 liters of beverage. Also included in parentheses are data for 1,000 gallons of beverage delivered (10,700 containers). These totals result from the aggregation into each impact category of all values from each process and subprocess of each container system.

B. Ranking Procedures

In order to draw conclusions about the comparative environmental impact of these nine systems, it is necessary to develop a procedure to rank these systems. Table 8 contains the rank of the nine systems for each impact category. A survey of the numbers in Table 8 reveals that overall ranking of the systems is not an easy task. There is no container system which either leads or lags in all impact categories. ALUM leads in one category and is last in two categories, exemplifying the problems of simple ranking systems.

However, the 19-RET ranks first in five of the seven categories, second in one, and fourth in the remaining category. (A ranking of first means that the smallest quantitative value was incurred by that system in that impact category. Thus, a ranking of "one" is the most desirable and a ranking of 9 is the least desirable.) The 10-RET system also ranks high--

TABLE 6

BEER CONTAINER SYSTEMS DESCRIPTIONS

Abbreviation	Container Weight (kg)	Container Weight (Oz)	Description
19-RET	0.277	9.8	Glass 19-trip on-premise returnable bottle - steel crown closure - three trip paper packaging
10-RET	0.277	9.8	Glass 10-trip off-premise returnable bottle - steel crown closure - three-trip paper packaging
5-RET	0.277	9.8	Five-trip off-premise returnable bottle - steel crown closure - one-trip paper packaging
ABS	0.035	1.2	ABS one-way plastic bottle - steel crown closure
ALSTL	0.054	1.9	Three-piece all steel can, one way
PCG	0.159	5.6	Plastic coated one-way glass bottle - steel crown closure
OWG	0.186	6.6	One-way glass bottle - steel crown closure
CSTL	0.050	1.8	Conventional three-piece steel can - aluminum ring pull closure
ALUM	0.020	0.7	Two-piece one-way all-aluminum can (15 percent of cans recycled)

Note: All bottle systems include paper packaging of empty and filled bottles. Paperboard six-pack carriers were included in all bottle systems except the 19-trip off-premise. All can systems include paper packaging of empty and filled cans. Plastic ring six-pack carriers were included.

Source: Midwest Research Institute.

TABLE 7

SUMMARY OF COMPOSITE DATA FOR CONTAINER SYSTEMS FOR 1,000 LITERS (AND 1,000 GALLONS) BEER

	19-RET	10-RET	5-RET	ABS	ALSTL	PCG	OWG	CSTL	ALUM
Raw Materials - kg	114.9	186.9	411.9	118.3	326.1	791.3	903.5	329.0	237.9
(lb)	(958.9)	(1,560)	(3,438)	(987.6)	(2,722)	(6,604)	(7,541)	(2,746)	(1,986)
Energy - 10^9 joule	4.43	6.02	12.0	17.6[a/]	10.8	16.9	17.9	15.0	20.9
(10^6 Btu)	(15.90)	(21.61)	(42.88)	(63.32)	(38.63)	(60.66)	(64.38)	(53.73)	(75.03)
Water - 10^3 liter	11.35	15.42	32.52	41.71	39.02	35.05	36.94	34.10	15.11
(1,000 gal.)	(11.35)	(15.42)	(32.52)	(41.71)	(39.02)	(35.05)	(36.94)	(34.10)	(15.11)
Industrial Solid Waste - cu m	0.049	0.067	0.111	0.054	0.808	0.222	0.250	0.696	0.270
(cu ft)	(6.59(	(8.91)	(14.94)	(7.21)	(108.0)	(29.71)	(33.46)	(93.00)	(36.13)
Atmospheric Emissions-kg	8.45	11.28	24.00	28.84	17.47	29.44	31.29	26.59	38.73
(lb)	(70.52)	(94.15)	(200.3)	(240.7)	(145.8)	(245.7)	(261.1)	(221.9)	(323.2)
Waterborne Wastes - kg	3.29	4.17	8.29	8.24	2.17	6.51	6.76	4.12	7.08
(lb)	(27.47)	(34.76)	(69.17)	(68.79)	(18.14)	(54.32)	(56.46)	(34.35)	(59.08)
Post-consumer Solid Wastes - cu m	0.054	0.089	0.216	0.202	0.026	0.278	0.307	0.024	0.020
(cu ft)	(7.16)	(11.96)	(28.88)	(27.05)	(3.49)	(37.16)	(40.97)	(3.22)	(2.75)

a/ This includes 5.70 x 10^9 joules or 17.26 x 10^6 Btu which is the energy equivalent of oil and natural gas used as a material resource.

Source: Table 13, p. 21, Volume II.

TABLE 8

RANK OF CONTAINER SYSTEMS IN EACH IMPACT CATEGORY
1,000 LITERS (AND 1,000 GALLONS) BEER

	19-RET	10-RET	5-RET	ABS	ALSTL	PCG	OWG	CSTL	ALUM
Raw Materials	1	3	7	1	5	8	9	5	4
Energy	1	2	4	6	3	6	6	5	9
Water	1	2	4	9	4	4	4	4	2
Industrial Solid Wastes	1	3	4	1	9	5	6	8	6
Atmospheric Emissions -	1	2	4	6	3	6	6	5	9
Waterborne Wastes	2	3	8	8	1	5	5	3	5
Post-consumer Solid Wastes	4	5	6	6	2	8	9	2	1

Source: Table 7

Note: A tie was declared when two numbers were found to be closer than 10 percent of the lower number. The "ties" are underlined.

TABLE 9

RANKING OF COMPOSITE DATA FOR FOUR CONVENTIONAL CONTAINER SYSTEMS FOR 1,000 LITERS (AND 1,000 GALLONS) BEER

	10-RET	OWG	CSTL	ALUM
Raw Materials	1	4	3	2
Energy	1	3	2	4
Water	1[a]	3	3	1
Industrial Solid Waste	1	2	4	2
Atmospheric Emissions	1	3	2	4
Waterborne Wastes	1	3	1	3
Post-consumer Solid Wastes	3	4	2	1

Source: Table 7

a/ See Note on Table 8.

TABLE 10

COMPARISON OF 10-RET WITH SECOND RANKED COMPETITION (Conventional Containers)

	Nearest Competitor	Percent Difference[a/]
Raw Materials	ALUM	27
Energy	CSTL	150
Water	ALUM	Tie
Industrial Solid Wastes	OWG	273
Atmospheric Emissions	CSTL	135
Waterborne Wastes	CSTL	Tie
Post-consumer Waste[b/]		

Source: Table 7

a/ Percent Difference = $\frac{\text{(Second Ranked Competitor) - (10-RET)}}{\text{10-RET}} \times 100$

b/ 10-RET ranks third in this category, behind ALUM and CSTL. There is a 78 percent difference between ALUM and 10-RET.

second and third in all categories except one, where it ranks fifth. Thus, we conclude that the two higher trippage rate returnable systems are the ones with the most favorable overall resource and environmental profiles, but further definitive ranking of containers is not discernable using this tabular ranking technique.

Of the three returnable options studied, 10-RET is the system which most closely approximates the national average situation today, and will continue to be most representative for at least five years. The 10-RET was then compared with the three conventional one-way systems now widely used. These four systems account for almost all of the beer (and soft drinks) containers used today.

The returnable system ranks highest compared to conventional systems (Table 9). It leads in six of the seven impact categories. The magnitude of the lead of 10-RET over the one-way systems was also calculated (Table 10). In three of the categories--energy, industrial solid waste and atmospheric emissions--the lead by 10-RET exceeds 100 percent, with a tie or smaller lead for three other categories. The 10-RET energy requirements range from only 0.4 times as much as CSTL to only 0.29 as much as for ALUM; and the 10-RET leads OWG by 70 percent in the category of industrial solid waste. The one category that 10-RET does not lead is post-consumer solid waste, where ALUM leads, accounting for 78 percent less than 10-RET.

The relationship of 10-RET to the three experiemental (developmental) or little used systems was also compared (Table 11). Here, the 10-RET leads in three categories, and is second in the remaining four categories. The lead of the returnable system is not as impressive as in the comparison with conventional systems, but the returnable container is still the one which overall results in lowest impact. The PCG system is ranked third or fourth in all categories except one, where it is ranked second, so it appears to have the least favorable profile of these developmental systems.

The 10-RET impacts were then compared to its next lowest "non-conventional" container competitor for each category (Table 12). The gaps between 10-RET and the next lowest competitor are large in all cases. Thus, the 10-RET container appears to have the most favorable resource and environmental profile of all eight container options.

Significant technical innovations in the near future could alter these findings. For example, the development of a lightweight all-steel can could significantly close the gap between 10-RET and ALSTL, although the possibilities of a reversal in ranks seem remote. In addition, there may be comparable favorable developments in returnable container systems in the future.

TABLE 11

RANKING OF COMPOSITE DATA FOR FOUR CONTAINER SYSTEMS FOR 1,000 LITERS (AND 1,000 GALLONS) BEER

	10-RET	ABS	ALSTL	PCG
Raw Materials - kg	2	1	3	4
Energy - 10^9 joule	1	3[a]	2	3
Water - 10^3 liter	1	4	2	2
Industrial Solid Waste - cu m	2	1	4	3
Atmospheric Emissions - kg	1	3	2	3
Waterborne Wastes - kg	2	4	1	3
Post-consumer Solid Wastes - cu m	2	3	1	4

Source: Table 7.
a/ See note on Table 8.

TABLE 12

COMPARISON OF 10-RET WITH NEXT LOWEST COMPETITOR
(HYPOTHETICAL OR LITTLE USED CONTAINERS)

	Next Lowest Ranked Competitor	Percent Difference[a/]
Raw Materials	ALSTL	75
Energy	ALSTL	79
Water	ALSTL PCG	153
Industrial Solid Wastes	PCG	231
Atmospheric Emissions	ALSTL	55
Waterborne Wastes	PCG	56
Post-consumer Solid Wastes	ABS	127

Source: Table 7

a/ Percent Difference = $\frac{\text{(Next Lowest Ranked Competitor)} - \text{(10-RET)}}{\text{10-RET}} \times 100$

Thus, we conclude that the returnable containers giving 10 trips or more possess an advantage over other container systems from an environmental and resource use point of view. However, based on Table 7, we cannot rank the one-way systems relative to one another without a more detailed analysis scheme, which was beyond the prescribed scope of this study.*

C. Discussion of Systems

Details concerning the data and calculations from which Table 7 and the rankings were drawn can be found in the Volume II. However, some of the more important details of the results are presented here. This includes a brief description for each container alternative along with a discussion of the special factors which bear on the rankings of the containers.

19-RET, 10-RET and 5-RET Systems: These returnable systems utilize a 12-ounce glass bottle weighing 277 grams which on the average makes 19, 10 or 5 trips before being discarded. Each bottle is capped with a 1.8 gram steel closure. A major distinction in these systems is that the 19-RET system is a container which is used "on-premise." That is, the beverage is consumed at a business establishment. The 10-RET and 5-RET are "off-premise" type containers and are taken off-premise for consumption. The off-premise container requires a six-pack carrier, while 19-RET does not. The 10-RET is assumed to achieve three trips for its six-pack container, as well as the corrugated container that carries the filled six-packs. But for 5-RET, we have assumed only one trip for the paper packaging.

The assumption of using one-way carrier packaging for 5-RET is valid for the situation as it existed in Oregon in 1973. At that time, the breweries were receiving their off-premise returnable bottles "in any package" that was handy at the retail store from which the bottles were returned. Packages that belonged to competitors were discarded at the brewery. However, we assume that given sufficient time and planning, the situation could improve to the point where more careful sorting would occur and higher trippage would be experienced for the boxes and six-pack carriers.

The environmental advantage of the returnable systems lies in the fact that much less material and energy is needed for bottle construction to deliver a given quantity of beverage than for a corresponding one-way container. In fact, a single returnable container will deliver 19, 10 or 5 units of beverage compared to only one for a one-way bottle. This is partially offset by the fact that returnable bottles are heavier and require more raw materials per bottle than one-ways, and they also require transportation for the return trip, and extensive washing. Additional points of interest can be found in the detailed data in Volume II.

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* MRI has used a more comprehensive and detailed ranking and weighting methodology on similar studies which does give definitive results on the containers. However, emphasis in this study was placed on the quantitative results, with interpretation of the results left largely to the reader.

The detailed profile of 5-RET (Volume II, Table 9) shows that a high percentage of the impacts are related to the one-trip paper carrier, while the glass container manufacturing and filling operations account for most of the remainder. Since the carrier package assumptions are quite important, we performed calculations for a 5-RET system with various trips for the packaging. If two trips per carrier package are used instead of one trip, the energy requirements for 5-RET are lowered from $12 \times 10^9/1{,}000\ \ell$ to 9.0×10^9 j. At three trips per package, the energy for 5-RET is 8×10^9 j, moving it much closer to 10-RET. (The other impacts are reduced by significant amounts also.) Thus, the assumptions concerning the paper carrier for 5-RET affect its relative position to the other containers. In other words, the trippage rate on the carrier is as important to the overall results as the prime container itself.

ABS: The ABS system utilizes a 35-gram ABS plastic bottle in a one-way configuration. This is a hypothetical bottle, and to our knowledge, no company is planning to market this particular bottle. However, the impacts of this bottle are judged to be similar to impacts which are produced by proprietary nitrile based polymers presently being test marketed as beverage containers. Therefore, even though this system is a hypothetical construction, it approximates plastic containers projected for future use.

An important impact in the ABS profile is energy use. The ABS system ranks sixth in energy use. An important aspect of this energy value is that it contains the energy equivalent of the hydrocarbon feedstock that goes into the plastic resin. In fact, the energy of the material resource accounts for 32 percent of the total ABS energy. It is interesting to note that even though this plastic uses a fuel for a material feedstock, there is one other system--ALUM--that leads to a significantly greater utilization of energy per unit of delivered product than ABS. However, as a one-way system, ABS still requires 4.0 times as much energy as the first place 19-RET system.

If the hydrocarbon feedstock for ABS is counted as kilograms of raw material rather than joules of energy, the ABS system then ranks fourth in energy (rather than sixth), and ties with the 5-RET system.

Two other important impacts for ABS are air pollution and water pollution, for which the ABS ranks sixth for the former and eighth for the latter. The detailed calculations in Volume II of this report show that the air pollutant total for ABS is 23 percent hydrocarbon emissions. The average for all container options in air pollution is 18 percent hydrocarbons. In most areas of the country, hydrocarbon emissions are considered to be less important than most other air emissions. In addition, an indeterminate, but large, fraction of the hydrocarbon emissions listed for ABS is methane, usually not considered to be a pollutant. Thus, the air pollution for ABS would be judged as slightly less serious than for other systems, but this difference would not affect the ranking of the ABS system.

The water pollution from the ABS system has several important components. The largest component is that related to paper packaging manufacturing which produces BOD and suspended solids discharges aggregating 47 percent by weight of the total container system water pollution. Another 17 percent is generated off-site as oil field brine (dissolved solids), a serious fresh water pollutant that can result from improperly disposed brine associated with oil and gas production. The rest of the water pollution is generated on-site at the container manufacturing and processing plants.

ABS ranks last in water use, requiring 3.7 times as much as 19-RET. However, this is primarily cooling water used in petrochemical manufacture and is not considered to be as significant as the other impact categories.

ALSTL: The ALSTL system is the one way all steel can, and is characterized by low water pollution (ranked 1), low post-consumer waste (ranked 2), and relatively low air pollution, water use and energy requirements (ranked 3). Thus, ALSTL leads the one way containers in five of the seven categories; ALSTL is apparently the one way container with the least overall resource and environmental impact.

The high ranking of ALSTL in the areas of water effluents, air discharges energy use, and water use may seem surprising in view of the highly publicized environmental problems of steel mills. However, allocation of those impacts to this particular steel product results in quite low values per unit of finished product as compared to other one way containers.

The one high impact in the ALSTL profile is industrial solid wastes, in which ALSTL ranks last. The ALSTL container produces sixteen times more industrial solid waste than 19-RET. The waste is primarily inorganic mining wastes, generated by the extraction and purification of high grade iron ore from the ore bearing rocks. These solid wastes can cause considerable environmental problems at the sites where they are generated.

PCG and OWG: These two systems are both basically glass systems. The OWG system uses a 186-gram glass bottle. The PCG system uses a 157-gram glass bottle with a 2-gram plastic coat. A steel crown is used in both cases. The plastic coat accounts for only 1 percent of the PCG system weight requirements, so the PCG profile is quite similar to the OWG profile and will not be discussed separately.

The OWG system ranks last in both the raw materials and post-consumer solid waste categories, and PCG ranks eighth in those two categories. The high raw material use is because glass containers require more kilograms of raw materials for their manufacture than the other systems. This is shown by the fact that OWG is by far the heaviest one way container, outweighing next place ALSTL (54 grams) by a factor of 3.4. The large post-consumer waste values are caused by a combination of the high weight of the container, coupled with relatively high volume of the container material per unit of beverage. This combination causes a relatively large volume of landfill space for each container. (We assumed the container would not be "cushioned" in mixed waste and would be crushed in the process of disposal.)

Other significant impacts for glass include the fact that OWG ranks sixth in energy use and air pollution (PCG ranks sixth in air pollution and sixth in energy, also). The large energy requirement is mainly concentrated in two operations (Volume II, Table 8): glass manufacture accounts for 53 percent of the OWG system energy total and paper packaging accounts for 26 percent of the energy. Thus, these two operations account for 79 percent of the total OWG energy. These two operations also account for most of the air pollution, with glass manufacture accounting for 32 percent (mostly nitrogen oxides and hydrocarbons), and paper packaging also accounting for 32 percent (mostly particulates and sulfur oxides).

In the remaining impact categories, OWG ranks fourth in water use, sixth in industrial solid waste (PCG ranks fifth in industrial wastes and fourth in water use). In water pollution, OWG and PCG are tied for fifth place. Sixty-eight percent of this is attributed to packaging. Glass manufacturing plants generally do not have significant water pollution problems, and this is reflected in the favorable position of OWG in the water pollution category.

CSTL: The conventional bimetal can consists of a steel body and bottom with an aluminum ring pull top. The weight of the steel used per can is 43 grams, while the lid requires only 5.4 grams. However, even though the lid comprises only 11 percent by weight of the can metal, its manufacture accounts for 43 percent of the energy requirements as well as significant amounts of the other impact categories (see Volume II). Thus, CSTL as opposed to ALSTL produces considerably more impact on the environment as a result of the aluminum closure's environmental impacts.

One of the most significant impacts for CSTL is the industrial solid waste associated with iron ore mining (as discussed for ALSTL). CSTL ranks eighth in this category. Also of importance is energy use and air emissions associated with the aluminum top. The top accounts for 40 percent of the air emission total of CSTL.

Post-consumer waste disposal of CSTL is small. (In fact, all of the metal can systems have quite low post-consumer disposal profiles.) This is the result of two factors. First, can systems require less packaging for carriers because they do not require "cushioning" to the extent that glass containers do; and cans utilize the plastic ring six-pack carriers which occupy only about one-tenth as much volume as paper carriers. Recently, the use of adhesives to bind six-packs has come into play as well. The second factor is that metal has a high density, requiring minimum material volume per unit of beverage compared to other materials and thus require considerably less landfill space per unit of beverage delivered. In fact, a steel can occupies only 8 percent of compacted volume of a one-way glass container.

ALUM: The aluminum can for the ALUM system is a 20-gram all aluminum can with a ring pull top. This system has the highest impacts on the environment in two categories--energy use and air emissions. It produces the least impact in the category of post-consumer solid waste and ranks second in water use.

ALUM requires 1.2 times as much energy as does OWG, the system ranked next in energy, and 4.7 times as much as 19-RET. The massive electric energy requirements have been cited as environmental factors in the aluminum industry. Industry spokesmen often counter that their high usage of hydropower should be the determining factor. However, MRI's calculations have been based on the point of view that national average electricity fuel and hydropower data should apply in all cases because of the large-scale interregional nature of many electric power grids. In addition, it is contrary to the basic concept of resource and environmental profile analysis to treat one selected industry differently than others in the source of electrical power. While it is true that the aluminum industry does use a proportionately higher percent of hydropower, this usage in effect precludes others from proportional use of hydropower. The total electrical energy pool and national fuel profile is the most important consideration--from a total systems view point. In addition, water power will decline in importance as the use of coal and nuclear energy for power generation increases. Thus, growth in aluminum production in the U.S.A. will have to be based largely on fossil or nuclear fuel.*

Another major impact for ALUM is atmospheric emissions; ALUM container manufacture shows 1.3 times as much atmospheric emissions as next ranked ABS, PCG and OWG, and 4.6 times as much as 19-RET. The source of the air emissions is primarily electric power generation and sulfur oxides and particulates combined form 49 percent of the air emissions (coal combustion) as compared to 42 percent for the all systems average. Thus, the air emissions values show a slightly higher composite concentration of these two air pollutants.

In the other impact categories, ALUM ranks much higher. It is sixth in industrial solid wastes, second in water use, fourth in raw material use and first in post-consumer disposal. Its high ranking in post-consumer solid waste is because the aluminum can uses very little material, and because metal cans result in minimum volume per unit of beverage and therefore occupies little landfill space. The aluminum can weight of only 20 grams is by far the lightest container. Also, we have calculated the ALUM system on the basis of 15 percent can recycling which further reduces solid waste, energy requirements, materials, etc., over a non-recycling option.

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* In fact, the industry will likely seek out untapped worldwide sources of hydropower in preference.

D. Energy Considerations

In the closing months of 1973, a dramatic national "energy crisis" came to the fore. This "crisis" was caused in part by a sudden reduction in volume of worldwide petroleum reserves which were available to the U.S. Changes such as this can cause alterations in the relative importance of impact categories. In fact, in times of emergency, only one impact category, such as energy, may be the only impact of importance.

To examine our REPA results in terms of energy alone, an analysis of total energy requirements for each system, as well as the sources of energy, were developed for the various container options (Tables 13 and 14). In the long term, total energy use is a very important parameter. The various forms of energy may be interchangeable if long-term planning is utilized, and no great advantage can be presently ascertained with any degree of certainty by using coal as an energy source rather than oil. However, for the short term, oil and natural gas are in quite short supply and industrial use of these fuels competes with home heating and other uses closely coupled to "quality of life." Thus, in the short term, it appears the use of hydrocarbons by industry is generally considered to be a less desirable form of energy use than coal or wood (although the associated environmental effluents may be lower in the case of the use of hydrocarbons).

For the conventional containers, the three glass returnable configurations are lower in total energy use, and the 19-RET and 10-RET presently utilize less total hydrocarbon fuels than do the conventional one-way systems (Tables 13 and 14). For the conventional one-way systems, CSTL utilizes about the same hydrocarbon energy as 5-RET, but only 64 percent as much hydrocarbon fuel as OWG, and only 57 percent as much as ALUM. Thus, CSTL appears to require less of those important fuel resources, although it utilizes 2.2 times more coal than OWG.

For the "nonconventional" beer containers (ALSTL, ABS and PCG) ALSTL compares well with 10-RET in hydrocarbon fuel usage, but utilizes 5.3 times as much coal, and 1.8 times as much total energy. The ABS container is ranked sixth in total energy use and ninth in petroleum use. Thus, ABS does not fare well in the energy analysis. This hydrocarbon usage is in part related to the large amounts of natural gas and petroleum used as a material resource (5.7×10^9 joules petroleum and natural gas) for which alternate materials do not presently exist. However, some of this energy could be recovered by incinerating solid waste streams and recovering the energy.*

* It should be noted that plastic formulations other than the one used here by MRI may result in lower energy values than those used here.

TABLE 13

ENERGY REQUIREMENTS BY FUEL SOURCE FOR CONTAINER SYSTEMS DELIVERING BEER IN 10^9 J/1,000 ℓ (or 10^6 Btu/1,000 gal)

	19-RET		10-RET		5-RET		ABS[a/]		ALSTC[a/]		PCG[a/]		OWG		CSTC		ALUM	
Petroleum	1.45	(5.20)	1.79	(6.42)	3.23	(11.59)	8.46	(30.35)	1.42	(5.09)	3.64	(13.06)	3.84	(13.76)	2.83	(10.14)	4.81	(17.26)
Natural Gas	1.72	(6.17)	2.42	(8.68)	4.38	(15.71)	4.86	(17.44)	2.98	(10.69)	8.53	(30.59)	9.10	(32.66)	4.88	(17.51)	8.62	(30.94)
Hydrocarbon Subtotal	3.17	(11.37)	4.21	(15.10)	7.61	(27.30)	13.32[b/]	(47.79)[b/]	4.40	(15.78)	12.17	(43.65)	12.94	(46.42)	7.71	(27.65)	13.43	(48.20)
Coal	0.71	(2.55)	0.97	(3.48)	1.95	(7.00)	2.32	(8.32)	6.11	(21.92)	2.74	(9.83)	2.95	(10.59)	6.60	(23.67)	6.12	(21.94)
Wood Fiber	0.49	(1.76)	0.76	(2.73)	2.23	(8.00)	1.64	(5.88)	0.05	(0.18)	1.71	(6.13)	1.78	(6.38)	0.04	(0.16)	0.04	(0.16)
Misc. (hydro and nuclear)	0.06	(0.21)	0.08	(0.29)	0.16	(0.57)	0.35	(1.26)	0.21	(0.75)	0.26	(0.93)	0.27	(0.98)	0.59	(2.13)	1.29	(4.62)
Total Energy	4.43	(15.90)	6.02	(21.60)	12.00	(42.90)	17.60	(63.30)	10.80	(38.60)	16.90	(60.50)	17.90	(64.4)	14.90	(53.60)	20.90	(74.92)

a/ These are little used as beer containers.
b/ This includes 5.7×10^9 joules (20×10^6 Btu) petroleum and natural gas equivalent used as a material resource.

TABLE 14

RANKING OF SYSTEMS FOR ENERGY REQUIREMENTS FOR EACH FUEL SOURCE

	19-RET	10-RET	5-RET	ABS[a]	ALSTL[a]	PCG[a]	OWG	CSTL	ALUM
Petroleum	1[b]	3	5	9	1	6	6	4	8
Natural Gas	1	2	4	5	3	7	9	5	7
Hydrocarbon Subtotal	1	2	4	6	2	6	6	4	6
Coal	1	2	3	4	7	5	6	7	7
Wood Fiber	4	5	9	6	1	6	6	1	1
Misc. (Hydro and Nuclear)	1	2	3	7	4	5	5	8	9
Total Energy	1	2	4	6	3	6	6	5	9

a/ These are little used as been containers.

b/ See note on Table 8.

It is our contention that energy requirements should be viewed in the context of withdrawals from a national or world-wide energy reservoir which is limited in extent. However, an alternative view is to consider energy usage in a more confined context. The effect of doing this can be seen by using the aluminum can as an example. We have assumed that usage of electricity by aluminum smelters is an energy withdrawal from our nation's electricity reservoir, and have used national statistics to compute the fuels used to generate electricity. Aluminum companies contend that their smelters draw on local energy reservoirs, and thus use "low impact" hydroelectric power to a much greater extent than the national average. We have recalculated the ALUM column on Table 13 using aluminum industry data and have listed the results in Table 15.

A comparison with the Table 14 shows that this consideration improves the position of ALUM with respect to petroleum use and overall energy requirements. However, this calculation does not improve ALUM enough to be a serious contender with the returnable systems.

TABLE 15

ALTERNATIVE ENERGY REQUIREMENTS BY FUEL SOURCE FOR ALUM CONTAINER SYSTEM

	10^9 j/ 1,000 ℓ	(10^6 Btu/ 1,000 gal.)	New Rank on Table 14
Petroleum	3.26	(11.70)	5
Natural gas	7.70	(27.62)	7
Hydrocarbon Subtotal	10.96	(39.32)	6
Coal	5.15	(18.47)	7
Wood fiber	0.04	(0.16)	1
Miscellaneous (hydro and nuclear)	1.54	(5.54)	9
Total Energy	17.70	(63.49)	6

Note: We have assumed the following energy profile for electricity used in aluminum smelting--coal 37.8 percent, natural gas 14.8 percent, and hydroelectric 47.4 percent.

The energy analysis, then, does not change the conclusions previously reached. The returnable systems, especially 19-RET and 10-RET, have the lowest energy values. They require less total energy and generally require less hydrocarbon fuel than do the one-way systems.

CHAPTER IV

REUSE AND RECYCLING

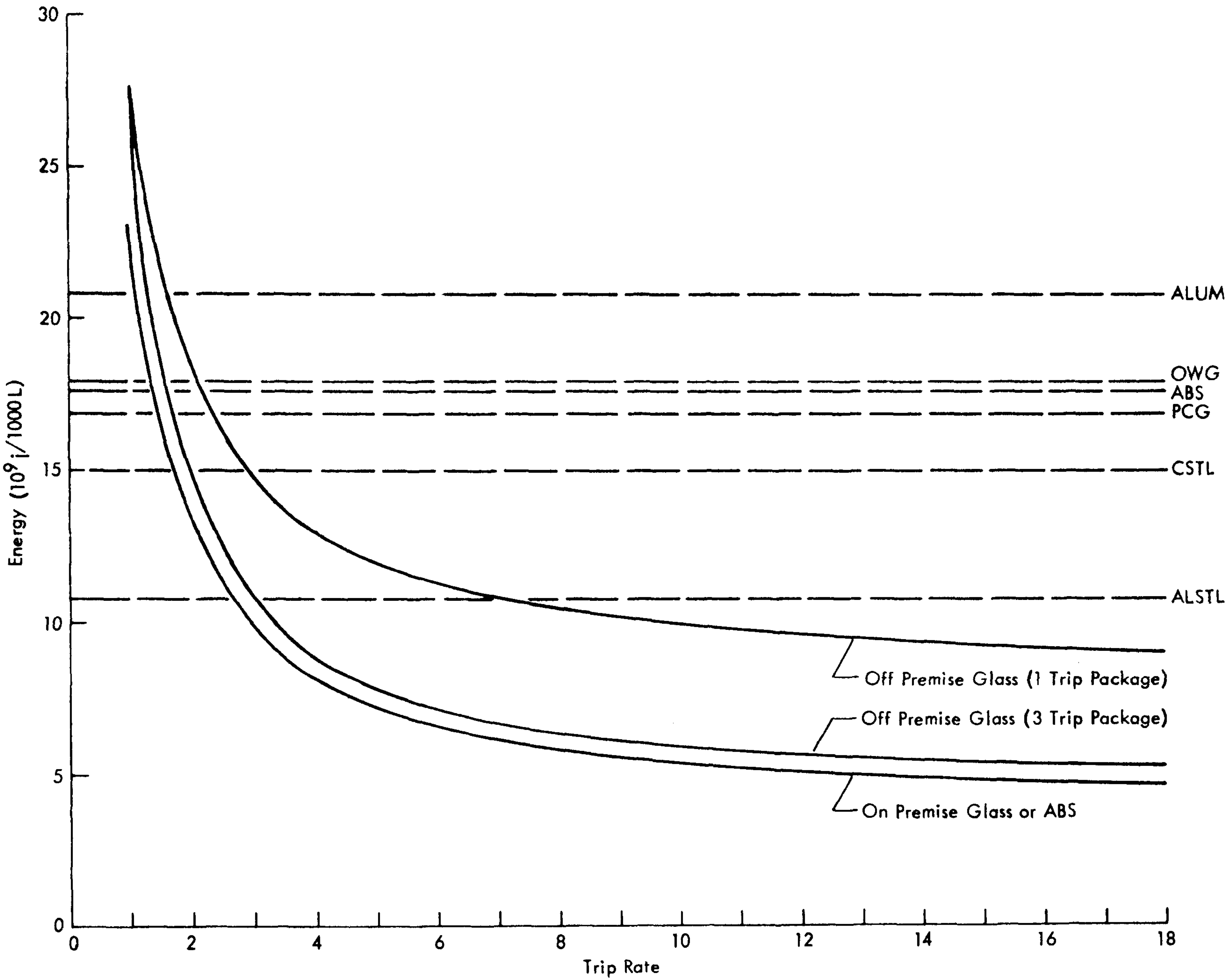
One of the possible means of achieving a more favorable environmental profile is by employing reuse and recycle options. The reason that these options are of potential benefit to the environment is that reuse and recycle bypasses most of the basic virgin materials. Manufacturing operations produce relatively high impacts on the environment and can be bypassed on reuse or recycling options. However, the bypassing of these manufacturing operations must be weighed against the new operations of product reuse and of secondary materials recovery, processing and transportation.

A. Returnable Bottles

An example of environmental effects of product reuse is given in Figure 3. The parameter selected for this example calculation was energy. However, similar changes occur in the other six parameters of a REPA profile. Four bottle systems are plotted so that the environmental improvement at various trippage rates is shown. The four systems are: (1) on-premise glass bottles with three-trip paper packaging; (2) off-premise glass bottles with one-trip paper packaging; (3) off-premise glass bottles with three-trip paper packaging; and (4) a hypothetical on-premise ABS returnable bottle with three-trip paper packaging.

The initial part of the four curves (low trippage) shows a very steep downward slope, indicating a considerable lowering of the system energy requirements at low trippage rates. In fact, at only two trips, the on-premise bottles require less energy than every one-way container, except ALSTL. At three trips, the off-premise containers surpass all one-way systems except ALSTL, and on-premise containers surpass even ALSTL. At four trips, the off-premise system with three-trip packaging, requires less energy than ALSTL, but the off-premise system with one-trip packaging requires about eight trips to reach that point.

The rapid leveling off of the returnable curves implies that a lower limit exists for returnable containers. In fact, this lower limit is the requirement for returnable reprocessing (e.g., transportation, washing), new closure and packaging energy which is about 3.7 for the on-premise bottle, 4.4 for the off-premise, three-trip packaging system and 8.3 for the off-premise, one-trip packaging. The implication is that for returnable systems


Energy (10^9 j/1000L)
30
25
20
15
10
5
0
Trip Rate
0
2
4
6
8
10
12
14
16
18
ALUM
OWG
ABS
PCG
CSTL
ALSTL
Off Premise Glass (1 Trip Package)
Off Premise Glass (3 Trip Package)
On Premise Glass or ABS

capable of high trip rates, the impacts of manufacturing the bottle are negligible. For returnable bottles, then, impacts may be minimized by using durable bottles capable of high trip rates. This is counter to current trends of using lighter bottles where possible. The reason for this is that market factors and current consumer use patterns tend to favor the lighter bottles, even though environmental considerations may favor a heavier bottle reused many more times than the current average.

An interesting calculation can be made concerning one type of possible marketing change. Most beverage markets are served by a broad array of returnable and one-way containers. However, legislation or changes in marketing conditions could bring about a change in the mix of container types used. For example, laws banning or restricting in some way the availability of one-way containers can convert a marketing area to use only returnable containers.

The change to a "returnable only" situation will generally produce new aspects of these systems. We have previously pointed out that one problem the beer industry has experienced in Oregon as a result of the "bottle law" is that each company has not secured their own carrier packaging back with the returnable bottles, thus effectively reducing the trip rate of the packaging. Another question which arises is if customers accustomed to throwing away convenience packaging will return the bottles for the deposit or throw them away, thus creating a "one-trip" situation for the returnable bottle system.

The heavier returnable bottle discarded after one trip requires more energy than most one-way systems (Figure 3). The question then arises as to what fraction of the market can be served by "one-trip returnable" (1-RET) before it is environmentally desirable to utilize one-way containers designed for one time use and discard.

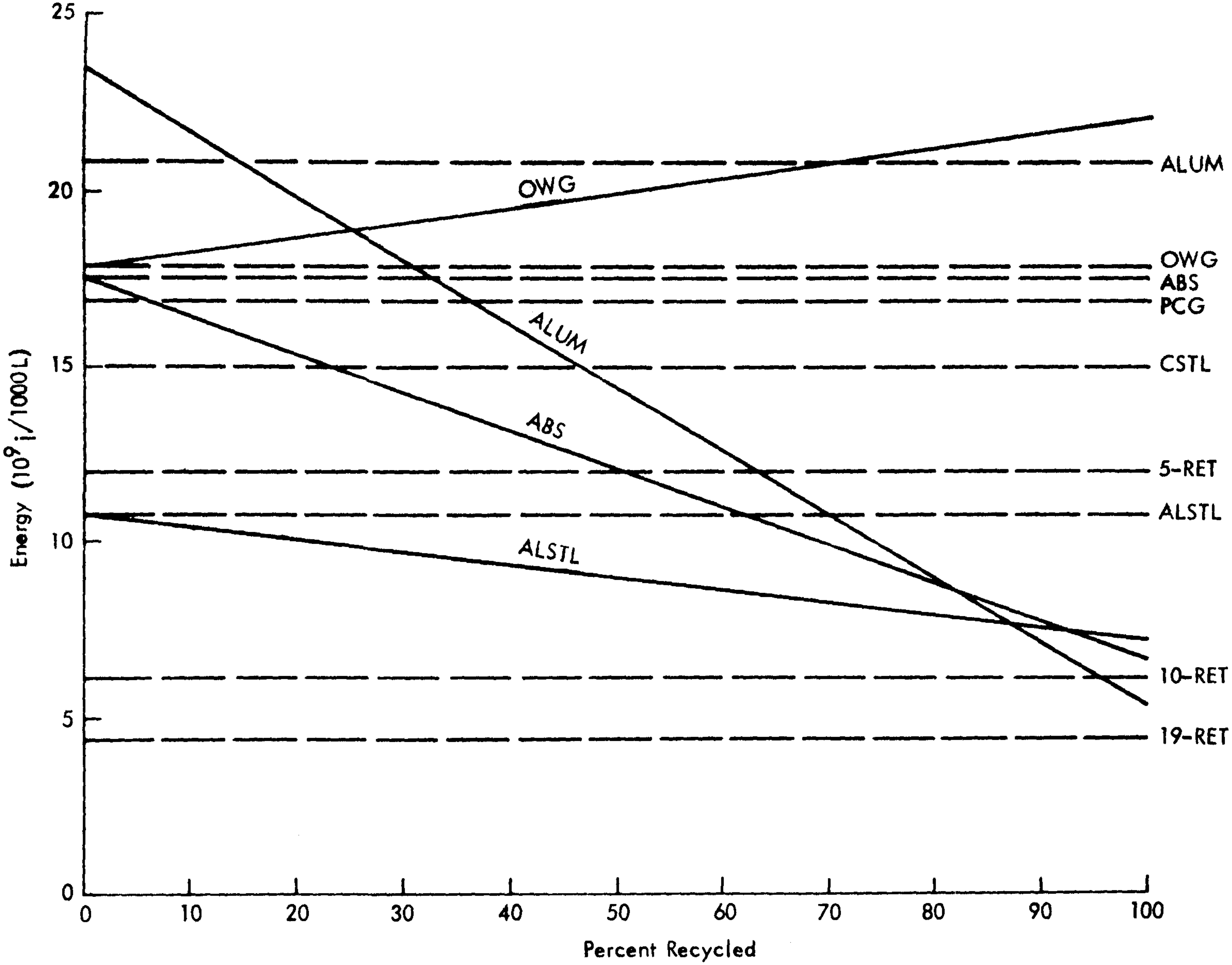
To answer this question, we calculated three market composites and the percent of returnable bottles which must be discarded after one trip before the market composite energy requirement rises to 15.0×10^9j per 1,000 ℓ of beer, the value for the lowest energy commonly available one-way system (CSTL). Those three composites should cover a realistic range which would be experienced in selected United States regional markets. The first composite assumes that the market is partially 19-RET, with the remainder of the market being 1-RET (one-trip off-premise). The second composite is a mix of off-premise 5-RET and 1-RET. The third mix assumes that the market is 20 percent 19-RET, with the remainder being shared between 5-RET and 1-RET.

The results of the calculation show that the market share for 1-RET must be 45 percent, 19 percent and 28 percent, respectively. Thus, in the most pessimistic case of having only 5-RET and 1-RET systems present, consumers must discard 19 percent of the returnable bottles after one trip before a currently available one-way system shows lower overall energy use. But, if higher trip rates and more favorable conditions exist, about 28 to 45 percent of the returnables must be discarded after one trip before a conventional one-way system has a lower energy use.

B. Recycling

The effect of recycling on the total system energy is depicted in Figure 4. This figure shows that impressive gains are made by recycling aluminum, plastic or steel from solid waste streams. This is most evident for ALUM, where the energy of 23.6×10^9j for 1,000 ℓ of beer is reduced to 5.29×10^9j for 100 percent recycling, a 78 percent reduction. Improvements in the other systems are significant, but not as great. For steel, the improvements is 39 percent; for ABS, 62 percent; but for glass, a 23 percent increase is seen. This increase results because we assumed the solid waste glass recovery would be made from a relatively energy intensive wet recovery process followed by color sorting the glass from mixed "heavies" to upgrade it to furnace specification. However, energy savings by recycling glass of greater than 10 percent in the glass plant are not usually realized no matter what means of recovery are used. Thus, recovery and recycling of glass from retail stores or filling plants may result in marginal energy savings (but considerable reduction in solid waste). The energy saving values, for materials other than glass, are based on the fact that recycling bypasses many of the conventional manufacturing processes, but for glass this is not true.

One complicating factor of the recycled materials profiles is the assignment of energy to recover containers. If containers are recovered by mechanical means from a solid waste stream, the recovery energy is not large compared to the total recycled system energy requirements (i.e., if the whole waste stream is processed for recovery). However, recovering cans through a voluntary can reclamation center presents a different picture. In one circumstance, cans are transported by auto to a supermarket collection center, or other location to which a trip could be considered a necessity. The purpose of a trip such as this is primarily to buy food, or medicine, or other necessary goods so that the cans ride "piggy back." No energy of transportation needs to be assigned in this case. However, if a specific auto trip is undertaken to take cans to a reclamation center, then impacts of the entire round trip should be charged to the cans.



Energy (10⁹ j/1000L)
Percent Recycled
0
5
10
15
20
25
0
10
20
30
40
50
60
70
80
90
100
OWG
ALUM
ABS
ALSTL
ALUM
OWG
ABS
PCG
CSTL
5-RET
ALSTL
10-RET
19-RET

Figure 4

We have calculated the impacts of carrying aluminum cans to a voluntary collection center by auto. At 1 gallon of gasoline consumed per 100 cans, the change in the 100 percent recycled energy requirement of aluminum is to increase 82 percent, an increase from 5.25 to 9.55 x 10^9j. This represents a round-trip by car to a collection center only 10 to 15 miles from home with about four cases in the trunk. However, this is still an index value better than 5-RET or any other one-way system. In fact, a gasoline consumption of at least 2.2 gallons per 100 cans is required before the 100 percent recycled aluminum index becomes equal to CSTL, the "best" conventional one-way system. Thus, even though long travel with empty aluminum cans is a negative environmental factor, it is usually better than any currently used one-way system, as long as the "one-way" packaging is used in the first instance.

Looking at 100 percent recycling values is only of academic interest, of course, because such recovery rates from solid waste streams are not possible on a regional or national basis. Much of the potentially recoverable materials are discarded into waste streams in such low concentrations that to recover it economically is not possible. It is probable that only where quite large volumes of waste are processed, can recovery of materials be practiced economically. In addition, the discarded materials, when recovered, are sometimes contaminated so that reuse is difficult.

A possible recycling rate for various materials is difficult to determine, but for purposes of comparison, we used a 50 percent recycling rate compared to returnable options. Figure 4 shows that near 50 percent recycling both aluminum and glass have index values that are not as low as using any returnable container while ABS is about equal to 5-RET. However, none of the 50 percent recycled containers, not even 50 percent recycled ALSTL, have energy requirements lower than either 10-RET or 19-RET glass. In fact, recycling rates in excess of 90 percent are required before the one-way containers are equivalent to 10-RET containers.

In view of the fact that 50 percent recycling from postconsumer waste is approaching a realistic limit on a regional or national basis, we conclude that recycling substantially reduces energy use, but does not supplant reusable containers that make 10 trips or more. In fact, the 5-RET system which we consider as a "lowest limit" for returnable systems has a lower overall impact than glass and aluminum recycle systems, at 50 percent recycling rates.

On the other hand, two container systems not now widely used--ABS and ALSTL--may show more environmental improvement resulting from recycle options. ALSTL requires less energy than 5-RET and any recycling further reduces energy. However, the ABS one-way which requires more energy than 5-RET can become equivalent to it at less than 50 percent recycling. But this high a recycling rate seems improbable in the near term.

On the other hand, Figure 3 shows that a three-trip ABS returnable would require 12 x 10^9j of energy, the same as the 50 percent recycle ABS. Thus, it would seem that a logical choice is to look to ABS as a returnable system if energy reduction is desired. Or even better, an ABS returnable bottle made from recycled polymer could conceivably be used.

An examination of Figure 4 shows that the energy requirement for both all steel and aluminum cans for the range of 80 to 90 percent recycling falls between 5-RET and 10-RET. Thus, at those high recycling rates, the energy requirement for cans becomes comparable to conventional off-premise returnable glass bottle systems. This type of recovery could probably be accomplished with a technique that forces return of containers outside the municipal waste stream such as a deposit or other approach to bring beverage containers back into the use "loop" they were discarded from.

One environmental problem not quantified here is littering. To alleviate the littering of containers is a somewhat different consideration of course. Here one must deal with the habits of individual users of beverages. Oregon has sought remedy in a deposit; other approaches have been tried too. However, we did not attempt to incorporate litter as an analysis factor in this study.

CHAPTER I

BASIC CONVERSION FACTORS

This appendix contains data and information used to convert raw fuel and electric energy input values into corresponding environmental impact parameters. The basic factors are discussed in four sections:

A. Mobile and Stationary Sources

B. Electric Energy

C. Transportation

D. Conversion from Conventional Units to Metric Units

A. Mobile and Stationary Sources

A set of atmospheric emission factors resulting from the combustion of fuels has been developed by the authors of this report in cooperation with the Physical Sciences Division of Midwest Research Institute (MRI). They are reported in Table 1. These data represent both a comprehensive literature search and data collected from a nationwide telephone survey. The primary reference was Reference 44, but numerous other literature sources were used. The factors represent national average emissions after pollution controls have been applied. They are representative of projections of levels which will be experienced in 1975.

Factors relating to both precombustion and combustion impacts are included. Combustion factors relate only to impacts resulting from combustion of fuel and exclude secondary (or precombustion) environmental effects. Such secondary impacts are incurred in mining coal, refining oil and so on. To include these secondary factors, tables similar to Tables 2, 3, and 4 were derived, making use of the combustion factors in Table 1. These secondary factors are combined with the primary factors to yield a new set of factors for fuel combustion similar to those shown in the "total" columns of Table 1. These modified factors were then used to recalculate the quantities of Tables 2 and 3. This modification resulted in only small changes in Tables 2 and 3 and performing one more iteration insures that all secondary and higher order impacts are included. Thus, Tables 1, 2, and 3 include all secondary or higher order environmental impacts relating to fuel combustion.

TABLE 1

(Conventional Units)

FUEL FACTORS

	Gasoline (1000 gal) Pre-combustion	Gasoline (1000 gal) Combustion	Gasoline (1000 gal) Total	Diesel (1000 gal) Pre-combustion	Diesel (1000 gal) Combustion	Diesel (1000 gal) Total	Fuel Oil Mobile Source (1000 gal) Pre-combustion	Fuel Oil Mobile Source (1000 gal) Combustion	Fuel Oil Mobile Source (1000 gal) Total
Energy - 10^6 Btu	19.9	125.0	144.9	19.9	139.0	158.9	19.9	150.0	169.9
Solid Wastes - lb	36.2		36.2	36.2		36.2	36.2		36.2
Atmospheric Emissions - lb									
Particulates	4.2	11.0	15.2	4.2	13.0	17.2	4.2	23.0	27.2
Nitrogen Oxides	34.7	120.0	154.7	34.7	370.0	404.7	34.7	105.0	139.7
Hydrocarbons	54.3	103.0	157.3	54.3	37.0	91.3	54.3	5.0	59.3
Sulfur Oxides	31.7	6.0	37.7	31.7	27.0	58.7	31.7	302.0	333.7
Carbon Monoxide	11.3	1030.0	1041.3	11.3	225.0	236.3	11.3	130.0	141.3
Aldehydes	0.4	12.0	12.4	0.4	3.0	3.4	0.4	10.0	10.4
Other Organics	0.5	44.0	44.5	0.5	3.0	3.5	0.5		0.5
Ammonia	0.4		0.4	0.4		0.4	0.4		0.4
Lead	0.003	3.0	3.0	0.003		0.003	0.003		0.003
Total Atmospheric	137.5	1454.0	1466.5	137.5	678.0	815.5	137.5	575.0	712.5
Waterborne Wastes - lb									
Dissolved Solids (oil field brine)	80.9		80.9	80.9		80.9	80.9		80.9
Other	3.1		3.1	3.1		3.1	3.1		3.1
Total Waterborne	84.0		84.0	84.0		84.0	84.0		84.0

	Natural Gas Internal Combustion ($1000\ ft^3$) Pre-combustion	Natural Gas Internal Combustion ($1000\ ft^3$) Combustion	Natural Gas Internal Combustion ($1000\ ft^3$) Total	Natural Gas Industrial Heating ($1000\ ft^3$) Pre-combustion	Natural Gas Industrial Heating ($1000\ ft^3$) Combustion	Natural Gas Industrial Heating ($1000\ ft^3$) Total	Natural Gas Utility Heating ($1000\ ft^3$) Pre-combustion	Natural Gas Utility Heating ($1000\ ft^3$) Combustion	Natural Gas Utility Heating ($1000\ ft^3$) Total
Energy - 10^6 Btu	0.056	1.03	1.086	0.056	1.03	1.086	0.056	1.03	1.086
Solid Wastes - lb									
Atmospheric Emissions - lb									
Particulates	0.003		0.003	0.003	0.018	0.021	0.003	0.015	0.018
Nitrogen Oxides	0.357	6.0	6.357	0.357	0.214	0.571	0.357	0.600	0.957
Hydrocarbons	1.024	0.8	1.824	1.024	0.003	1.027	1.024	0.001	1.024
Sulfur Oxides	0.012		0.012	0.012		0.012	0.012		0.012
Carbon Monoxide	0.104	1.6	1.704	0.104	0.020	0.124	0.104	0.017	0.121
Aldehydes					0.002	0.002		0.001	0.001
Other Organics					0.005	0.005		0.003	0.003
Ammonia									
Lead									
Total Atmospheric	1.5	8.4	9.9	1.5	0.3	1.8	1.5	0.6	2.1
Waterborne Wastes - lb									
Dissolved Solids (oil field brine)	0.19		0.19	0.19		0.19	0.19		0.19
Other									
Total Waterborne	0.19		0.19	0.19		0.19	0.19		0.19

	Residual Oil Industrial Heating (1000 gal.) Pre-combustion	Residual Oil Industrial Heating (1000 gal.) Combustion	Residual Oil Industrial Heating (1000 gal.) Total	Fuel Oil Utility Heating (1000 gal.) Pre-combustion	Fuel Oil Utility Heating (1000 gal.) Pre-Combustion	Fuel Oil Utility Heating (1000 gal.) Total	Distillate Oil Indust. Heating (1000 gal.) Pre-combustion	Distillate Oil Indust. Heating (1000 gal.) Combustion	Distillate Oil Indust. Heating (1000 gal.) Total
Energy - 10^6 Btu	19.9	150.0	169.9	19.9	148.0	167.9	19.9	139.0	158.9
Solid Wastes - lb	36.2		36.2	36.2		36.2	36.2		36.2
Atmospheric Emissions - lb									
Particulates	4.2	23.0	27.2	4.2	8.0	12.2	4.2	15.0	19.2
Nitrogen Oxides	34.7	72.0	106.7	34.7	105.0	139.7	34.7	72.0	106.7
Hydrocarbons	54.3	3.0	57.3	54.3	2.0	56.3	54.3	3.0	57.3
Sulfur Oxides	31.7	250.0	281.7	31.7	254.0	285.7	31.7	142.0	173.7
Carbon Monoxide	11.3	4.0	15.3	11.3	3.0	14.3	11.3	4.0	15.3
Aldehydes	0.4	1.0	1.4	0.4	1.0	1.4	0.4	2.0	2.4
Other Organics	0.5		0.5	0.5		0.5	0.5		0.5
Ammonia	0.4		0.4	0.4		0.4	0.4		0.4
Lead	0.003		0.003	0.003		0.003	0.003		0.003
Total Atmospheric	137.5	353.0	490.5	137.5	373.0	510.5	137.5	238.0	375.5
Waterborne Wastes - lb									
Dissolved Solids (oil field brine)	80.9		80.9	80.9		80.9	80.9		80.9
Acid	0.2		0.2	0.2		0.2	0.2		0.2
Mital ion	0.1		0.1	0.1		0.1	0.1		0.1
Other	0.8		2.8	2.8		2.8	2.8		2.8
Total Waterborne	84.0		84.0	84.0		84.0	84.0		84.0

	Coal Industrial Heating (1000 lb) Pre-combustion	Coal Industrial Heating (1000 lb) Combustion	Coal Industrial Heating (1000 lb) Total	Coal Utility Heat (1000 lb) Pre-combustion	Coal Utility Heat (1000 lb) Combustion	Coal Utility Heat (1000 lb) Total	Diesel Locomotive (1000 gal) Pre-combustion	Diesel Locomotive (1000 gal) Combustion	Diesel Locomotive (1000 gal) Total
Energy - 10^6 Btu	0.2	13.1	13.3	0.2	13.1	13.3	19.9	139.0	158.9
Solid Wastes - lb	190.0	31.0	221.0	190.0	69.0	259.0	36.2		36.2
Atmospheric Emissions - lb									
Particulates	2.0	21.0	23.0	2.0	11.0	13.0	4.2	25.0	29.2
Nitrogen Oxides	0.5	9.0	9.5	0.5	9.0	9.5	34.7	370.0	404.7
Hydrocarbons	0.5	0.5	1.0	0.5	0.15	0.65	54.3	94.0	148.3
Sulfur Oxides	1.5	42.0	43.5	1.5	55.0	56.5	31.7	57.0	88.7
Carbon Monoxide	2.5	1.0	3.5	2.5	0.5	3.0	11.3	130.0	141.3
Aldehydes	0.01	0.003	0.013	0.01	0.003	0.013	0.4	5.5	5.9
Other Organics	0.02		0.02	0.02		0.02	0.5	7.0	7.5
Ammonia							0.4		0.4
Lead							0.003		0.003
Total Atmospheric	7.0	73.5	80.5	7.0	75.7	82.7	137.5	688.5	826.0
Waterborne Wastes - lb									
Dissolved Solids (oil field brine)							80.9		80.9
Acid	2.0		2.0	2.0		2.0	0.2		0.2
Mital ion	0.5		0.5	0.5		0.5	0.1		0.1
Other	0.5		0.5	0.5		0.5	2.8		2.8
Total Waterborne	3.0		3.0	3.0		3.0	84.0		84.0

TABLE I (Concluded)

FUEL FACTORS

	Gasoline (1,000 l) Pre-combustion	Gasoline Combustion	Gasoline Total	Diesel (1,000 l) Pre-combustion	Diesel Combustion	Diesel Total	Fuel Oil Mobile Source (1,000 l) Pre-combustion	Fuel Oil Mobile Source Combustion	Fuel Oil Mobile Source Total	(1,000 cu m) Natural Gas Internal Combustion Pre-combustion	Natural Gas Internal Combustion Combustion	Natural Gas Internal Combustion Total	(1,000 cu m) Natural Gas Industrial Heating Pre-combustion	Natural Gas Industrial Heating Combustion	Natural Gas Industrial Heating Total	(1,000 cu m) Natural Gas Utility Heating Pre-combustion	Natural Gas Utility Heating Combustion	Natural Gas Utility Heating Total
Energy - 10^9 j	5.5	34.8	40.3	5.5	38.7	44.2	5.5	41.8	47.3	2.1	38.4	40.5	2.1	38.4	40.5	2.1	38.4	40.5
Solid Wastes - kg	4.3		4.3	4.3		4.3	4.3		4.3									
Atmospheric emissions - kg																		
Particulates	0.5	1.3	1.8	0.5	1.6	2.1	0.5	2.8	3.3	0.05		0.05	0.05	0.3	0.35	0.05	0.2	0.25
Nitrogen Oxides	4.2	14.4	18.6	4.2	44.3	48.5	4.2	12.6	16.8	5.7	96.1	101.8	5.7	3.4	9.1	5.7	9.6	15.3
Hydrocarbons	6.5	12.3	18.8	6.5	4.4	10.9	6.5	0.6	7.1	16.4	12.8	29.2	16.4	0.05	16.45	16.4	0.02	16.42
Sulfur Oxides	3.8	0.7	4.5	3.8	3.2	7.0	3.8	36.2	40.0	0.2		0.2	0.2		0.2	0.2		0.2
Carbon Monoxide	1.4	123.4	124.8	1.4	27.0	28.4	1.4	15.6	17.0	1.7	25.6	27.3	1.7	0.3	2.0	1.7	0.3	2.0
Aldehydes	0.05	1.4	1.45	0.05	0.4	0.45	0.05	1.2	1.25					0.03	0.03		0.02	0.02
Other Organics	0.1	5.3	5.4	0.1	0.4	0.5	0.1		0.1					0.08	0.08		0.05	0.05
Ammonia	0.05		0.05	0.05		0.05	0.05		0.05									
Lead	0.0004	0.4	0.4004	0.0004		0.0004	0.0004		0.0004									
Total Atmospheric	16.6004	159.2	175.8004	16.6004	81.3	97.9004	16.6004	69.0	85.6004	24.05	134.5	158.55	24.05	4.16	28.21	24.05	10.19	34.24
Waterborne Wastes - kg																		
Dissolved Solids																		
(oil field brine)	9.3		9.3	9.3		9.3	9.3		9.3	3.0		3.0	3.0		3.0	3.0		3.0
Other	1.1		1.1	1.1		1.1	1.1		1.1									
Total Waterborne	10.4		10.4	10.4		10.4	10.4		10.4	3.0		3.0	3.0		3.0	3.0		3.0

	(1,000 l) Residual Oil Indust. Heating Pre-combustion	Residual Oil Indust. Heating Combustion	Residual Oil Indust. Heating Total	(1,000 l) Fuel Oil Utility Heating Pre-combustion	Fuel Oil Utility Heating Combustion	Fuel Oil Utility Heating Total	(1,000 l) Distillate Oil Industrial Heating Pre-combustion	Distillate Oil Industrial Heating Combustion	Distillate Oil Industrial Heating Total	(1,000 l) Coal Industrial Heat Pre-combustion	Coal Industrial Heat Combustion	Coal Industrial Heat Total	Coal Utility Heat (1,000 kg) Pre-combustion	Coal Utility Heat Combustion	Coal Utility Heat Total	Diesel Locomotive (1,000 l) Pre-combustion	Diesel Locomotive Combustion	Diesel Locomotive Total
Energy - 10^9 j	5.5	41.8	47.3	5.5	41.2	46.7	5.5	38.7	44.2	0.47	30.5	31.0	0.45	30.5	31.0	5.5	38.7	44.2
Solid Wastes - kg	4.3		4.3	4.3		4.3	4.3		4.3	190.0	31.0	221.0	190.0	69.0	259.0	4.3		4.3
Atmospheric emissions - kg																		
Particulates	0.5	2.8	3.3	0.5	1.0	1.5	0.5	1.8	2.3	2.0	21.0	23.0	2.0	11.0	13.0	0.5	3.0	3.5
Nitrogen Oxides	4.2	8.6	12.8	4.2	12.6	16.8	4.2	8.6	12.8	0.5	9.0	9.5	0.5	9.0	9.5	4.2	44.3	48.5
Hydrocarbons	6.5	0.4	6.9	6.5	0.2	6.7	6.5	0.4	6.9	0.5	0.5	1.0	0.5	0.2	0.7	6.5	11.3	17.8
Sulfur Oxides	3.8	30.0	33.8	3.8	30.4	34.2	3.8	17.0	20.8	1.5	42.0	43.5	1.5	55.0	56.5	3.8	6.8	10.6
Carbon Monoxide	1.4	0.5	1.9	1.4	0.4	1.8	1.4	0.5	1.9	2.5	1.0	3.5	2.5	0.5	3.0	1.4	15.6	17.0
Aldehydes	0.05	0.1	0.15	0.05	0.1	0.15	0.05	0.2	0.25	0.01	0.002	0.012	0.01	0.002	0.012	0.05	0.7	0.75
Other Organics	0.1		0.1	0.1		0.1	0.1		0.1	0.02		0.02	0.02		0.02	0.1	0.8	0.9
Ammonia	0.05		0.05	0.05		0.05	0.05		0.05							0.05		0.05
Lead	0.0004		0.0004	0.0004		0.0004	0.0004		0.0004							0.0004		0.0004
Total Atmospheric	16.6004	42.4	59.0004	16.6004	44.7	61.3004	16.6004	28.5	45.1004	7.03	73.502	80.532	7.03	75.702	82.732	16.6004	82.5	99.1004
Waterborne Wastes - kg																		
Dissolved Solids																		
(oil field brine)	9.3		9.3	9.3		9.3	9.3		9.3							9.3		9.3
Acid										2.0		2.0	2.0		2.0			
Metal ions										0.5		0.5	0.5		0.5			
Other	1.1		1.1	1.1		1.1	1.1		1.1	0.5		0.5	0.5		0.5	1.1		1.1
Total Waterborne	10.4		10.4	10.4		10.4	10.4		10.4	3.0		3.0	3.0		3.0	10.4		10.4

TABLE 2

PRECOMBUSTION ENVIRONEMENTAL IMPACTS RESULTING FROM PRODUCTION AND PROCESSING OF 1,000 CUBIC FEET OF NATURAL GAS

	Production	Processing	Total Precombustion
Energy - 10^6 Btu	0.021	0.035	0.056
Atmospheric emissions - lb			
Particulates	0.002	0.001	0.003
Nitrogen oxides	0.119	0.238	0.357
Hydrocarbons	0.495	0.529	1.024
Sulfur oxides	0.010	0.002	0.012
Carbon monoxide	0.038	0.066	0.104
Total Atmospheric	0.66	0.84	1.50
Waterborne wastes - lb			
Dissolved solids (oil field brine)	0.184	0.007	0.19

TABLE 3

PRECOMBUSTION ENVIRONMENTAL IMPACTS RESULTING FROM PRODUCTION, REFINING AND DELIVERY OF 1,000 GALLONS OF LIQUID HYDROCARBON FUEL

	Production	Refining	Transportation	Total
Energy - 10^6 Btu	1.4	17.5	1.0	19.9
Solid wastes - lb				
Process	4.2			4.2
Fuel combustion	2.6	10.2	0.06	12.9
Mining	3.9	15.2	___	19.1
Total	10.7	25.4	0.06	36.2
Atmospheric emissions - lb				
Particulate	0.34	3.82	0.07	4.2
Nitrogen oxides	3.02	27.16	4.53	34.7
Hydrocarbon	10.83	42.16	1.34	54.3
Sulfur oxide	2.14	29.12	0.48	31.7
Carbon monoxide	1.63	7.75	1.92	11.3
Aldehydes	0.04	0.38	0.02	0.4
Other organics	0.01	0.43	0.01	0.5
Ammonia		0.42		0.4
Lead	___	___	0.003	0.0
Total Atmospheric	18.0	111.2	8.4	137.6
Waterborne wastes - lb				
Dissolved solids (oil field brine)	77.33	3.23	0.31	80.9
Suspended solids		0.63		0.6
BOD		0.36		0.4
COD		1.12		1.1
Phenol		0.10		0.1
Sulfide		0.13		0.1
Oil		0.21		0.2
Acid	0.04	0.15		0.2
Metal ion	0.01	0.04	___	0.1
Total waterborne	77.4	6.0	0.3	84.0

B. Electric Energy

The environmental impacts associated with use of electrical energy are summarized in Table 4. The impacts were calculated on the basis of a composite kilowatt-hour (kwhr). A composite kilowatt-hour is defined as 1 kilowatt-hour generated by the U.S. national average mix of fossil fuels and hydroelectric power. Data were obtained from the Edison Electric Institute for 1972.[78/]

Hydropower was assigned an energy equivalent of 3,413 Btu per kilowatt-hour and nuclear energy was assigned an energy equivalent of 21,330 Btu per kilowatt-hour. The amounts of fuel required are the total 1972 U.S. fuel requirements for electric utilities, divided by the total number of kilowatt-hours sold to customers. Impact factors from Table 1 were combined with the fuel quantities to arrive at the impact values in Table 4.

C. Transportation

Environmental impacts occur when goods are transported because of the consumption of fossil fuels to provide necessary energy. In this study, the modes of transportation included are rail, truck, pipeline, and barge. These impacts were calculated by determining the kinds and amounts of fuels used by each mode on a national average basis. Impacts were then calculated for 1,000 ton-miles.

1. Rail: A complete set of fuel consumption data[94/] indicates that diesel fuel accounted for 98 percent of the energy expended by railroads in 1968. We assumed that 100 percent of the energy was supplied by diesel fuel and that 5.63×10^{14} Btu of fuel were used. This fuel use resulted in 7.68×10^{11} ton-miles of transportation.[79/] The corresponding fuel consumption was 5.25 gallons per 1,000 ton-miles. This value was combined with information in Table 1 to yield the impacts presented in Table 5.

2. Truck: In 1967, a total of 9.29×10^9 miles were traveled by trucks engaged in intercity highway hauling. This resulted in 1.10×10^{11} ton-miles of transportation.[80/] It is estimated that 35 percent of these miles were traveled by gasoline engine trucks while 65 percent were traveled by diesel fueled trucks.[87/] National average fuel mileage data are not available, but a reasonable assumption based on actual experience is that this type of truck travel results in fuel consumption rates of about 5 miles per gallon for either type of fuel. Thus, 6.5×10^8 gallons of gasoline and 1.20×10^9 gallons of diesel fuel were used in 1967. From this, it was calculated that 5.9 gallons of gasoline and 10.9 gallons of diesel fuel were consumed per 1,000 ton-miles. Using data in Table 1, impacts were calculated and reported in Table 5.

TABLE 4

ENVIRONMENTAL IMPACTS RESULTING FROM GENERATION AND DELIVERY OF 1,000 COMPOSITE KILOWATT-HOURS OF ELECTRICITY, 1972

	Coal	Oil	Natural Gas	Other	Total
Quantity	0.22 Ton	13.1 Gal.	2.522 Cu Ft		
Percent of Btu	48.2	17.0	23.5	11.3[b]	100
Impacts					
Energy - 10^6 Btu[a]	5.35	1.89	2.61	1.25	11.1
Solid wastes - lb					
Mining	83.6	-	-	-	83.6
Fuel combustion	30.4	0.3	-	-	30.7
Atmospheric emissions - lb					
Particulates	5.7	0.2	0.6		6.5
Nitrogen oxides	4.2	1.6	5.5		11.3
Hydrocarbons	0.3	0.6	3.5		4.4
Sulfur oxides	24.9	3.7	0.1		28.7
Carbon monoxide	1.3	0.1			1.4
Other	0.01	0.03	0.01		0.05
Total Atmospheric	36.4	6.3	9.2	-	52
Waterborne wastes - lb					
Acid	0.96	0.06	0.58		1.6
Metal ion	0.24	0.01	0.11		0.4
Other	0.20	0.60	0.59		1.4
Total waterborne	1.4	0.7	1.3	-	3.4

a/ These values were derived from Reference 1.

b/ Includes 15 percent of total kilowatt-hours as hydropower and 3 percent as nuclear. The energy equivalent for hydropower is 0.585 x 10^6 Btu and for nuclear is 0.661 x 10^6 Btu. No other impacts were determined in this category.

3. <u>Barge</u>: During 1966, barge traffic resulted in 5.0×10^{11} ton-miles of transportation.[81] Fuel consumption was 6.99×10^8 gallons of diesel fuel and 3.09×10^9 gallons of residual.[95] Therefore, 1.4 gallons of diesel fuel and 6.1 gallons of residual were consumed per 1,000 ton-miles. Again, impacts were calculated and are listed in Table 5.

4. <u>Crude oil and products pipeline:</u> Sources in the pipeline industry report that, on the average, about 30 cubic feet of natural gas fuel are required to transport one barrel of oil 300 miles through a pipeline. This requirement translates to 30 cubic feet for 45 ton-miles, or 0.67 cubic feet of natural gas per ton-mile of crude petroleum transportation. This factor, combined with information from Table 1, enabled us to calculate the impacts for 1,000 ton-miles of pipeline transportation. Pipeline transportation impacts for moving other types of liquids of interest in this study were assumed to be approximately the same as for crude oil.

According to the data of Table 5, transportation by truck is the most environmentally detrimental of the four transportation modes. This result is due to the relative inefficiency of the gasoline engine. Truck transportation ranks highest in every impact category. Computer analysis comparing the four transport modes showed that the impacts for trucks is more than double that of barge transportation, greater than triple that of rail transportation, and nearly five times worse that pipeline transport.

D. Conversion from Conventional to Metric Units

In the course of this study a large existing data bank was utilized in making the calculations outlined in this chapter. Because of the costly and time consuming problems in converting this data bank to metric units, all calculations were carried out in conventional units. Therefore, the container system summary table (Table B-13) is in conventional units, showing the various impacts per one million 12-ounce containers. However, the discussions in Volume I will be based on metric units, with the product base size being 1,000 liters of beverage. The following list of factors was used to make those conversions from impacts per twelve million ounces to impacts per 1,000 liters.

Conventional Unit	x	Conversion Factor	=	Metric (SI) Unit
lb		0.4536		kg
Btu		1055.		j
gal		3.785		ℓ
cu ft		0.02832		cu m
fl oz		0.02957		ℓ
lb/12 x 10^6 fl oz		0.001278		kg/10^3 ℓ
10^6 Btu/12 x 10^6 fl oz		0.002973		10^9 j/10^3 ℓ
gal/12 x 10^6 fl oz		0.01067		1/10^3 ℓ
cu ft/12 x 10^6 fl oz		0.00007981		cu m/10^3 ℓ

TABLE 5

FUEL CONSUMPTION AND ENVIRONMENTAL IMPACTS RESULTING FROM 1,000 TON-MILES OF TRANSPORTATION BY EACH MODE

	Rail	Truck	Barge	Pipeline
Fuel				
Gasoline - gal.		5.9		
Diesel - gal.	5.3	10.9	1.4	
Fuel oil - gal.			6.1	
Natural gas - cu ft				670
Energy - 10^6 Btu	0.8	2.5	1.2	0.7
Solid wastes (fuel combustion) - lb	0.13	0.40	0.18	
Atmospheric emissions - lb				
Particulates	0.17	0.32	0.21	0.01
Nitrogen oxides	2.05	5.08	1.31	5.09
Hydrocarbon	0.72	1.73	0.41	1.47
Sulfur oxides	0.46	0.83	2.11	0.01
Carbon monoxide	0.45	8.66	1.17	1.41
Aldehydes	0.03	0.12	0.07	
Other organics	0.04	0.07	0.01	
Ammonia				
Lead	____	0.02	____	____
Total Atmospheric	3.9	16.8	5.3	8.0
Waterborne wastes - lb				
Dissolved solids (oil field brine)	0.394	1.260	0.562	0.147
COD	0.004	0.013	0.006	
Acid	0.001	0.003	0.001	
Metal ion		0.001		
Other	0.005	0.016	0.008	____
Total Waterborne	0.40	1.29	0.57	0.15

CHAPTER II

GLASS BOTTLES

This chapter contains the basic data and outlines the calculations made to determine the resource and environmental profiles of glass beverage containers. Eight basic container systems are considered. Of these eight, four are returnable systems and four are one-way systems. The four returnable systems are three beer systems with differing trip rates and paper packaging options, and one soft drink system. The four one-way systems are the conventional beer and soft drink containers, a hypothetical one-way from recycled glass and a plastic coated glass one-way designed for beer. Details for these systems are shown in Figures 1 and 2, and Table 6. Figure 1 is an overall glass container system flow diagram, Figure 2 and Table 6 provide numerical material summaries.

This chapter discusses glass bottle systems in the following sequence.

A. General Discussion of Computer Generated Tables
B. Overview
C. Glass Sand Mining
D. Limestone Mining
E. Lime Manufacture
F. Natural Soda Ash Mining
G. Soda Ash Manufacture
H. Feldspar Mining
I. Glass Container Manufacture
J. Closures
K. Plastic Coated Bottles
L. Paper Packaging
M. Bottle Filling
N. Solid Waste Disposal
O. Nonreturnable and Returnable Glass Containers
P. Glass Recycling

A. General Discussion of Computer Generated Tables

Table 7 is in the form that computer generated tables in this report will duplicate, and the discussion that follows can be generalized to all of those computer tables. The table is divided into three main sections: (1) input to systems, (2) output from systems, and (3) summary.

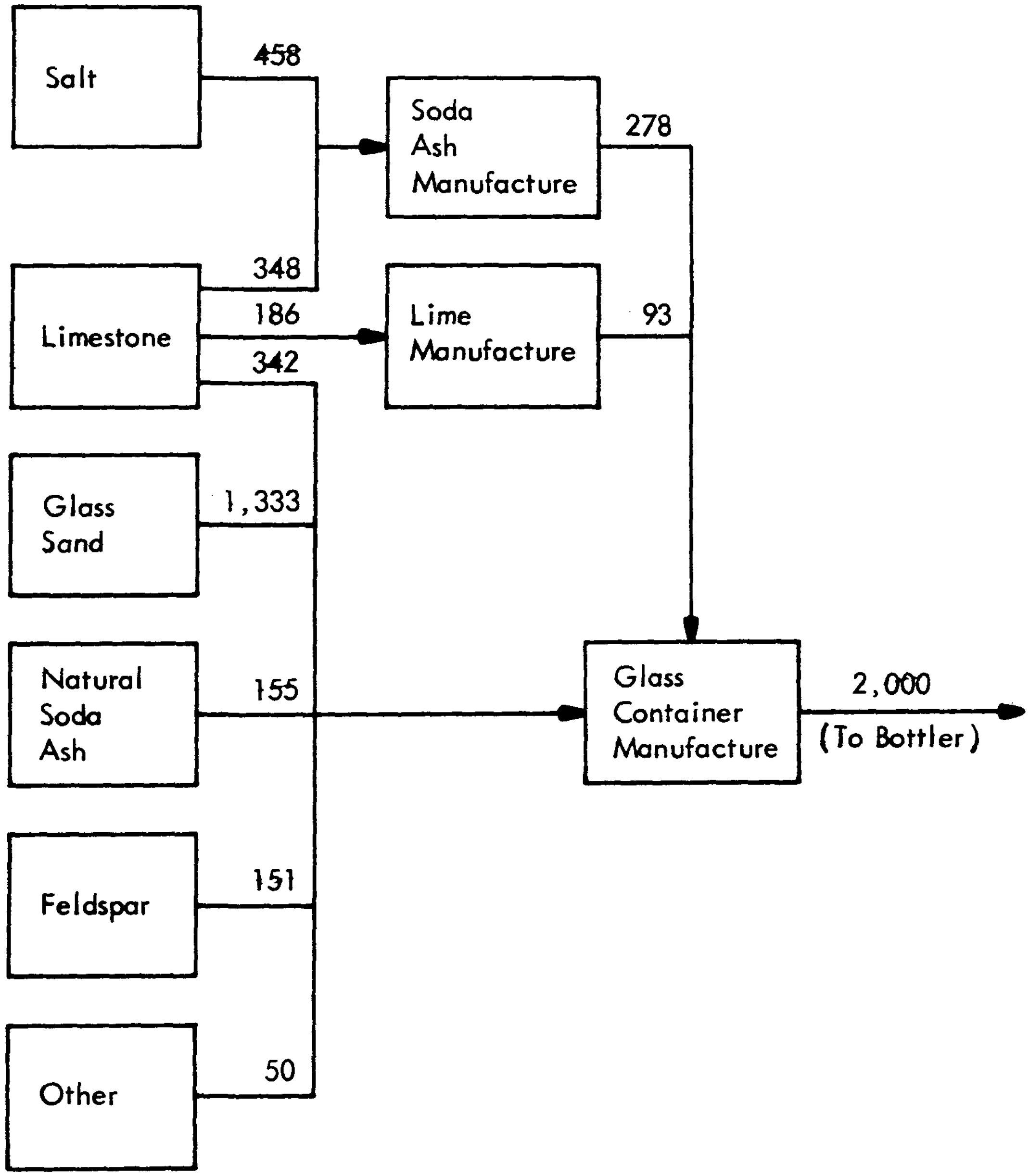


Figure 1 - Materials Requirements for the Manufacture of 1 Ton Glass (pounds)

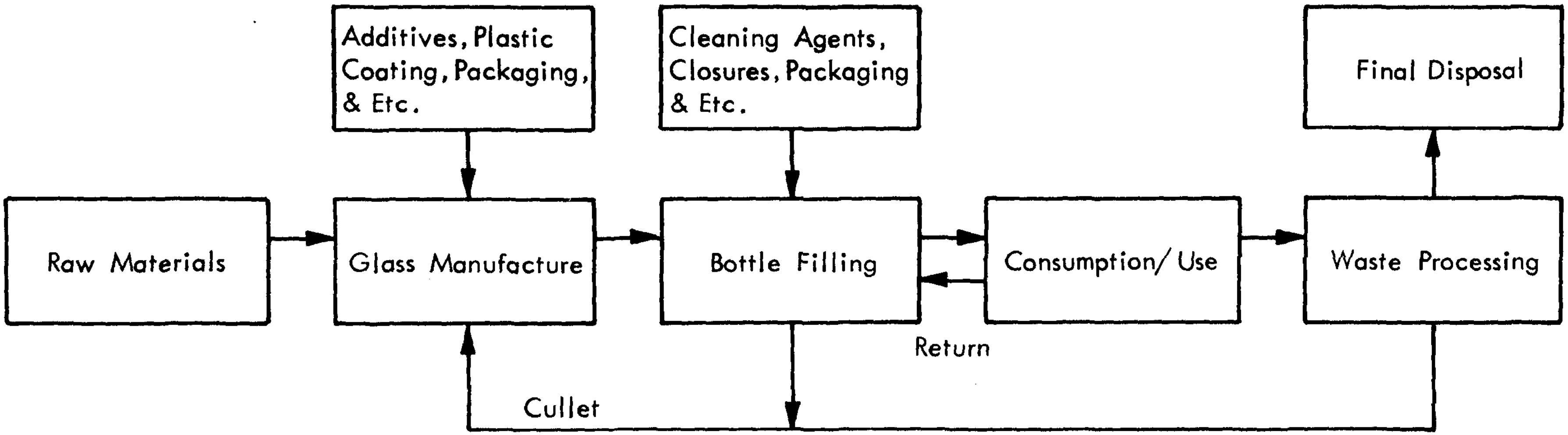


Figure 2 - Materials Flow for Glass Container Systems

TABLE 6

CONTAINER RELATED MATERIALS REQUIRED FOR 1 MILLION FILLINGS (TONS)

	Returnable Bottles				One-Way Bottles			
	19 Trip On-Premise (Three-Trip Paper Packaging)	10 Trip Off-Premise (Three-Trip Paper Packaging)	5 Trip Off-Premise (One-Trip Paper Packaging)	15 Trip Soft Drink (Three-Trip Paper Packaging	Soft Drink	Plastic Coated	Recycled Glass	Conventional Glass
Glass Containers	16	30	61	22	260	173	205	205
Closures	2	2	2	2	2	2	2	2
Paper Packaging								
Corrugated	13	13	39	1.4	22	11.4	13.5	13.5
Bleached Kraft	-	5.7	17	7.3	14.3	29	29	29
Cleaning Agents	1.5	1.5	1.5	1.25	-	-	-	-
Plastic Coat	-	-	-	-	-	2.2	-	-

Note: All container volumes were 12 ounces, except 15-trip soft drink which was 16 ounces.
All containers were for beer, except the two specified for soft drink.

TABLE 7

IMPACTS FOR 1 MILLION GLASS CONTAINERS

		19 TRIP ON PREM RETURN GLASS	10 TRIP OFF PREM RETURN GLASS	5 TRIP OFF PREM RETURN GLASS	PLASTIC COATED GLASS	ONE WAY GLASS 100 PCNT RECYCLE	ONE WAY GLASS	SOFT DRINK 15-TRIP RETURN	SOFT DRINK ONE-WAY GLASS
INPUTS TO SYSTEMS									
NAME	UNITS								
MATERIAL WOOD FIBER	POUNDS	28992.	41110.	120339.	82101.	87976.	86041.	18162.	62627.
MATERIAL LIMESTONE	POUND	15497.	28047.	54445.	153112.	1649.	177303.	23287.	224431.
MATERIAL IRON ORE	POUND	5809.	5809.	5809.	5809.	5809.	5811.	5809.	5815.
MATERIAL SALT	POUND	10552.	17203.	31194.	80272.	0.	93093.	14145.	118069.
MATERIAL GLASS SAND	POUND	21120.	40260.	80520.	231000.	2706.	267894.	33000.	339768.
MATERIAL NAT SODA ASH	POUND	2480.	4727.	9455.	27125.	0.	31457.	3875.	39897.
MATERIAL FELDSPAR	POUND	2416.	4605.	9211.	26425.	0.	30645.	3775.	38867.
MATERIAL BAUXITE ORE	POUND	0.	0.	0.	0.	0.	0.	0.	0.
MATERIAL PROCESS ADD	POUNDS	3032.	4491.	11354.	13343.	6517.	14752.	2639.	15331.
ENERGY PROCESS	MIL BTU	1224.	1717.	3526.	5042.	7020.	5461.	1257.	6094.
ENERGY TRANSPORT	MIL BTU	266.	308.	493.	537.	435.	574.	223.	531.
ENERGY OF MATL RESOURCE	MIL BTU	1.	1.	1.	108.	1.	1.	1.	1.
WATER VOLUME	THOU GAL	1064.	1445.	3048.	3285.	2703.	3462.	1004.	2975.
OUTPUTS FROM SYSTEMS									
NAME	UNITS								
SOLID WASTES PROCESS	POUND	13434.	21922.	42265.	101373.	18513.	115977.	16055.	141701.
SOLID WASTES FUEL COMB	POUND	2380.	3550.	9458.	8931.	11350.	9409.	2321.	8249.
SOLID WASTES MINING	POUND	29979.	36392.	52071.	96007.	37003.	106969.	33766.	127832.
SOLID WASTE POST-CONSUM	CUBIC FT	672.	1121.	2708.	3484.	1443.	3841.	821.	3425.
ATMOS PARTICULATES	POUND	1406.	2119.	5210.	6418.	4793.	7040.	1359.	7180.
ATMOS NITROGEN OXIDES	POUND	1260.	1617.	2924.	4140.	5367.	4367.	1116.	4731.
ATMOS HYDROCARBONS	POUND	908.	1199.	2094.	3797.	4085.	3750.	964.	4419.
ATMOS SULFUR OXIDES	POUND	1928.	2447.	5629.	5473.	9318.	5922.	1435.	6490.
ATMOS CARBON MONOXIDE	POUND	782.	965.	1665.	2098.	2021.	2228.	1238.	2496.
ATMOS ALDEHYDES	POUND	13.	16.	26.	31.	40.	34.	16.	37.
ATMOS OTHER ORGANICS	POUND	34.	44.	84.	87.	85.	92.	54.	99.
ATMOS ODOROUS SULFUR	POUND	239.	364.	1061.	808.	855.	840.	186.	579.
ATMOS AMMONIA	POUND	27.	42.	72.	183.	16.	211.	36.	264.
ATMOS HYDROGEN FLOURIDE	POUND	0.	0.	0.	0.	0.	0.	0.	0.
ATMOS LEAD	POUND	1.	1.	2.	2.	2.	2.	3.	3.
ATMOS MERCURY	POUND	0.	0.	0.	0.	0.	0.	0.	0.
ATMOSPHERIC CHLORINE	POUND	13.	13.	13.	0.	0.	0.	11.	0.
WATERBORNE FLUORIDES	POUND	0.	0.	0.	0.	0.	0.	0.	0.
WATERBORNE DISS SOLIDS	POUND	324.	415.	742.	1060.	1634.	1095.	280.	1182.
WATERBORNE BOD	POUND	1593.	1883.	3592.	1914.	2026.	1986.	528.	1391.
WATERBORNE PHENOL	POUND	0.	0.	1.	1.	1.	1.	0.	1.
WATERBORNE SULFIDES	POUND	0.	0.	1.	1.	1.	1.	0.	1.
WATERBORNE OIL	POUND	6.	9.	15.	40.	45.	43.	7.	54.
WATERBORNE COD	POUND	2.	3.	5.	17.	12.	6.	2.	6.
WATERBORNE SUSP SOLIDS	POUND	578.	854.	1951.	1805.	1575.	1888.	606.	1385.
WATERBORNE ACID	POUND	57.	75.	142.	204.	293.	218.	73.	250.
WATERBORNE METAL ION	POUND	14.	19.	36.	51.	73.	54.	18.	62.
WATERBORNE CHEMICALS	POUND	0.	0.	0.	0.	0.	0.	0.	1.
WATERBORNE CYANIDE	POUND	0.	0.	0.	0.	0.	0.	0.	0.
WATERBORNE ALKALINITY	POUND	0.	0.	0.	0.	0.	0.	1000.	0.
WATERBORNE CHROMIUM	POUND	0.	0.	0.	0.	0.	0.	0.	0.
WATERBORNE IRON	POUND	0.	0.	0.	0.	0.	0.	0.	0.
WATERBORNE ALUMINUM	POUND	0.	0.	0.	0.	0.	0.	0.	0.
WATERBORNE NICKEL	POUND	0.	0.	0.	0.	0.	0.	0.	0.
WATERBORNE MERCURY	POUND	0.	0.	0.	0.	0.	0.	0.	0.
WATERBORNE LEAD	POUND	0.	0.	0.	0.	0.	0.	0.	0.
SUMMARY OF ENVIRONMENTAL IMPACTS									
NAME	UNITS								
RAW MATERIALS	POUNDS	89898.	146253.	322326.	619187.	104657.	706997.	104692.	844805.
ENERGY	MIL BTU	1491.	2026.	4020.	5587.	7456.	6036.	1481.	6626.
WATER	THOU GAL	1064.	1445.	3048.	3285.	2703.	3462.	1004.	2975.
INDUSTRIAL SOLID WASTES	CUBIC FT	618.	835.	1401.	2785.	903.	3137.	704.	3750.
ATM EMMISSIONS	POUNDS	6612.	6827.	18779.	23037.	26563.	24486.	6417.	26298.
WATERBORNE WASTES	POUNDS	2576.	3259.	6485.	5093.	5661.	5293.	2515.	4333.
POST-CONSUMER SOL WASTE	CUBIC FT	672.	1121.	2708.	3484.	1443.	3841.	821.	3425.

At the top of Table 7 we see the input to systems section. In that section is found a detailed display of the amounts of materials, energy and water input to each of the nine systems considered here. For example, the first number in the first column shows that the total manufacturing system for 1 million 19-trip on-premise returnable glass bottles (starting from extraction of raw materials from the ground through final disposal) requires 28,992 pounds of wood fiber.

The second section of the table shows the output from the systems, measured in terms of the solid wastes, atmospheric emissions and water pollutants.

Finally, the lower section contains an aggregated summary of the first two sections. For example, all of the lines in the "input to systems" section of the table which are labeled as materials are summed and listed as "Raw Materials" in the summary table. The other impacts are summed and reported in similar fashion.

The overview section of this chapter contains eight tables of the same type as Table 7. However, Table 14 contains basic data from which the other tables were derived. Table 14 results from computer calculations converting raw data into the various impact categories. For example, the first column on Table 14 is for glass sand mining. This column is based on Table 15, p. 26. The computer converts values such as 0.0058 ton coal (Table 15) into its various impacts, such as the air pollutants (Table 1), and aggregates the value for 1 ton of glass sand mining as shown in Table 14. These values, along with the other values are then combined to form the systems as shown in other tables, such as Table 7. This is done by using flow diagrams such as Figure 1, which shows that 1,333 pounds (0.666 ton) sand are required for 1 ton of glass manufacture. Then, finally the computer is instructed to include 16 tons of glass (Table 6) for 1 million fillings of a 19-trip returnable. The other data needed to build the systems are treated in the same fashion.

B. Overview

This section contains eight computer generated tables which summarize the environmental impacts of glass bottles. Table 7 displays the impacts for 1 million containers of each of the systems. Table 8 shows the impacts for 1 ton of nonreturnable bottles as allocated to each component process. Tables 9 and 10 present the impacts for returnable systems, also broken down by component processes. Table 11 presents the GCP System.

TABLE 8

IMPACTS FOR 1 TON OF GLASS ONE-WAY CONTAINER SYSTEM

NAME	UNITS	FELDSPAR MINING 151 LBS	GLASS SAND MINING 1333 LBS	SODA ASH MINING 155 LBS	SODA ASH MFG 278 LBS	LIME MFG 92 LBS	LIMESTON MINING 876 LBS	SALT MINING 458 LBS	GLASS CONT FAB 2000 LBS	DISPOSAL	STEEL CLOSURE 20 LBS	TRANS	FILLING BOTTLES 2000 LBS	PACKAGIN 404 LBS
INPUTS TO SYSTEMS														
MATERIAL WOOD FIBER	POUNDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	397.387
MATERIAL LIMESTONE	POUND	0.000	0.000	0.000	347.500	184.000	0.000	0.000	334.000	0.000	8.247	0.000	0.000	0.000
MATERIAL IRON ORE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	29.044	0.000	0.000	0.000
MATERIAL SALT	POUND	0.000	0.000	0.000	458.700	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL GLASS SAND	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1320.000	0.000	0.000	0.000	0.000	0.000
MATERIAL NAT SODA ASH	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	155.000	0.000	0.000	0.000	0.000	0.000
MATERIAL FELDSPAR	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	151.000	0.000	0.000	0.000	0.000	0.000
MATERIAL BAUXITE ORE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL PROCESS ADD	POUNDS	0.000	0.000	0.000	1.251	0.000	0.000	0.000	40.000	0.000	1.390	0.000	0.000	28.160
ENERGY PROCESS	MIL BTU	.052	.529	.040	1.851	.214	.016	.044	15.474	0.000	.490	0.000	.683	7.006
ENERGY TRANSPORT	MIL BTU	.048	.040	0.000	0.000	.002	.014	.005	.194	.139	.009	1.500	0.000	.746
ENERGY OF MATL RESOURCE	MIL BTU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.005	0.000	0.000	0.000
WATER VOLUME	THOU GAL	.341	1.207	.093	2.336	.015	.041	.230	1.168	.009	.555	.087	1.484	8.803
OUTPUTS FROM SYSTEMS														
SOLID WASTES PROCESS	POUND	0.000	0.000	0.000	464.260	16.790	0.000	0.000	45.000	0.000	8.179	0.000	9.800	25.503
SOLID WASTES FUEL COMB	POUND	.140	.535	0.000	3.057	.298	.034	.007	8.317	.035	.268	.349	.631	36.467
SOLID WASTES MINING	POUND	345.351	2.238	9.240	18.223	1.681	.093	.016	21.987	0.000	106.212	0.000	2.681	10.417
SOLID WASTE POST-CONSUM	CUBIC FT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	18.202	0.000	0.000	0.000	0.000
ATMOS PARTICULATES	POUND	1.158	.250	.771	5.192	1.812	5.691	.003	4.105	.015	.599	.193	.315	13.610
ATMOS NITROGEN OXIDES	POUND	.168	.441	.021	1.254	.144	.045	.028	10.157	.148	.197	3.236	.450	4.721
ATMOS HYDROCARBONS	POUND	.052	.374	.038	.400	.096	.018	.043	12.574	.150	.405	1.173	.397	2.511
ATMOS SULFUR OXIDES	POUND	.138	.639	.000	4.828	.408	.036	.015	9.297	.036	.427	.654	.918	11.146
ATMOS CARBON MONOXIDE	POUND	.093	.181	.005	.392	.046	.041	.012	2.084	1.625	.086	3.962	.096	1.952
ATMOS ALDEHYDES	POUND	.001	.002	.000	.005	.000	.001	.000	.038	.012	.001	.062	.002	.036
ATMOS OTHER ORGANICS	POUND	.002	.005	.000	.004	.001	.001	.000	.068	.160	.001	.142	.002	.046
ATMOS ODOROUS SULFUR	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.021	0.000	0.000	3.842
ATMOS AMMONIA	POUND	.000	.000	0.000	.974	.000	.000	.000	.003	.000	.053	.004	.000	.005
ATMOS HYDROGEN FLOURIDE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ATMOS LEAD	POUND	.000	.000	0.000	.000	.000	.000	.000	.000	.003	.000	.007	.000	.001
ATMOS MERCURY	POUND	.000	.000	0.000	.000	.000	.000	.000	.000	0.000	.000	0.000	.000	.000
ATMOSPHERIC CHLORINE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE FLUORIDES	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE DISS SOLIDS	POUND	.027	.086	.007	.211	.019	.009	.010	2.715	.074	.042	.745	.119	1.204
WATERBORNE BOD	POUND	.000	.000	0.000	.000	.000	.000	.000	.002	.000	.000	.002	.000	9.137
WATERBORNE PHENOL	POUND	.000	.000	0.000	.002	.000	.000	.000	.001	.000	.000	.001	.000	.001
WATERBORNE SULFIDES	POUND	.000	.000	0.000	.000	.000	.000	.000	.001	.000	.000	.001	.000	.001
WATERBORNE OIL	POUND	.000	.000	0.000	.000	.000	.000	.000	.201	.000	.011	.001	.000	.001
WATERBORNE COD	POUND	.000	.000	0.000	.002	.000	.000	.000	.007	.001	.000	.008	.001	.010
WATERBORNE SUSP SOLIDS	POUND	.000	.665	0.000	.974	.000	.000	.000	.004	.000	.053	.005	.000	7.026
WATERBORNE ACID	POUND	.007	.030	0.000	.192	.019	.002	.000	.422	.000	.096	.001	.035	.252
WATERBORNE METAL ION	POUND	.002	.008	0.000	.048	.005	.000	.000	.106	.000	.024	.000	.009	.063
WATERBORNE CHEMICALS	POUND	0.000	0.000	0.000	.002	0.000	0.000	0.000	0.000	0.000	.001	0.000	0.000	0.000
WATERBORNE CYANIDE	POUND	0.000	0.000	0.000	.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE ALKALINITY	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE CHROMIUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE IRON	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE ALUMINUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE NICKEL	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE MERCURY	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE LEAD	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SUMMARY OF ENVIRONMENTAL IMPACTS														
RAW MATERIALS	POUNDS	0.000	0.000	0.000	807.451	184.000	0.000	0.000	2000.000	0.000	38.681	0.000	0.000	425.567
ENERGY	MIL BTU	.100	.569	.040	1.851	.215	.031	.049	15.666	.139	.505	1.500	.683	7.752
WATER	THOU GAL	[illegible]	1.207	.093	2.336	.015	.041	.230	1.168	.009	.555	.087	1.484	8.803
INDUSTRIAL SOLID WASTES	CUBIC FT	[illegible]	.037	.125	6.555	.253	.002	.000	1.017	.000	1.548	.005	.177	1.018
ATM EMMISSIONS	POUNDS	[illegible]	1.892	.835	13.049	2.508	5.834	.101	38.326	2.149	1.791	9.433	2.181	37.670
WATERBORNE WASTES	POUNDS	[illegible]	.789	.007	1.432	.042	.011	.010	3.458	.076	.227	.764	.164	[illegible]
POST-CONSUMER SOL WASTE	CUBIC FT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	18.202	0.000	0.000	0.000	0.000

TABLE 9

IMPACTS FOR 1 MILLION 5-TRIP OFF PREMISE RETURNABLE GLASS BOTTLES

		BOTTLE SYSTEM 61 TONS	FILLING	PACKAGE	DISPOSAL	TRANS	STEEL CLOSURE 4000 LBS
INPUTS TO SYSTEMS							
NAME	UNITS						
MATERIAL WOOD FIBER	POUNDS	0.	0.	122279.	0.	0.	0.
MATERIAL LIMESTONE	POUND	52795.	0.	0.	0.	0.	1649.
MATERIAL IRON ORE	POUND	0.	0.	0.	0.	0.	5809.
MATERIAL SALT	POUND	27981.	3213.	0.	0.	0.	0.
MATERIAL GLASS SAND	POUND	80520.	0.	0.	0.	0.	0.
MATERIAL NAT SODA ASH	POUND	9455.	0.	0.	0.	0.	0.
MATERIAL FELDSPAR	POUND	9211.	0.	0.	0.	0.	0.
MATERIAL BAUXITE ORE	POUND	0.	0.	0.	0.	0.	0.
MATERIAL PROCESS ADD	POUNDS	2516.	48.	8648.	0.	0.	278.
ENERGY PROCESS	MIL BTU	1111.	418.	1927.	0.	0.	96.
ENERGY TRANSPORT	MIL BTU	18.	0.	220.	13.	243.	2.
ENERGY OF MATL RESOURCE	MIL BTU	0.	0.	0.	0.	0.	1.
WATER VOLUME	THOU GAL	331.	421.	2199.	1.	14.	111.
OUTPUTS FROM SYSTEMS							
NAME	UNITS						
SOLID WASTES PROCESS	POUND	32089.	2036.	6594.	0.	0.	1636.
SOLID WASTES FUEL COMB	POUND	756.	219.	8494.	3.	56.	54.
SOLID WASTES MINING	POUND	24329.	1173.	5407.	0.	0.	21242.
SOLID WASTE POST-CONSUM	CUBIC FT	0.	0.	0.	2590.	0.	0.
ATMOS PARTICULATES	POUND	1158.	95.	3859.	1.	34.	120.
ATMOS NITROGEN OXIDES	POUND	748.	259.	1340.	14.	543.	39.
ATMOS HYDROCARBONS	POUND	829.	286.	696.	14.	197.	81.
ATMOS SULFUR OXIDES	POUND	937.	378.	4192.	3.	108.	85.
ATMOS CARBON MONOXIDE	POUND	174.	50.	565.	287.	566.	17.
ATMOS ALDEHYDES	POUND	3.	1.	10.	1.	10.	0.
ATMOS OTHER ORGANICS	POUND	5.	2.	14.	41.	21.	0.
ATMOS ODOROUS SULFUR	POUND	0.	0.	1073.	0.	0.	4.
ATMOS AMMONIA	POUND	60.	0.	1.	0.	1.	11.
ATMOS HYDROGEN FLOURIDE	POUND	0.	0.	0.	0.	0.	0.
ATMOS LEAD	POUND	0.	0.	0.	0.	1.	0.
ATMOS MERCURY	POUND	0.	0.	0.	0.	0.	0.
ATMOSPHERIC CHLORINE	POUND	0.	13.	0.	0.	0.	0.
WATERBORNE FLUORIDES	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE DISS SOLIDS	POUND	188.	90.	333.	7.	120.	8.
WATERBORNE BOD	POUND	0.	1000.	2631.	0.	0.	0.
WATERBORNE PHENOL	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE SULFIDES	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE OIL	POUND	12.	0.	0.	0.	0.	2.
WATERBORNE COD	POUND	1.	0.	3.	0.	1.	0.
WATERBORNE SUSP SOLIDS	POUND	100.	260.	1598.	0.	1.	11.
WATERBORNE ACID	POUND	41.	11.	72.	0.	0.	19.
WATERBORNE METAL ION	POUND	10.	3.	18.	0.	0.	5.
WATERBORNE CHEMICALS	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE CYANIDE	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE ALKALINITY	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE CHROMIUM	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE IRON	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE ALUMINUM	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE NICKEL	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE MERCURY	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE LEAD	POUND	0.	0.	0.	0.	0.	0.
SUMMARY OF ENVIRONMENTAL IMPACTS							
NAME	UNITS						
RAW MATERIALS	POUNDS	182479.	3261.	130927.	0.	0.	7736.
ENERGY	MIL BTU	1130.	418.	2147.	13.	243.	101.
WATER	THOU GAL	331.	421.	2199.	1.	14.	111.
INDUSTRIAL SOLID WASTES	CUBIC FT	772.	46.	277.	0.	1.	310.
ATM EMMISSIONS	POUNDS	3913.	1084.	11751.	361.	1481.	358.
WATERBORNE WASTES	POUNDS	353.	1365.	4655.	7.	123.	45.
POST-CONSUMER SOL WASTE	CUBIC FT	0.	0.	0.	2590.	0.	0.

TABLE 10

IMPACTS FOR 1 MILLION 19-TRIP ON PREMISE RETURNABLE GLASS CONTAINERS

		BOTTLE SYSTEM 16.0 TON	FILLING	PACKAGE	DISPOSAL	TRANS	STEEL CLOSURE 4000 LBS
INPUTS TO SYSTEMS							
NAME	UNITS						
MATERIAL WOOD FIBER	POUNDS	0.	0.	29169.	0.	0.	0.
MATERIAL LIMESTONE	POUND	13848.	0.	0.	0.	0.	1644.
MATERIAL IRON ORE	POUND	0.	0.	0.	0.	0.	5809.
MATERIAL SALT	POUND	7339.	3213.	0.	0.	0.	0.
MATERIAL GLASS SAND	POUND	21120.	0.	0.	0.	0.	0.
MATERIAL NAT SODA ASH	POUND	2480.	0.	0.	0.	0.	0.
MATERIAL FELDSPAR	POUND	2416.	0.	0.	0.	0.	0.
MATERIAL BAUXITE ORE	POUND	0.	0.	0.	0.	0.	0.
MATERIAL PROCESS ADD	POUNDS	660.	48.	2059.	0.	0.	278.
ENERGY PROCESS	MIL BTU	292.	418.	419.	0.	0.	98.
ENERGY TRANSPORT	MIL BTU	5.	0.	51.	3.	205.	2.
ENERGY OF MATL RESOURCE	MIL BTU	0.	0.	0.	0.	0.	1.
WATER VOLUME	THOU GAL	87.	421.	435.	0.	12.	111.
OUTPUTS FROM SYSTEMS							
NAME	UNITS						
SOLID WASTES PROCESS	POUND	8417.	2036.	1353.	0.	0.	1636.
SOLID WASTES FUEL COMB	POUND	198.	219.	1872.	1.	48.	54.
SOLID WASTES MINING	POUND	6381.	1173.	1190.	0.	0.	21242.
SOLID WASTE POST-CONSUM	CUBIC FT	0.	0.	0.	642.	0.	0.
ATMOS PARTICULATES	POUND	304.	95.	863.	0.	29.	120.
ATMOS NITROGEN OXIDES	POUND	196.	259.	300.	4.	464.	39.
ATMOS HYDROCARBONS	POUND	218.	286.	153.	4.	169.	81.
ATMOS SULFUR OXIDES	POUND	246.	378.	1133.	1.	92.	85.
ATMOS CARBON MONOXIDE	POUND	46.	50.	129.	71.	467.	17.
ATMOS ALDEHYDES	POUND	1.	1.	2.	0.	8.	0.
ATMOS OTHER ORGANICS	POUND	1.	2.	3.	10.	17.	0.
ATMOS ODOROUS SULFUR	POUND	0.	0.	237.	0.	0.	4.
ATMOS AMMONIA	POUND	16.	0.	0.	0.	1.	11.
ATMOS HYDROGEN FLOURIDE	POUND	0.	0.	0.	0.	0.	0.
ATMOS LEAD	POUND	0.	0.	0.	0.	1.	0.
ATMOS MERCURY	POUND	0.	0.	0.	0.	0.	0.
ATMOSPHERIC CHLORINE	POUND	0.	13.	0.	0.	0.	0.
WATERBORNE FLUORIDES	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE DISS SOLIDS	POUND	49.	90.	73.	2.	102.	8.
WATERBORNE BOD	POUND	0.	1000.	596.	0.	0.	0.
WATERBORNE PHENOL	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE SULFIDES	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE OIL	POUND	3.	0.	0.	0.	0.	2.
WATERBORNE COD	POUND	0.	0.	1.	0.	1.	0.
WATERBORNE SUSP SOLIDS	POUND	26.	260.	282.	0.	1.	11.
WATERBORNE ACID	POUND	11.	11.	16.	0.	0.	19.
WATERBORNE METAL ION	POUND	3.	3.	4.	0.	0.	5.
WATERBORNE CHEMICALS	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE CYANIDE	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE ALKALINITY	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE CHROMIUM	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE IRON	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE ALUMINUM	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE NICKEL	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE MERCURY	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE LEAD	POUND	0.	0.	0.	0.	0.	0.
SUMMARY OF ENVIRONMENTAL IMPACTS							
NAME	UNITS						
RAW MATERIALS	POUNDS	47863.	3261.	31228.	0.	0.	7736.
ENERGY	MIL BTU	296.	418.	470.	3.	205.	101.
WATER	THOU GAL	87.	421.	435.	0.	12.	111.
INDUSTRIAL SOLID WASTES	CUBIC FT	202.	46.	60.	0.	1.	310.
ATM EMMISSIONS	POUNDS	1026.	1084.	2820.	90.	1246.	356.
WATERBORNE WASTES	POUNDS	93.	1365.	472.	2.	104.	45.
POST-CONSUMER SOL WASTE	CUBIC FT	0.	0.	0.	642.	0.	0.

TABLE 11

IMPACTS FOR 1 MILLION PLASTIC COATED GLASS BOTTLES

		POLYSTY FOAM JACKET 4400 LBS	GLASS SYSTEM FILLING ETC.
INPUTS TO SYSTEMS			
NAME	UNITS		
MATERIAL WOOD FIBER	POUNDS	0.	82101.
MATERIAL LIMESTONE	POUND	0.	153112.
MATERIAL IRON ORE	POUND	0.	5809.
MATERIAL SALT	POUND	0.	80272.
MATERIAL GLASS SAND	POUND	0.	231000.
MATERIAL NAT SODA ASH	POUND	0.	27125.
MATERIAL FELDSPAR	POUND	0.	26425.
MATERIAL BAUXITE ORE	POUND	0.	0.
MATERIAL PROCESS ADD	POUNDS	22.	13321.
ENERGY PROCESS	MIL BTU	149.	4894.
ENERGY TRANSPORT	MIL BTU	0.	537.
ENERGY OF MATL RESOURCE	MIL BTU	107.	1.
WATER VOLUME	THOU GAL	39.	3246.
OUTPUTS FROM SYSTEMS			
NAME	UNITS		
SOLID WASTES PROCESS	POUND	299.	101074.
SOLID WASTES FUEL COMB	POUND	133.	6799.
SOLID WASTES MINING	POUND	361.	95646.
SOLID WASTE POST-CONSUM	CUBIC FT	0.	3484.
ATMOS PARTICULATES	POUND	30.	6388.
ATMOS NITROGEN OXIDES	POUND	199.	3942.
ATMOS HYDROCARBONS	POUND	466.	3331.
ATMOS SULFUR OXIDES	POUND	138.	5335.
ATMOS CARBON MONOXIDE	POUND	44.	2054.
ATMOS ALDEHYDES	POUND	0.	31.
ATMOS OTHER ORGANICS	POUND	0.	86.
ATMOS ODOROUS SULFUR	POUND	0.	809.
ATMOS AMMONIA	POUND	0.	1[illegible]3.
ATMOS HYDROGEN FLOURIDE	POUND	0.	0.
ATMOS LEAD	POUND	0.	2.
ATMOS MERCURY	POUND	0.	0.
ATMOSPHERIC CHLORINE	POUND	0.	0.
WATERBORNE FLUORIDES	POUND	0.	0.
WATERBORNE DISS SOLIDS	POUND	73.	987.
WATERBORNE BOD	POUND	10.	1904.
WATERBORNE PHENOL	POUND	0.	1.
WATERBORNE SULFIDES	POUND	0.	1.
WATERBORNE OIL	POUND	2.	3[illegible].
WATERBORNE COD	POUND	11.	6.
WATERBORNE SUSP SOLIDS	POUND	4.	1801.
WATERBORNE ACID	POUND	7.	197.
WATERBORNE METAL ION	POUND	2.	[illegible]9.
WATERBORNE CHEMICALS	POUND	0.	0.
WATERBORNE CYANIDE	POUND	0.	0.
WATERBORNE ALKALINITY	POUND	0.	0.
WATERBORNE CHROMIUM	POUND	0.	0.
WATERBORNE IRON	POUND	0.	0.
WATERBORNE ALUMINUM	POUND	0.	0.
WATERBORNE NICKEL	POUND	0.	0.
WATERBORNE MERCURY	POUND	0.	0.
WATERBORNE LEAD	POUND	0.	0.
SUMMARY OF ENVIRONMENTAL IMPACTS			
NAME	UNITS		
RAW MATERIALS	POUNDS	22.	619165.
ENERGY	MIL BTU	256.	[illegible]
WATER	THOU GAL	39.	3246.
INDUSTRIAL SOLID WASTES	CUBIC FT	11.	2775.
ATM EMMISSIONS	POUNDS	878.	22159.
WATERBORNE WASTES	POUNDS	109.	4984.
POST-CONSUMER SOL WASTE	CUBIC FT	0.	3484.

TABLE 12

IMPACTS FOR 1 MILLION SOFT DRINK CONTAINERS

INPUTS TO SYSTEMS

NAME	UNITS	15 RET	ABS	ALSTL	PCG	CSTL	OWG	ALUM
MATERIAL WOOD FIBER	POUNDS	18162.	45274.	2928.	56746.	2703.	62627.	2699.
MATERIAL LIMESTONE	POUND	23287.	1649.	53682.	183404.	43021.	224431.	9139.
MATERIAL IRON ORE	POUND	5809.	5808.	189060.	5809.	139652.	5815.	0.
MATERIAL SALT	POUND	14145.	0.	0.	96327.	3335.	118069.	9260.
MATERIAL GLASS SAND	POUND	33000.	0.	0.	277200.	0.	339766.	0.
MATERIAL NAT SODA ASH	POUND	3875.	0.	0.	32550.	0.	39897.	0.
MATERIAL FELDSPAR	POUND	3775.	0.	0.	31710.	0.	38867.	0.
MATERIAL BAUXITE ORE	POUND	0.	0.	0.	0.	57232.	0.	153047.
MATERIAL PROCESS ADD	POUNDS	2639.	5587.	9481.	12982.	11489.	15331.	12017.
ENERGY PROCESS	MIL BTU	1257.	2637.	3279.	5299.	4427.	6094.	6124.
ENERGY TRANSPORT	MIL BTU	223.	910.	241.	473.	286.	531.	274.
ENERGY OF MATL RESOURCE	MIL BTU	1.	1921.	55.	108.	276.	1.	589.
WATER VOLUME	THOU GAL	1004.	2992.	3658.	2673.	3197.	2975.	1417.

OUTPUTS FROM SYSTEMS

NAME	UNITS	15 RET	ABS	ALSTL	PCG	CSTL	OWG	ALUM
SOLID WASTES PROCESS	POUND	16055.	5819.	56508.	116813.	46459.	141701.	14486.
SOLID WASTES FUEL COMB	POUND	2321.	6375.	2022.	7420.	5319.	8249.	11277.
SOLID WASTES MINING	POUND	33766.	30987.	691626.	109044.	593618.	127832.	224632.
SOLID WASTE POST-CONSUM	CUBIC FT	821.	2018.	327.	3488.	302.	3425.	258.
ATMOS PARTICULATES	POUND	1359.	2321.	4019.	6135.	4777.	7180.	5153.
ATMOS NITROGEN OXIDES	POUND	1116.	5476.	1786.	4221.	3207.	4731.	5774.
ATMOS HYDROCARBONS	POUND	964.	5207.	3206.	4189.	4229.	4419.	4800.
ATMOS SULFUR OXIDES	POUND	1435.	4198.	3047.	5655.	6175.	6490.	11503.
ATMOS CARBON MONOXIDE	POUND	1238.	2773.	1257.	2293.	2131.	2496.	3082.
ATMOS ALDEHYDES	POUND	16.	29.	16.	33.	22.	37.	28.
ATMOS OTHER ORGANICS	POUND	54.	102.	33.	92.	47.	99.	50.
ATMOS ODOROUS SULFUR	POUND	186.	439.	162.	532.	124.	579.	22.
ATMOS AMMONIA	POUND	36.	51.	346.	217.	257.	264.	3.
ATMOS HYDROGEN FLOURIDE	POUND	0.	0.	0.	0.	19.	0.	53.
ATMOS LEAD	POUND	3.	3.	2.	3.	2.	3.	2.
ATMOS MERCURY	POUND	0.	0.	0.	0.	0.	0.	0.
ATMOSPHERIC CHLORINE	POUND	11.	0.	0.	0.	13.	0.	37.
WATERBORNE FLUORIDES	POUND	0.	0.	0.	0.	82.	0.	226.
WATERBORNE DISS SOLIDS	POUND	280.	1017.	366.	1079.	665.	1182.	1102.
WATERBORNE BOD	POUND	528.	1426.	74.	1282.	121.	1391.	209.
WATERBORNE PHENOL	POUND	0.	0.	0.	1.	1.	1.	2.
WATERBORNE SULFIDES	POUND	0.	1.	0.	1.	1.	1.	1.
WATERBORNE OIL	POUND	7.	124.	75.	47.	176.	54.	381.
WATERBORNE COD	POUND	2.	994.	14.	16.	718.	6.	1899.
WATERBORNE SUSP SOLIDS	POUND	606.	1101.	379.	1259.	398.	1385.	369.
WATERBORNE ACID	POUND	73.	193.	632.	222.	664.	250.	581.
WATERBORNE METAL ION	POUND	18.	48.	158.	55.	171.	62.	159.
WATERBORNE CHEMICALS	POUND	0.	9.	4.	0.	226.	1.	610.
WATERBORNE CYANIDE	POUND	0.	0.	0.	0.	0.	0.	0.
WATERBORNE ALKALINITY	POUND	1000.	0.	0.	0.	0.	0.	0.
WATERBORNE CHROMIUM	POUND	0.	0.	0.	0.	0.	0.	0.
WATERBORNE IRON	POUND	0.	1.	0.	0.	0.	0.	0.
WATERBORNE ALUMINUM	POUND	0.	1.	0.	0.	0.	0.	0.
WATERBORNE NICKEL	POUND	0.	1.	0.	0.	0.	0.	0.
WATERBORNE MERCURY	POUND	0.	0.	0.	0.	0.	0.	0.
WATERBORNE LEAD	POUND	0.	0.	0.	0.	0.	0.	0.

SUMMARY OF ENVIRONMENTAL IMPACTS

NAME	UNITS	15 RET	ABS	ALSTL	PCG	CSTL	OWG	ALUM
RAW MATERIALS	POUNDS	104692.	58318.	255151.	696728.	257432.	844805.	186162.
ENERGY	MIL BTU	1481.	5469.	3574.	5881.	4990.	6626.	6986.
WATER	THOU GAL	1004.	2992.	3658.	2673.	3197.	2975.	1417.
INDUSTRIAL SOLID WASTES	CUBIC FT	704.	583.	10127.	3149.	8713.	3750.	3380.
ATM EMMISSIONS	POUNDS	6417.	20600.	13873.	23370.	21005.	26298.	30506.
WATERBORNE WASTES	POUNDS	2515.	4915.	1703.	3962.	3224.	4333.	5541.
POST-CONSUMER SOL WASTE	CUBIC FT	821.	2018.	327.	3488.	302.	3425.	258.

TABLE 13

IMPACTS FOR 1 MILLION BEER CONTAINERS

NAME	UNITS	19 RET	10 RET	5 RET	ABS	ALSTL	PCG	OWG	CSTL	ALUM
INPUTS TO SYSTEMS										
MATERIAL WOOD FIBER	POUNDS	28992.	41110.	120339.	77267.	2928.	82101.	86041.	2703.	2699.
MATERIAL LIMESTONE	POUND	15497.	28047.	54445.	1649.	53682.	153112.	177303.	43821.	9139.
MATERIAL IRON ORE	POUND	5809.	5809.	5809.	5808.	189060.	5809.	5811.	139652.	0.
MATERIAL SALT	POUND	10552.	17203.	31194.	0.	0.	80272.	93093.	3335.	4250.
MATERIAL GLASS SAND	POUND	21120.	40260.	80520.	0.	0.	231000.	267894.	0.	0.
MATERIAL NAT SODA ASH	POUND	2480.	4727.	9455.	0.	0.	27125.	31457.	0.	0.
MATERIAL FELDSPAR	POUND	2416.	4605.	9211.	0.	0.	26425.	30645.	0.	0.
MATERIAL BAUXITE ORE	POUND	0.	0.	0.	0.	0.	0.	0.	57232.	153047.
ENERGY SOURCE PETROLEUM	MILL BTU	488.	603.	1086.	2632.	462.	1197.	1290.	945.	1602.
ENERGY SOURCE NAT GAS	MILL BTU	578.	815.	1474.	1620.	372.	2798.	3062.	1612.	2881.
ENERGY SOURCE COAL	MILL BTU	240.	327.	657.	780.	2055.	922.	993.	2219.	2057.
ENERGY SOURCE MISC	MILL BTU	19.	27.	53.	117.	71.	87.	92.	208.	433.
ENERGY SOURCE WOOD FIBER	MILL BTU	166.	255.	750.	551.	17.	575.	598.	15.	15.
MATERIAL PROCESS ADD	POUNDS	3032.	4491.	11354.	7861.	9483.	13343.	14757.	11491.	12319.
ENERGY PROCESS	MIL BTU	1224.	1717.	3526.	3131.	3379.	5042.	5461.	4526.	6223.
ENERGY TRANSPORT	MIL BTU	266.	308.	493.	884.	188.	537.	574.	235.	222.
ENERGY OF MATL RESOURCE	MIL BTU	1.	1.	1.	1921.	55.	108.	1.	[illegible]	[illegible]
WATER VOLUME	THOU GAL	1064.	1445.	3048.	3909.	3657.	3285.	3462.	3196.	1416.
OUTPUTS FROM SYSTEMS										
SOLID WASTES PROCESS	POUND	13434.	21922.	42265.	9154.	56508.	101373.	115977.	46459.	14486.
SOLID WASTES FUEL COMB	POUND	2380.	3550.	9458.	8739.	2088.	8931.	9409.	5389.	11361.
SOLID WASTES MINING	POUND	29979.	36392.	52071.	32153.	692039.	96007.	106969.	594022.	225040.
SOLID WASTE POST-CONSUM	CUBIC FT	672.	1121.	2708.	2536.	327.	3484.	3841.	302.	258.
ATMOS PARTICULATES	POUND	1406.	2119.	5210.	3459.	4066.	6418.	7040.	4825.	5202.
ATMOS NITROGEN OXIDES	POUND	1260.	1617.	2924.	5721.	1793.	4140.	4367.	3215.	5781.
ATMOS HYDROCARBONS	POUND	908.	1199.	2094.	5261.	3206.	3797.	3750.	4229.	4900.
ATMOS SULFUR OXIDES	POUND	1928.	2447.	5629.	4718.	3176.	5473.	5922.	6302.	11631.
ATMOS CARBON MONOXIDE	POUND	782.	965.	1665.	2463.	887.	2098.	2228.	1769.	2716.
ATMOS ALDEHYDES	POUND	13.	16.	26.	25.	12.	31.	34.	18.	23.
ATMOS OTHER ORGANICS	POUND	34.	44.	84.	93.	18.	87.	92.	32.	34.
ATMOS ODOROUS SULFUR	POUND	239.	364.	1061.	773.	162.	808.	840.	124.	22.
ATMOS AMMONIA	POUND	27.	42.	72.	52.	346.	183.	211.	257.	3.
ATMOS HYDROGEN FLOURIDE	POUND	0.	0.	0.	0.	0.	0.	0.	19.	53.
ATMOS LEAD	POUND	1.	1.	2.	2.	0.	2.	2.	1.	1.
ATMOS MERCURY	POUND	0.	0.	0.	0.	0.	0.	0.	0.	0.
ATMOSPHERIC CHLORINE	POUND	13.	13.	13.	0.	0.	0.	0.	13.	47.
WATERBORNE FLUORIDES	POUND	0.	0.	0.	0.	0.	0.	0.	82.	225.
WATERBORNE DISS SOLIDS	POUND	324.	415.	742.	1171.	358.	1060.	1095.	656.	1094.
WATERBORNE BOD	POUND	1593.	1883.	3592.	2202.	74.	1914.	1986.	121.	209.
WATERBORNE PHENOL	POUND	0.	0.	1.	0.	0.	1.	1.	1.	2.
WATERBORNE SULFIDES	POUND	0.	0.	1.	1.	0.	1.	1.	1.	1.
WATERBORNE OIL	POUND	6.	9.	15.	124.	75.	40.	43.	175.	341.
WATERBORNE COD	POUND	2.	3.	5.	994.	14.	17.	6.	718.	1899.
WATERBORNE SUSP SOLIDS	POUND	578.	854.	1951.	1793.	379.	1805.	1888.	498.	369.
WATERBORNE ACID	POUND	57.	75.	142.	201.	637.	204.	216.	669.	[illegible]
WATERBORNE METAL ION	POUND	14.	19.	36.	50.	159.	51.	54.	172.	161.
WATERBORNE CHEMICALS	POUND	0.	0.	0.	9.	4.	0.	0.	226.	610.
WATERBORNE CYANIDE	POUND	0.	0.	0.	0.	0.	0.	0.	0.	0.
WATERBORNE ALKALINITY	POUND	0.	0.	0.	0.	0.	0.	0.	0.	0.
WATERBORNE CHROMIUM	POUND	0.	0.	0.	0.	0.	0.	0.	0.	0.
WATERBORNE IRON	POUND	0.	0.	0.	1.	0.	0.	0.	0.	0.
WATERBORNE ALUMINUM	POUND	0.	0.	0.	1.	0.	0.	0.	0.	0.
WATERBORNE NICKEL	POUND	0.	0.	0.	1.	0.	0.	0.	0.	0.
WATERBORNE MERCURY	POUND	0.	0.	0.	0.	0.	0.	0.	0.	0.
WATERBORNE LEAD	POUND	0.	0.	0.	0.	0.	0.	0.	0.	0.
SUMMARY OF ENVIRONMENTAL IMPACTS										
RAW MATERIALS	POUNDS	89898.	146253.	322326.	92586.	255153.	619187.	706997.	257434.	186164.
ENERGY	MIL BTU	1491.	2026.	4020.	5936.	3622.	5687.	6036.	5037.	7834.
WATER	THOU GAL	1064.	1445.	3048.	3909.	3657.	3285.	3462.	3196.	1416.
INDUSTRIAL SOLID WASTES	CUBIC FT	618.	835.	1401.	676.	10134.	2785.	3137.	8719.	3387.
ATM EMMISSIONS	POUNDS	6612.	8827.	18779.	22567.	13667.	23037.	24446.	20804.	30303.
WATERBORNE WASTES	POUNDS	2576.	3259.	6485.	6449.	1701.	5093.	5293.	3221.	5539.
POST-CONSUMER SOL WASTE	CUBIC FT	672.	1121.	2708.	2536.	327.	3484.	3841.	302.	258.

TABLE 14

IMPACTS FOR 1 TON EACH PROCESS IN THE GLASS SYSTEM

NAME	UNITS	GLASS SAND MINING	LIMESTON MINING	LIME MFG	SODA ASH MINING	SALT MINING (BRINE)	SODA ASH MANUF	FELDSPAR MINING	GLASS CONTAIN FAB	POLYSTY FOAM JACKET
INPUTS TO SYSTEMS										
MATERIAL WOOD FIBER	POUNDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL LIMESTONE	POUND	0.000	0.000	4000.000	0.000	0.000	2500.000	0.000	334.000	0.000
MATERIAL IRON ORE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL SALT	POUND	0.000	0.000	0.000	0.000	0.000	3300.000	0.000	0.000	0.000
MATERIAL GLASS SAND	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1320.000	0.000
MATERIAL NAT SODA ASH	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	155.000	0.000
MATERIAL FELDSPAR	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	151.000	0.000
MATERIAL BAUXITE ORE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL PROCESS ADD	POUNDS	0.000	0.000	0.000	0.000	0.000	9.000	0.000	40.000	10.000
ENERGY PROCESS	MIL BTU	.795	.038	4.648	.521	.193	13.318	.687	15.474	67.607
ENERGY TRANSPORT	MIL BTU	.061	.033	.037	0.000	.021	0.000	.640	.194	0.000
ENERGY OF MATL RESOURCE	MIL BTU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	48.800
WATER VOLUME	THOU GAL	1.815	.094	.322	1.209	1.004	16.802	4.547	1.168	17.693
OUTPUTS FROM SYSTEMS										
SOLID WASTES PROCESS	POUND	0.000	0.000	365.000	0.000	0.000	3340.000	0.000	45.000	136.000
SOLID WASTES FUEL COMB	POUND	.804	.077	6.476	0.000	.031	21.995	1.866	8.317	68.233
SOLID WASTES MINING	POUND	3.366	.213	36.541	120.000	.071	131.100	4604.6[illegible]	81.987	164.023
SOLID WASTE POST-CONSUM	CUBIC FT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ATMOS PARTICULATES	POUND	.376	13.023	39.382	10.010	.012	37.349	15.484	4.105	13.502
ATMOS NITROGEN OXIDES	POUND	.663	.104	3.140	.274	.124	9.022	2.244	10.157	90.240
ATMOS HYDROCARBONS	POUND	.563	.042	2.088	.493	.186	2.879	.694	18.574	212.029
ATMOS SULFUR OXIDES	POUND	.961	.083	8.880	.006	.064	34.734	1.840	9.297	62.016
ATMOS CARBON MONOXIDE	POUND	.272	.094	.998	.060	.052	2.819	1.244	2.084	19.988
ATMOS ALDEHYDES	POUND	.003	.001	.009	.001	.002	.035	.017	.038	.106
ATMOS OTHER ORGANICS	POUND	.007	.003	.017	.002	.002	.028	.026	.068	.222
ATMOS ODOROUS SULFUR	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ATMOS AMMONIA	POUND	.000	.000	.000	0.000	.000	7.007	.002	.003	0.000
ATMOS HYDROGEN FLOURIDE	POUND	0.000	0.000	0.000	0.000	0.000	0.080	0.000	0.000	0.000
ATMOS LEAD	POUND	.000	.000	.000	0.000	.000	.000	.001	.000	0.000
ATMOS MERCURY	POUND	.000	.000	.000	0.000	.000	.001	.000	.000	.001
ATMOSPHERIC CHLORINE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE FLUORIDES	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE DISS SOLIDS	POUND	.129	.020	.412	.091	.042	1.519	.359	2.715	33.231
WATERBORNE BOD	POUND	.000	.000	.000	0.000	.000	.003	.001	.002	4.403
WATERBORNE PHENOL	POUND	.000	.000	.000	0.000	.000	.011	.000	.001	.001
WATERBORNE SULFIDES	POUND	.000	.000	.000	0.000	.000	.002	.000	.001	.001
WATERBORNE OIL	POUND	.000	.000	.000	0.000	.000	.002	.000	.201	1.002
WATERBORNE COD	POUND	.000	.000	.001	0.000	.000	.013	.004	.007	5.013
WATERBORNE SUSP SOLIDS	POUND	1.000	.000	.001	0.000	.000	7.008	.002	.004	2.008
WATERBORNE ACID	POUND	.046	.004	.405	0.000	.001	1.383	.090	.422	3.142
WATERBORNE METAL ION	POUND	.011	.001	.101	0.000	.000	.346	.023	.106	.785
WATERBORNE CHEMICALS	POUND	0.000	0.000	0.000	0.000	0.000	.012	0.000	0.000	0.000
WATERBORNE CYANIDE	POUND	0.000	0.000	0.000	0.000	0.000	.002	0.000	0.000	0.000
WATERBORNE ALKALINITY	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE CHROMIUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE IRON	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE ALUMINUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE NICKEL	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE MERCURY	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE LEAD	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SUMMARY OF ENVIRONMENTAL IMPACTS										
RAW MATERIALS	POUNDS	0.000	0.000	4000.000	0.000	0.000	5809.000	0.000	2000.000	10.000
ENERGY	MIL BTU	.856	.070	4.684	.521	.214	13.318	1.327	15.668	116.407
WATER	THOU GAL	1.815	.094	.322	1.209	1.004	16.802	4.547	1.168	17.693
INDUSTRIAL SOLID WASTES	CUBIC FT	.056	.004	5.508	1.620	.001	47.157	62.188	1.017	4.863
ATM EMMISSIONS	POUNDS	2.845	13.349	54.514	10.846	.441	93.874	21.503	38.326	398.905
WATERBORNE WASTES	POUNDS	1.187	.025	.920	.091	.044	10.300	.480	3.458	49.586
POST-CONSUMER SOL WASTE	CUBIC FT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TABLE 14 (Concluded)

	UNITS	PACKAGE CORRUG	PACKAGE BLEACHED KRAFT	FILLING RETURNAB BEER BOTTLE	FILLING ONE WAY BEER	DISPOSAL	FILLING RETURN SOFT DRINK	FILLING ONE WAY SOFT DRINK	STEEL CLOSURE	SEPARATE CULLET
INPUTS TO SYSTEMS										
NAME	UNITS									
MATERIAL WOOD FIBER	POUNDS	1991.728	2037.800	0.000	0.000	0.000	0.000	110.734	0.000	0.000
MATERIAL LIMESTONE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	874.680	0.000
MATERIAL IRON ORE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2904.400	0.000
MATERIAL SALT	POUND	0.000	0.000	15.744	0.000	0.000	10.174	0.000	0.000	0.000
MATERIAL GLASS SAND	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL NAT SODA ASH	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL FELDSPAR	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL BAUXITE ORE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL PROCESS ADD	POUNDS	140.587	144.840	.236	0.000	0.000	.152	7.871	138.972	0.000
ENERGY PROCESS	MIL BTU	28.641	39.203	2.046	.683	0.000	1.407	3.152	49.033	11.584
ENERGY TRANSPORT	MIL BTU	3.468	3.962	.000	0.000	.116	.000	.654	.946	.259
ENERGY OF MATL RESOURCE	MIL BTU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.501	0.000
WATER VOLUME	THOU GAL	29.720	52.423	2.064	1.484	.007	1.198	3.652	55.462	.461
OUTPUTS FROM SYSTEMS										
NAME	UNITS									
SOLID WASTES PROCESS	POUND	92.411	148.690	9.977	9.800	0.000	.114	11.888	817.939	0.000
SOLID WASTES FUEL COMB	POUND	127.828	168.819	1.075	.631	.029	1.790	10.705	26.827	13.861
SOLID WASTES MINING	POUND	81.279	107.686	5.746	2.681	0.000	6.286	9.727	10621.160	33.440
SOLID WASTE POST-CONSUM	CUBIC FT	0.000	0.000	0.000	0.000	11.800	0.000	11.016	0.000	-11.800
ATMOS PARTICULATES	POUND	58.930	74.490	.466	.315	.012	.394	4.405	59.919	3.770
ATMOS NITROGEN OXIDES	POUND	20.492	25.814	1.268	.450	.124	1.059	2.761	19.747	9.538
ATMOS HYDROCARBONS	POUND	10.423	13.971	1.400	.397	.126	.976	1.806	40.489	4.367
ATMOS SULFUR OXIDES	POUND	77.392	46.267	1.853	.918	.030	1.682	3.972	42.735	23.398
ATMOS CARBON MONOXIDE	POUND	8.777	10.517	.245	.096	.833	.169	3.646	8.853	2.076
ATMOS ALDEHYDES	POUND	.157	.195	.007	.002	.010	.003	.046	.084	.077
ATMOS OTHER ORGANICS	POUND	.213	.248	.008	.002	.036	.005	.166	.105	.061
ATMOS ODOROUS SULFUR	POUND	16.161	21.264	0.000	0.000	0.000	0.000	1.155	2.120	0.000
ATMOS AMMONIA	POUND	.020	.027	.001	.000	.000	.000	.003	5.308	.017
ATMOS HYDROGEN FLOURIDE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ATMOS LEAD	POUND	.005	.006	.000	.000	.002	.000	.000	.001	.002
ATMOS MERCURY	POUND	.001	.001	.000	.000	0.000	.000	.000	.000	.000
ATMOSPHERIC CHLORINE	POUND	0.000	0.000	.062	0.000	0.000	.040	0.000	0.000	0.000
WATERBORNE FLUORIDES	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE DISS SOLIDS	POUND	4.977	6.709	.442	.119	.062	.171	.713	4.186	3.625
WATERBORNE BOD	POUND	40.706	49.428	4.901	.000	.000	.360	2.687	.006	.009
WATERBORNE PHENOL	POUND	.004	.005	.000	.000	.000	.000	.001	.002	.003
WATERBORNE SULFIDES	POUND	.005	.006	.000	.000	.000	.000	.001	.003	.004
WATERBORNE OIL	POUND	.005	.007	.000	.000	.000	.000	.001	1.063	.005
WATERBORNE COD	POUND	.042	.056	.002	.001	.001	.000	.006	.024	.038
WATERBORNE SUSP SOLIDS	POUND	19.276	44.092	1.275	.000	.000	.760	2.398	5.315	.023
WATERBORNE ACID	POUND	1.094	1.375	.055	.035	.000	.093	.149	9.646	.647
WATERBORNE METAL ION	POUND	.274	.344	.014	.009	.000	.023	.037	2.412	.162
WATERBORNE CHEMICALS	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.064	0.000
WATERBORNE CYANIDE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE ALKALINITY	POUND	0.000	0.000	0.000	0.000	0.000	3.800	0.000	0.000	0.000
WATERBORNE CHROMIUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE IRON	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE ALUMINUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE NICKEL	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE MERCURY	POUND	0.000	0.000	.000	0.000	0.000	.000	0.000	0.000	0.000
WATERBORNE LEAD	POUND	0.000	0.000	.000	0.000	0.000	.000	0.000	0.000	0.000
UMMARY OF ENVIRONMENTAL IMPACTS										
NAME	UNITS									
RAW MATERIALS	POUNDS	2132.315	2182.640	15.979	0.000	0.000	10.327	118.605	3868.052	0.000
ENERGY	MIL BTU	32.109	43.165	2.046	.683	.116	1.408	3.807	50.480	11.843
WATER	THOU GAL	29.720	52.423	2.064	1.484	.007	1.198	3.652	55.462	.461
INDUSTRIAL SOLID WASTES	CUBIC FT	4.971	5.745	.227	.177	.000	.109	.436	154.790	.539
ATM EMMISSIONS	POUNDS	192.571	192.799	5.369	2.181	1.173	4.326	18.347	179.661	43.307
WATERBORNE WASTES	POUNDS	66.383	102.022	6.69	.164	.063	5.229	5.992	22.720	4.517
POST-CONSUMER SOL WASTE	CUBIC FT	0.000	0.000	0.000	0.000	11.800	0.000	11.016	0.000	-11.800

Table 12 is a comparison of soft drink containers and Table 13 is the comparison of beer containers. This table is the basis for the discussions in Volume I. Finally, Table 14 shows the results of direct conversion of raw data contained in the remainder of this chapter into the appropriate impacts.

The summary section of Table 7 verifies the widely believed fact that reusable glass beverage containers produce less impact than single use containers of the same material. This is true even after the additional weight needed for structural integrity and additional processing and transportation is taken into account for returnable systems. The nonreturnable system produces more impacts in every category than the 10- or 19-trip returnables.

Table 8 shows the relative environmental impacts of the component processes of the one-way bottle system. It is interesting to note that two processes--paper packaging and glass manufacture--account for most of the impacts. The glass plant alone leads in three of the seven categories, while paper packaging leads in two of the others. Energy use is the most serious impact of the glass plant. Energy use in that one operation makes up 56 percent of the energy required for the entire bottle system.

Tables 9 and 10 show the importance of component processes for returnable systems. Table 9 shows that impacts associated with the 5-trip returnable are concentrated in glass manufacturing and packaging. The filling step, mainly bottle washing (including heating of the water) contributes lesser impacts. The filling plant impacts are mainly water pollution from washing and energy.

For the 19-trip on-premise returnable, Table 10 shows the glass manufacturing is relatively less important. The filling is more important, but closure impacts and transportation are also significant sources of environmental degradation. However, the largest single system impact is packaging, leading all other subsystems in three categories.

Table 11 summarizes the impacts for plastic coated glass. The plastic used here is polystyrene, but other plastics have similar profiles. However, the amount of plastic required in the coating is so small it contributes only a small percent of the system impact total. Thus, its advantage lies in the fact that less glass is required for PCG than for a conventional container.

Tables 12 and 13 are included here for reference. Table 12 is a comparison of soft drink containers and Table 13 is a comparison of beer containers. These tables are quite similar; and Table 13 is discussed in detail in Volume I. Table 14 converts the raw data found in the remainder of this chapter to environmental profiles. This table was discussed in Section A.

C. Glass Sand Mining

Glass sand is the predominant raw material for glass manufacture. It comprises 44 percent of the raw materials shown in Figure 1 and is the source of almost all of the silicon dioxide present in finished container glass. Silicon dioxide is the major chemical constituent of glass and amounts to approximately 70 percent by weight of finished container glass.

Glass sand is a high purity quartz sand which usually contains less than 1 percent of other materials. These stringent purity restrictions prevent the use of most of the sand available in this country. However, sizable deposits of glass sand do exist in New Jersey in the form of unconsolidated sand banks, and as sandstones found in the Alleghenies and the Mississippi Valley. In addition, there are smaller deposits located in various sections of the country.

The mining operations chosen depend on the nature of the deposit at each location. The mining operations range from simply scooping sand from a pit or bank and loading it into a truck to quarrying hard sandstone in a fashion similar to the procedures used to extract limestone. In the latter event, extensive crushing, washing and screening may be necessary.

Data pertaining to the mining of 1 ton of glass sand are shown in Table 15 along with the source of each number. The resulting impacts may be found in Summary Table 14. As shown by the composite index in Table 8, the overall environmental impact of mining sand is small as compared to other operations considered in glass manufacturing.

TABLE 15

DATA FOR MINING OF 1 TON GLASS SAND

		Sources
Energy		84
Coal	0.0058 ton	
Distillate	0.31 gal.	
Residual	0.11 gal.	
Gas	431 cu ft	
Gasoline	0.076 gal.	
Electricity	13.9 kwhr	
Water volume, 1,800 gal.		85
Waterborne wastes		
Suspended solids--1 lb		68,73
Transportation		
Rail	90 ton-miles	79
Barge	3 ton-miles	81
Truck	27 ton-miles	68

D. Limestone Mining

Limestone is used by the glass industry as a source of calcium oxide in glass furnace operations. The limestone is heated in the furnace so that carbon dioxide is released, leaving calcium oxide behind. Calcium oxides act as a chemical stabilizer in the finished glass product.

Limestone is quarried primarily from open pits. The most economical method of recovering the stone has been blasting, followed by mechanical crushing and screening. According to the Bureau of Mines,[90] environmental problems plague these crushed stone producers more than any other mineral industry except sand and gravel. The reason for this is that limestone typically is mined quite close to the ultimate consumer, which frequently dictates that the mining operation be near, or even within, heavily populated areas. Hence, their environmental problems are accentuated by their high visibility.

The environmental consequences of limestone mining include: noise from heavy equipment and from blasting; dust from mining, crushing and screening; solid residues not properly disposed of; general unsightliness; and occasional contamination of streams. None of these problems is insurmountable and many quarries are presently operated in an acceptable fashion.

Data concerning the quantifiable environmental impacts of limestone mining are summarized in Table 16. The impacts are summarized in Table 14. Even though the quarrying operations may be objectionable as a neighborhood problem, they produce relatively small impacts on a tonnage basis. The major problem is dust (particulates). However, compared to the other operations in the glass system (Table 8), the impacts of limestone mining are quite small.

TABLE 16

DATA FOR MINING OF 1 TON LIMESTONE

		Sources
Energy		84
Coal	0.00012 ton	
Distillate	0.16 gal.	
Residual	0.013 gal.	
Natural gas	9.3 cu ft	
Gasoline	0.049 gal.	
Electricity	2.0 kwhr	
Water volume	91 gal.	85
Process atmospheric emissions		
Particulates	13 lb	52
Transportation		
Rail	10 ton-miles	79
Water	26 ton-miles	81
Truck	42 ton-miles	68

E. Lime Manufacture

Lime is produced by calcining limestone. Limestone (calcium carbonate) is heated in a kiln to a high temperature so that any water present is driven off and the carbonate is broken up by the evolution of carbon dioxide. The product remaining is lime (calcium oxide). Significant environmental impacts occur due to fuel combustion and due to material losses. For 1 ton of lime produced approximately 0.8 ton of carbon dioxide is released. An additional 0.2 ton of material impacts on the environment in the form of solid waste and as dust (particulate emission). The data are summarized in Table 17. The impacts are summarized in Table 14.

TABLE 17

DATA FOR MANUFACTURE OF 1 TON LIME

		Sources
Virgin raw materials	4,000 lb	15
Energy		84
Coal	0.090 ton	
Distillate	0.17 gal.	
Residual	0.76 gal.	
Natural Gas	1,670 cu ft	
Gasoline	0.067 gal.	
Electricity	28 kwhr	
Water	270 gal.	85
Solid wastes	365 lb	15,52
Process atmospheric emissions		
Particulates	35 lb	15,52
Transportation		88
Rail	144 ton-miles	
Truck	54 ton-miles	

The most important impacts of lime manufacture are raw materials use and air and water pollution. The raw materials are mostly limestone which is a readily available mineral, so its use does not seriously deplete reserves. The air pollution problem is mainly particulates which arise from dust losses, although some arise from coal combustion. The water pollution problem is of particular interest because it comes entirely from acid coal mine drainage. Thus, the water pollution problem is generally beyond the control of the lime manufacturer.

Table 8 shows that the lime manufacturing impacts are a small percentage of the glass bottle profile.

F. <u>Natural Soda Ash Mining</u>

Soda ash, which is the common name for sodium carbonate, is used in glass manufacture as a fluxing agent. Under the temperature conditions of a glass furnace the carbonate is converted to sodium oxide which lowers the melting and working temperature and decreases the viscosity of the melt. Sodium oxide is the second most abundant material in finished glass, constituting about 15 percent of the finished glass weight.

Soda ash is obtainable in either its natural form or in a manufactured form. This section of the chapter deals with its natural form which accounts for about 36 percent of the soda ash used by the glass industry.

The most abundant supply of natural soda ash (trona) is obtained from three mines near Green River, Wyoming. The crude trona is mined from beds nearly 1,500 feet below the surface using the room and pillar technique. The trona is processed and refined at the mine site to produce soda ash.

Detailed information is not available to assess accurately the energy impacts of trona mining. However, most of the mining techniques have been borrowed from existing coal mining technology so the energy impacts of trona mining were estimated by using coal mining data. The dominant energy use in the refining process is the calcining of bicarbonate to produce the carbonate. This impact was added to the "coal mining" impacts to produce the estimate of energy use for trona mining.

The estimate of the energy uses is summarized in Table 18. The other data in the table were obtained or estimated from literature sources concerning trona mining.

Summary Table 8 shows that natural soda ash mining produces fairly small environmental impacts as compared to the other operations in glass manufacture. However, the substantially greater use of energy as compared to the other mined minerals leads to higher atmospheric emissions than experienced by other minerals' mining operations.

TABLE 18

DATA FOR MINING OF 1 TON NATURAL SODA ASH

		Sources
Energy Natural gas	480 cu ft	68
Water volume	1,200 gal.	85
Mining wastes	120 lb	16
Process atmospheric emission Particulates	10 lb	68
Transportation Rail	650 ton-miles	16,68

G. Soda Ash Manufacture

The principal means of manufacturing soda ash is by the Solvay process. Figure 3 depicts the overall process flow which combines limestone and salt to produce soda ash. Lime, ammonia and sodium bicarbonate are important intermediate materials.

Data relating to the impacts associated with producing the concentrated brine necessary for soda ash manufacture are shown in Table 19. The customary method of obtaining brine for Solvay process plants is to pump water into a natural underground salt dome and to pump out the concentrated brine. This procedure produces virtually no waste products except those due to fuel combustion to supply the necessary energy. Detailed data were not available to describe the energy requirements of this process so they were estimated by using census data for rock salt mining which includes many of the same basic operations as the hydraulic mining method. Impacts associated with brine production are all quite small as shown in Table 14. No significant contribution is made to bottle manufacture as shown in Table 8.

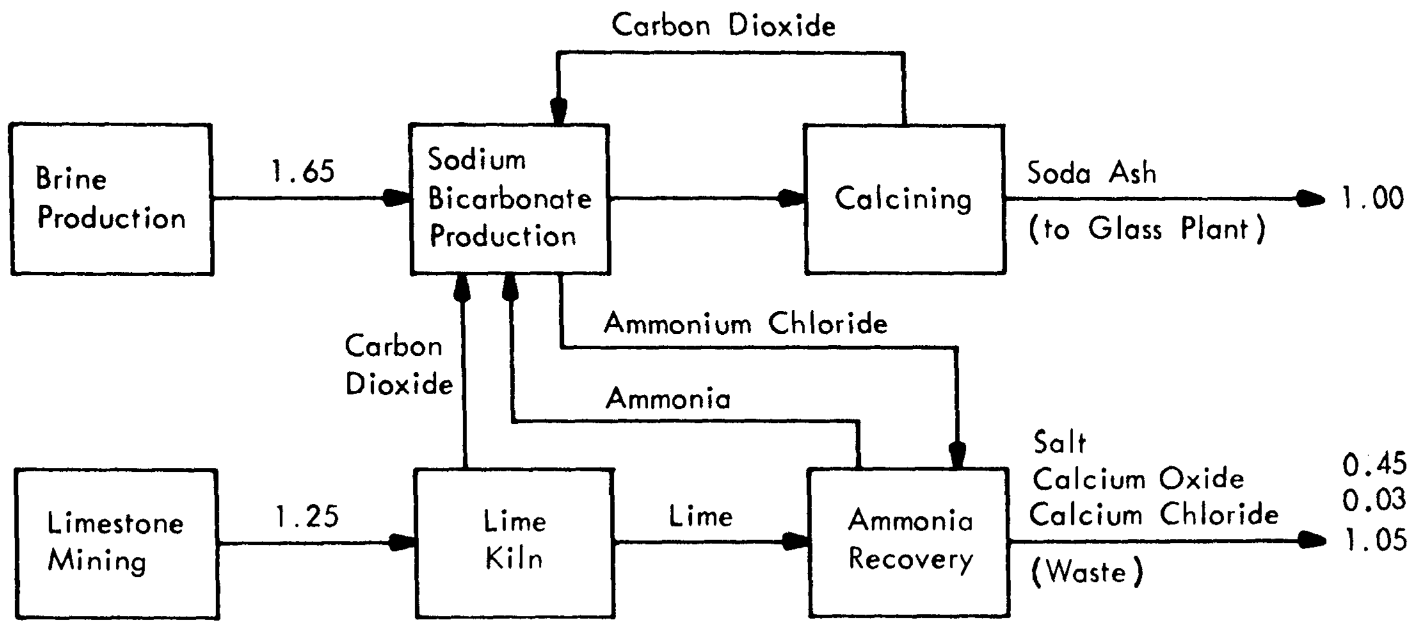


Figure 3 - Materials Requirements for the Manufacture of 1 Ton Soda Ash by the Solvay Process (ton)

TABLE 19

DATA FOR PRODUCTION OF 1 TON SALT AS BRINE

		Source
Energy		84
Electricity	0.85 kwhr	
Fuel oil	0.11 gal.	
Gas	169 cu ft	
Gasoline	0.014 gal.	
Water volume	1,000 gal.	68

Overall environmental impacts for manufacture of 1 ton of soda ash are quite high per ton output when compared to the other operations in the glass system as shown in Table 14. A basic factor effecting this is the inefficiency in utilization of raw materials (Table 20). Considerable quantities of salt which enter the process simply pass on through so that approximately 0.5 ton of salt must be disposed of as a solid waste for each ton of soda ash produced. In addition, over 1 ton of calcium chloride and calcium oxide is produced. Even though these materials are sometimes sold, they usually are simply dumped. Not only do these inefficiencies represent a solid waste problem but the impacts associated with the various mining and preparation processes are "wasted" since they cannot be allocated to co-products. Thus, soda ash production must carry the full load.

Another important factor affecting the environmental profile of soda ash manufacture is the use of coal and residual oils as primary sources of fuel. These give rise to high values for atmospheric emissions.

Table 8 shows that for soda ash manufacture, six impact categories occur to a significant degree.

H. Feldspar Mining

Feldspar is an aluminum silicate mineral which is used in glass manufacture to obtain aluminum oxide. This oxide acts as a stabilizer and improves the stability and durability of the glass microstructure. It is added in small quantities and generally makes up less than 3 percent of the total glass weight.

TABLE 20

DATA FOR MANUFACTURE OF 1 TON SODA ASH BY THE SOLVAY PROCESS

		Source
Virgin raw materials		16
Salt	3,300 lb	
Limestone	2,500 lb	
Other materials (ammonia, sodium sulfide)	9 lb	
Energy		16,68
Coal	0.235 ton	
Residual	16.7 gal.	
Gas	1,200 cu ft	
Coke	0.1 ton	
Water volume	16,000 gal.	85
Process solid wastes	3,340 lb	16
Process atmospheric emissions		
Ammonia	7 lb	43
Particulates	21 lb	52,68
Waterborne wastes		
Suspended solids	7 lb	68
Transportation		
Rail	220 ton-miles	80
Barge	116 ton-miles	83
Truck	25 ton-miles	68

Feldspar is mined in 13 states but North Carolina and California produce 65 percent of the nation's total. Hence, transportation expenses to bring feldspar to glass plants may be quite high. Feldspar is mined primarily by open pit quarry techniques. Usually drilling and blasting are required although this is not always so.

The data pertaining to the impacts associated with feldspar mining are in Table 21, with the impacts summarized in Summary Table 14. The dominant impact is the considerable mining waste associated with feldspar mining. More solid waste is associated with this operation per ton of material than any other operation for glass manufacture. Also, there is a significant amount of air pollution which is primarily dust produced by mining and crude ore processing.

TABLE 21

DATA FOR MINING OF 1 TON FELDSPAR

		Source
Energy		84
Distillate	3.8 gal.	
Gas	60 cu ft	
Gasoline	0.25 gal.	
Electricity	56 kwhr	
Water volume	4,500 gal.	86
Mining wastes	4,600 lb	97
Atmospheric emissions		68
Particulates	15 lb	
Transportation		68
Rail	500 ton-miles	

I. Glass Container Manufacture

Glass container manufacture is carried out in an integrated plant where raw materials are delivered and finished containers are shipped out. The raw materials are melted and refined in a glass furnace before being fed in a molten state to forming machines. These machines form and cool the glass container before annealing. After annealing, they are further cooled and packed for shipment. A considerable amount of glass breakage occurs inside the plant. This broken glass (cullet) is considered to be a valuable raw material and is recycled to the glass furnace. Typically, the raw material batch will include 15 percent cullet from internal sources.

Glass is a three dimensional random network of silicon and oxygen atoms with fluxes and stabilizers added. Thus, glass sand (silicon dioxide) is the primary raw material. Other important materials added include soda ash, lime or limestone and feldspar. In the glass furnace, soda ash is converted to sodium oxide which serves as a fluxing agent. The fluxing agents alter melting and working temperatures by decreasing the viscosity. Limestone yields lime (calcium oxide) in the glass furnace. Calcium oxide along with the aluminum oxide from feldspar are stabilizers and add desirable characteristics such as chemical durability to the final product. Other additives are made in small amounts to add color and to change refining characteristics for other purposes. Data pertaining to glass manufacture are in Table 22 with the corresponding impacts in Table 14.

Glass container plants are quite clean from an environmental effluent point of view as compared to many other types of industrial plants. This does not mean that glass plants are free of environmental ills, but the effluents are generally minimal. However, any large industrial plant may cause considerable local damage to the environment even though its impact per ton of material is quite low.

Table 8 shows that glass container manufacture produces greater impact in three of the seven impact categories than the other subsystems for container systems. Energy use in container manufacture accounts for 56 percent of the total energy category for container manufacture.

The formation of glass requires a considerable amount of heat to be expended in melting the inorganic chemicals and in sustaining the temperatures at which the necessary chemical reactions and subsequent refining take place. However, the widespread use of natural gas in glass furnaces results in quite low atmospheric emissions for this sizable energy expenditure.

TABLE 22

DATA FOR MANUFACTURE OF 1 TON GLASS CONTAINERS

		Source
Virgin raw materials		68,69,83,97,102
Sand	1,320 lb	
Limestone	334 lb	
Soda ash (natural)	155 lb	
Feldspar	151 lb	
Other	40 lb	
Packaging		
Corrugated	132 lb	
Energy		83
Distillate	1.2 gal.	
Residual	5.5 gal.	
Gas	10,700 cu ft	
Gasoline	0.023 gal.	
Electricity	263 kwhr	
Water	870 gal.	83
Process solid waste	45 lb	68
Process atmospheric emissions		43
Particulates	2 lb	
Waterborne wastes		68,71
Oil	0.2 lb	
Transportation		88
Rail	50 ton-miles	
Barge	2 ton-miles	
Truck	186 ton-miles	

Other important impacts for glass plants are atmospheric emissions and waterborne wastes. The atmospheric emissions are primarily from fuel combustion; other emissions are only about 2 pounds of particulates and are of minor importance. However, in some localities the use of fluorspar in the glass furnace may give rise to troublesome fluoride emissions. Waterborne wastes from glass plants result from use of oils on the glass forming line. But the major water pollutant associated with glass plant operations is the acid coal mine drainage associated with coal consumed as an energy source.

J. Closures

In order to provide a 12-ounce beer bottle comparable to the 12-ounce can, it is necessary to consider impacts related to closure manufacture. The typical closure for a glass beer bottle is a steel crown with a plastic liner. A typical weight for such a closure is 0.0040 pound. For 1 million containers, then, it would require 4,000 pounds or 2 tons steel. It was assumed that the impacts for these closures would be approximated on a tonnage basis by the impacts for the manufacture of finished steel cans. The reader is referred to Chapter 4 for a discussion of these impacts.

K. Plastic Coated Bottles

A recent innovation in glass bottles has been the development of plastic coated bottles. These coatings, or jackets, have the advantage of reducing the bruising and breaking of bottles as they strike one another or other objects and also reduce glass shattering. The environmental profile of these bottles is somewhat better than conventional one-way bottles because they can be fabricated with 10 to 20 percent less glass in them. The reason why less glass is possible is because the break and shatter resistance of the bottle allows lighter weight construction.

Table 23 contains data to calculate the impact of the plastic jacket. Polystyrene foam is the jacket used on the bottles called "Plasti-shield" bottles. However, these data would serve as a good estimate for the plastic coatings used on other bottles. Table 11 shows, the amount of plastic required is so small it accounts for very little of the total profile.

L. Paper Packaging

Paper packaging is used in significant quantities at two points in the beer bottle system. The first point is at the glass plant where the

TABLE 23

DATA FOR 1,000 POUNDS POLYSTYRENE FOAM JACKET

Materials		
	Crude Oil	966 lb.
	Natural Gas	316 lb.
	Additives	5 lb.
Energy		
	Natural Gas (internal combustion)	3,800 cu. ft.
	Natural Gas (heating)	17,300 cu. ft.
	Electricity	981 kwhr
Water		8,300 gal.
Industrial Solid Wastes		68 lb.
Process Atmospheric Emission		
	Hydrocarbons	77 lb.
	Sulfur Oxides	3 lb.
Waterborne Wastes		
	Dissolved Solids	12 lb.
	Oil	0.5 lb.
	BOD	2.2 lb.
	COD	2.5 lb.
	Suspended Solids	1.0 lb.
Transportation		
	Pipeline	131 ton-miles
	Barge	125 ton-miles
	Truck	210 ton-miles
	Rail	624 ton-miles

Source: 47

bottles are packed in corrugated containers for shipment to the bottling plant, and the second point is at the bottling plant where the filled containers are placed into paperboard packages such as "six pack" carriers.

The corrugated container is fabricated from two strong liners made of unbleached kraft paperboard with an inner fluted filler of corrugating medium. The corrugating medium can be made of recycled corrugated containers, or from a combination of types of virgin fibers. It is common in the glass industry to use a 100 percent virgin container, so we have based our example of a corrugated container on that premise.

Table 24 contains basic data relating to corrugated container manufacture. We have assumed that a corrugated container is fabricated from unbleached kraft linerboard which comprises 69 percent by weight of the box, and corrugating medium which is the remaining 31 percent. The corrugating medium is fabricated from fibers derived from two pulp types: 80 percent from NSSC pulp and 20 percent from unbleached kraft pulp.

Table 14 shows that the most serious environmental problem for the corrugated container manufacture is energy use. However, it should be noted that 10 million Btu, or 26 percent of this energy is derived from burning wood fiber. Thus, if only fossil fuels are considered, the energy problem is not as serious.

A second important impact is air pollution. This is dominated by the incineration of waste digestion liquors from NSSC pulp mills. This procedure is rapidly declining because of pollution control regulations, but is still practiced to some extent.

A third important problem is water pollution, which is caused by the basic wasteful nature of wood processing. Unacceptable fibers and other wood components are washed from the pulp and discarded as water pollutants.

Table 25 contains basic data for bleached paperboard product manufacture. The profile as seen on Table 14 is similar to that of corrugated boxes. However, the energy requirements are greater, water pollution is worse, but air pollution is less.

The air pollution from kraft mills differs from the air pollution from NSSC mills in that the most notable impact from kraft mills derives from odorous sulfur compounds. The horrible stench produced by the kraft pulping process is legendary, and where the odor is uncontrolled it produces a quite severe local impact.

TABLE 24

DATA FOR MANUFACTURE OF 1 TON CORRUGATED CONTAINERS

Virgin Raw Materials	
Wood fiber (bone dry basis)[a]	1,992 lb
Additives	140 lb
Energy	
Kraft Recovery Furnace	9.4×10^6 Btu
Auxiliary Boiler	16.8×10^6 Btu
Diesel	13.6 gal.
Electricity	320 kwhr
Water	29,400 gal.
Process Solid Waste	134 lb
Process Atmospheric Emissions	
Particulates	38 lb
Odorous Sulfur	5 lb
Sulfur Oxides	43 lb
Waterborne Wastes	
BOD	41 lb
Suspended Solids	19 lb
Transportation	
Rail	602 ton-miles
Truck	296 ton-miles
Water	12 ton-miles

a/ Thirty percent or 598 lb is derived from chips and wood residues.
Source: 48

TABLE 25

DATA FOR MANUFACTURE OF 1 TON BLEACHED KRAFT PAPERBOARD CARRIERS

Virgin Raw Materials	
Wood Fiber (bone dry basis)[a]	2,040 lb
Additives	140 lb
Energy	
Kraft recovery furnace	12.4×10^6 Btu
Auxiliary boiler	16.8×10^6 Btu
Diesel	13.8 gal.
Electricity	320 kwhr
Water	51,600 gal.
Process Solid Waste	134 lb
Process Atmospheric Emissions	
Particulates	38 lb
Odorous sulfur	7 lb
Waterborne Wastes	
BOD	50 lb
Suspended Solids	44 lb
Transportation	
Rail	644 ton-miles
Barge	12 ton-miles
Truck	308 ton-miles

a/ Thirty percent or 612 lb is derived from chips and wood residues.
Source: 48

Table 8 shows that the total paper packaging systems produce quite important impacts compared to the other operations.

M. Bottle Filling

New bottles enter the filling plant and are placed on high speed automated lines which clean, fill, close, pasteurize and package the bottles. The bottles are rinsed with clean water which need not be heated and moved along the line by electric motors. The only step requiring significant amounts of fuel is the pasteurizing step, thus the overall impacts of this step are not large compared to other steps.

Of interest is the fact that the corrugated shipping cartons in which the bottles are received are saved and used for shipping the filled bottles. Thus, the only new packaging required is for the six pack carriers.

Table 26 contains data relating to beer filling plants reporting for one-way and returnable bottles. A distinction is made between on-premise and off-premise returnable beer bottles in regards the packaging requirements. The on-premise bottle is boxed in a closed corrugated carton which lasts approximately three trips. However, the off-premise carton requires a six pack carrier as well as a corrugated carton. We have assumed here that the 5-RET off-premise package only makes one trip, but the packaging could serve for multiple trips if returned to the same brewer.

Significant differences exist between one-way and returnable bottle impacts at the filling plant for several reasons. The most important are those associated with the returnable bottle. They are the energy necessary to heat the washing water, the use of caustic washing compounds, and the resulting water pollution. However, it is customary to use the waste caustic solution to neutralize the acid brewery wastes. Thus, the alkaline water pollutants are converted to wastewater treatment sludges and become part of the solid wastes burden.

In addition to the data related to beer bottles, additional data are included here for soft drink bottles. Up to the filling plant, the beer and soft drink bottles utilize the same type of manufacturing operations. This results from the fact that soft drink bottles are made from the same type of glass but differ in weight and style from beer bottles.

Table 27 summarizes the data for soft drink bottles. Both one-way and returnable bottles are included. The data for beer and soft drinks are quite similar, although differing somewhat in most categories.

TABLE 26

DATA FOR FILLING AND DELIVERY OF 1 MILLION 12-OUNCE BEER BOTTLES

Materials				
	Paper packaging			
		One way	58,000 lb	(bleached kraft)
		On-premise returnable	27,000 lb	(corrugated container)
		Off-premise returnable	78,000 lb	(corrugated container)
		(one trip packaging)	34,000 lb	(bleached kraft)
	Cleaning agents			
		Sodium Hydroxide	3,000 lb	
Energy				
	One way			
		Coal	1 ton	
		Residual	150 gal.	
		Natural gas	60,000 cu ft	
		Electricity	2,000 kwhr	
	Returnable			
		Coal	1 ton	
		Residual	570 gal.	
		Natural gas	225,000 cu ft	
		Electricity	2,000 kwhr	
Water				
	One way		300,000 gal.	
	Returnable		400,000 gal.	
Industrial Solid Wastes			2,000 lb	
Waterborne Wastes				
	Returnable			
		BOD	1,000 lb	
		Suspended solids	260 lb	
Transportation				
	One way			
		Rail	50,000 ton-miles	
		Truck	40,000 ton-miles	
	Returnable			
		Rail	100,000 ton-miles	
		Truck	40,000 ton-miles	

Source: 68

TABLE 27

DATA FOR FILLING AND DELIVERY OF 1 MILLION 16-OUNCE SOFT DRINK BOTTLES

Materials		
Paper packaging		
	One way	28,600 lb (bleached kraft)
	Returnable	14,600 lb (bleached kraft)
Cleaning agents		
	Sodium Hydroxide	2,500 lb
Energy		
One way		
	Natural gas	123,000 cu ft
	Electricity	12,200 kwhr
Returnable		
	Natural gas	184,000 cu ft
	Electricity	13,300 kwhr
Water		
One way		200,000 gal.
Returnable		300,000 gal.
Industrial Solid Wastes		1,000 lb
Waterborne Wastes		
Returnable		
	Alkalinity	1,000 lb
	BOD	100 lb
	Suspended solids	200 lb
Transportation		
One way	Gasoline	110 gal. diesel
		500 gal. gasoline
Returnable	Gasoline	220 gal. diesel
		780 gal. gasoline

Source: 68

N. Solid Waste Disposal

The primary environmental impacts associated with solid waste disposal depends on the type of disposal taking place. Most of the solid waste stream in this country is disposed of on land. We will assume that 91 percent of solid waste is landfilled (or dumped) with the remaining 9 percent being incinerated. Recovery of materials from the post-consumer solid waste stream is practiced on a fairly small scale nationwide, so no recovery is included our disposal model.

Transportation is an important factor in disposal impacts. We have assumed a 20 mile average travel distance per load of refuse in a 20 yard compactor truck. Assuming that the truck efficiency is 5 miles per gallon of gasoline, and that the waste is compacted to 500 pounds per cubic yard, the fuel usage is 0.8 gallons gasoline per ton waste.

For the 9 percent of the "average" ton of solid waste incinerated, some air pollution results. However, the total pounds of pollutants generated by the 180 pounds (0.09 x 2,000 lb = 180 lb) of waste incinerated for each ton collected results in a total of 3.8 pounds of air pollution. The only significant contributor is carbon monoxide at 3.2 pounds. The remaining 0.6 pounds is distributed approximately equally among particulates,* sulfur oxides, hydrocarbons, nitrogen oxides and hydrogen chloride. However, we assume that inert materials such as glass and metals are essentially nonparticipants in the incineration process and are disposed of on land.

Table 28 contains the data from which impacts were calculated. Included are the volumes that solid waste occupies in a landfill. These numbers were derived by determining the theoretical densities of the materials. In actual fact, an unbroken bottle or an uncollapsed can often finds its way into landfills (or dumps). However, no data are available on typical behavior of the various containers in typical landfill operations. However, the important factor here is that some measure of relative volume of the various containers can be established and thus provide some estimate. Although data are lacking concerning all of the containers, it is our opinion that the volume occupied by the plastic container may be underestimated more than for the other containers. It is less likely that the plastic bottles will either compress like a can or break (or split) like a bottle than the conventional containers. On the other hand, the aluminum can will probably collapse and compress quite readily so that its relative volume may be overestimated here.

Table 8 shows the impacts due to disposal are small.

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* It is assumed that a 95 percent efficient precipitator is in place.

TABLE 28

DATA FOR DISPOSAL OF 1 TON SOLID WASTE

		Source
Energy		
Gasoline	0.8 gal.	68
Solid Waste Volume		68
Steel	4 cu ft/ton	
Glass and aluminum	12 cu ft/ton	
Paper and plastic[a/]	33 cu ft/ton	
Process Atmospheric Emissions[b/] (for combustible materials)		52
Carbon monoxide	3.2 lb	
Other	0.6 lb	

a/ This assumes that for 1 ton, there is 36 cu ft, but 9 percent is incinerated.

b/ For 180 pounds, or 9 percent of the waste. Nine percent is incinerated.

O. Nonreturnable and Returnable Glass Containers

At this point, the calculation of the environmental impacts of the glass container is straightforward. The material flow diagram (Table 6) indicates the amount of each material needed for the manufacture of 1 ton of glass containers. Summary Table 8 shows the results of performing the impact calculations for each of the materials needed in glass container manufacture.

For purposes of comparison, the above calculations may be converted to the basis of 1 million containers. Current data show that a typical one-way 12-ounce beer bottle weighs 0.41 pound. A spot check was made by weighing recently purchased bottles which verifies this weight. Thus, 1 million containers weigh 410,000 pounds or 205 tons. The impacts of 205 tons of glass containers are readily calculated. The impacts of 2 tons of steel closures need to be added as shown in Summary Table 8.

The impacts that should be attributed to the returnable glass bottle require close inspection. Current data[67,68] indicate that 12-ounce returnable beer bottles weigh about 0.61 pound per bottle (305 tons per million containers), or 50 percent more than the corresponding one-way bottle. In addition, in order to make the calculations comparable to the other container systems studied, all impacts must be considered including those which are incurred in preparing the returned container for refilling. Thus, we must consider transportation of the container from the retail site back to the bottler as well as impacts associated with cleaning the used bottle before refilling.

Of considerable importance in calculating impacts relating to returnable bottles is the number of times each bottle is reused, or "trippage." At present, the trippage experienced by on-premise returnable beer bottles is 19.[67,68] That is, on the average, each bottle is used 19 times. However, it is our opinion that the current returnable beer bottle is not comparable to the other container systems studied here. The usage of on-premise returnable beer bottles is by commercial customers such as taverns, as opposed to the personal take-home use experienced by other containers. An analogy can be drawn with the soft drink industry which experiences national average trippage of 15[67,68] which includes vending machine as well as supermarket and other take-home configurations. However, some soft drink industry spokesmen indicate that the actual trippage rate may be closer to 10 for the supermarket take-home package. One beer industry spokesman indicates that beer packages may experience even fewer trips in the supermarket configuration. Perhaps five trips or less would be experienced. It should be noted that good data concerning trip rates do not exist and the trippage actually achieved is quite difficult to determine accurately. Table 29 and Figure 4 contain the basic data for returnable bottle calculations.

TABLE 29

DATA FOR RETURNABLE GLASS CONTAINERS USED TO DELIVER 1 MILLION 12-OUNCE UNITS OF BEER

Glass Manufacture (where N = trippage)	305 tons ÷ N

(Other requirements on Table 6).

Source: 68

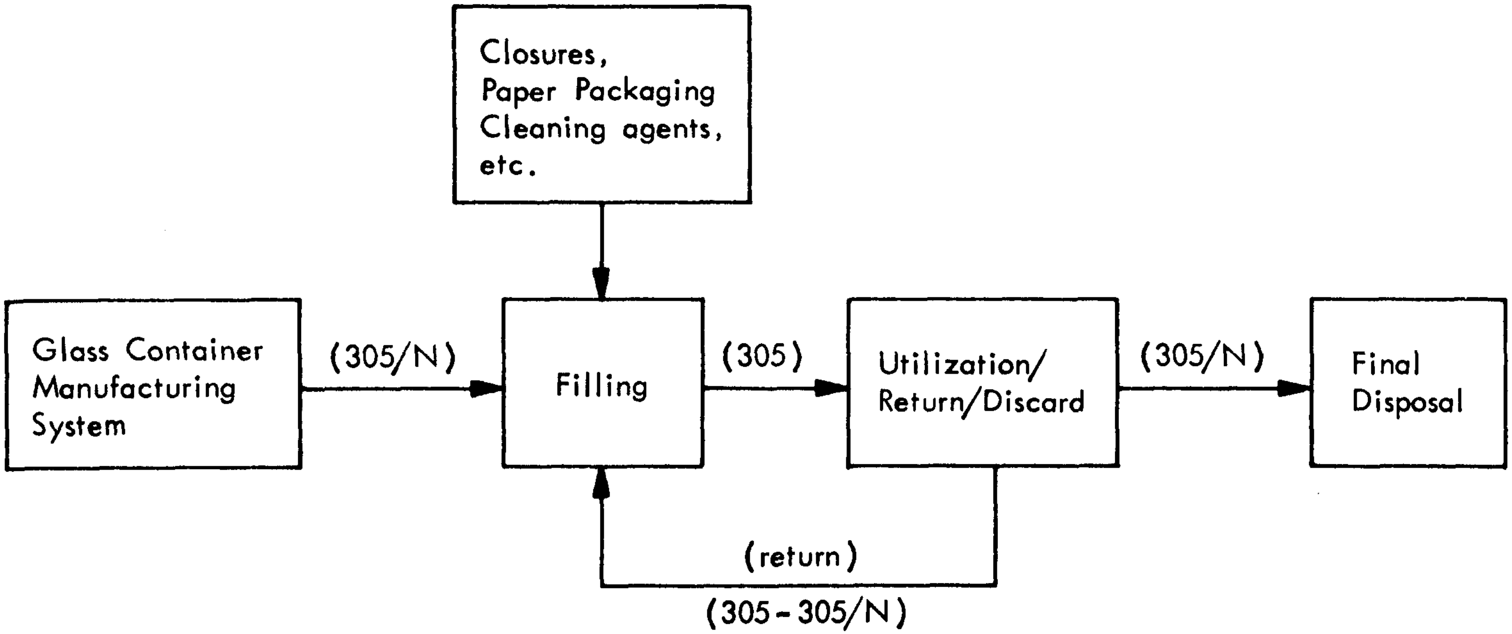

Figure 4 - Glass Flow to Provide Returnable Beer Bottles for 1 Million Containers at Any Trip Rate N (Tons)

P. Glass Recycling

Waste glass (known as cullet) is a valuable commodity to the glass industry. It is useful in glass furnaces to promote proper melting of the raw materials and is generally conceded to aid in the superior formation of glass. At the present time, most cullet is primarily an industrial scrap. Most of the cullet used is generated and recycled within the same glass plant, although glass container filling plants also routinely collect and sell their broken glass.

Several solid waste separation schemes are presently used on experimental, or pilot-plant basis to separate cullet from municipal solid waste streams. This has the advantage of reducing solid waste volume as well as providing a commodity of value to the glass industry.

Table 30 contains data pertinent to the operation of a hypothetical scaled up plant similar to the wet separation pilot plant designed by Black-Clawson Corporation. The pilot plant is in Franklin, Ohio.

TABLE 30

DATA FOR SEPARATION OF 1 TON GLASS CULLET FROM MUNICIPAL SOLID WASTE

Energy	
Residual oil	0.042 gal.
Electric	400 kwhr
Natural gas	8 cu ft
Postconsumer Solid Waste	-2,000 lb
Transportation	
Truck	100 ton-miles

Source: 66,68

CHAPTER III

ABS BOTTLE

This chapter contains the basic data and outlines the calculations made to determine the total environmental profile for ABS beer bottles. Three container options were studied: nonreturnable bottles, bottles made from 100 percent recycled resin, and 10-trip returnable bottles. A steel closure was used with each option.

Figure 5 shows a flow diagram for manufacturing the ABS bottle. Crude oil and natural gas are the principal raw materials required. Acrylonitrile, polybutadiene and styrene react to form the ABS resin. In the recycle option, the raw materials are the used, nonrefillable ABS bottle (which is cut up, melted, and processed to form other bottles), and the steel closure. The returnable bottle requires only cleaning materials and steel closures for raw materials.

This chapter discusses the ABS bottle systems in the following sequence.

A. Overview
B. Crude Oil Production
C. Benzene Manufacture
D. Natural Gas Production
E. Natural Gas Processing
F. Ethylene Manufacture
G. 1,3 Butadiene Manufacture
H. Ammonia Manufacture
I. Acrylonitrile Manufacture
J. Styrene Manufacture
K. Polybutadiene Manufacture
L. ABS Resin Manufacture
M. Bottle Fabrication
N. Container Options

A. Overview

This section contains the computer generated tables which summarize the environmental impacts of the ABS beer bottle. Table 31 shows the impacts for 1 million containers of each option. Table 32 shows the impacts that each subprocess contributes to the nonreturnable ABS bottle system. Table 33 contains the impacts for 1,000 pounds of each process in the ABS system.

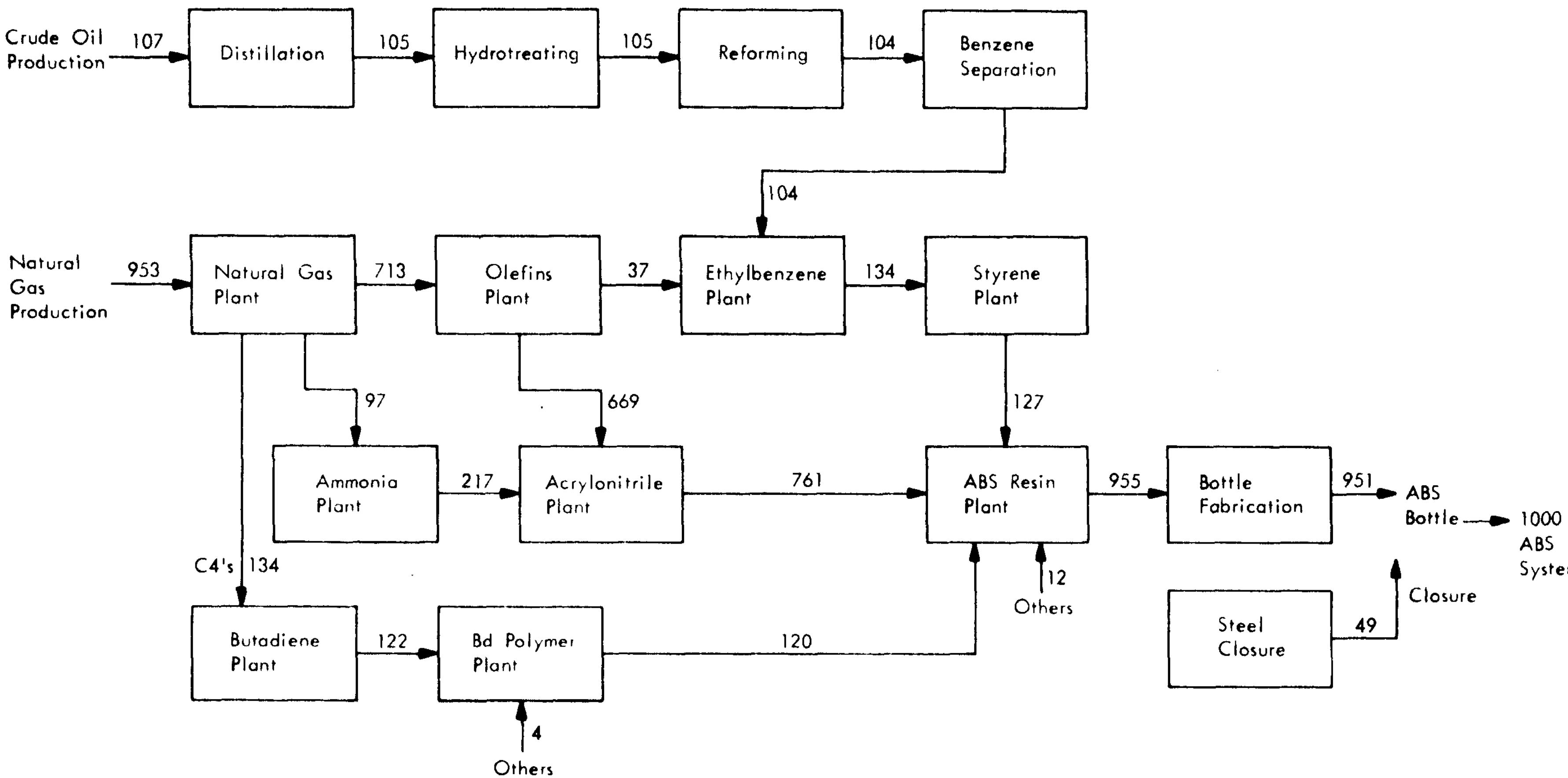

Figure 5 -Flow Diagram for Production of 1,000 Pounds of ABS Bottles (in pounds)

TABLE 31

IMPACTS FOR 1 MILLION ABS BOTTLES FOR THREE OPTIONS

		ONE WAY	ONE WAY 100 PCT RECYCLE	HYPOTHET 10 TRIP RETURNAB
INPUTS TO SYSTEMS				
NAME	UNITS			
MATERIAL WOOD FIBER	POUNDS	77267.	61134.	29308.
MATERIAL LIMESTONE	POUND	1649.	1649.	1649.
MATERIAL IRON ORE	POUND	5808.	5809.	5809.
MATERIAL SALT	POUND	0.	0.	3213.
MATERIAL GLASS SAND	POUND	0.	0.	0.
MATERIAL NAT SODA ASH	POUND	0.	0.	0.
MATERIAL FELDSPAR	POUND	0.	0.	0.
MATERIAL BAUXITE ORE	POUND	0.	0.	0.
MATERIAL PROCESS ADD	POUNDS	7861.	5028.	2710.
ENERGY PROCESS	MIL BTU	3131.	2016.	1160.
ENERGY TRANSPORT	MIL BTU	884.	212.	355.
ENERGY OF MATL RESOURCE	MIL BTU	1921.	1.	289.
WATER VOLUME	THOU GAL	3909.	2204.	1233.
OUTPUTS FROM SYSTEMS				
NAME	UNITS			
SOLID WASTES PROCESS	POUND	9154.	9069.	5078.
SOLID WASTES FUEL COMB	POUND	8739.	6935.	2567.
SOLID WASTES MINING	POUND	32153.	29559.	24582.
SOLID WASTE POST-CONSUM	CUBIC FT	2536.	1078.	1684.
ATMOS PARTICULATES	POUND	3459.	2799.	1194.
ATMOS NITROGEN OXIDES	POUND	5721.	1701.	1728.
ATMOS HYDROCARBONS	POUND	5261.	892.	1369.
ATMOS SULFUR OXIDES	POUND	4718.	3253.	2049.
ATMOS CARBON MONOXIDE	POUND	2463.	984.	1085.
ATMOS ALDEHYDES	POUND	25.	12.	14.
ATMOS OTHER ORGANICS	POUND	93.	67.	58.
ATMOS ODOROUS SULFUR	POUND	773.	642.	242.
ATMOS AMMONIA	POUND	52.	12.	18.
ATMOS HYDROGEN FLOURIDE	POUND	0.	0.	0.
ATMOS LEAD	POUND	2.	1.	1.
ATMOS MERCURY	POUND	0.	0.	0.
ATMOSPHERIC CHLORINE	POUND	0.	0.	13.
WATERBORNE FLUORIDES	POUND	0.	0.	0.
WATERBORNE DISS SOLIDS	POUND	1071.	313.	386.
WATERBORNE BOD	POUND	2202.	1491.	1658.
WATERBORNE PHENOL	POUND	0.	0.	0.
WATERBORNE SULFIDES	POUND	1.	0.	0.
WATERBORNE OIL	POUND	124.	2.	21.
WATERBORNE COD	POUND	994.	19.	151.
WATERBORNE SUSP SOLIDS	POUND	1793.	1350.	601.
WATERBORNE ACID	POUND	201.	155.	65.
WATERBORNE METAL ION	POUND	50.	39.	16.
WATERBORNE CHEMICALS	POUND	9.	0.	1.
WATERBORNE CYANIDE	POUND	0.	0.	0.
WATERBORNE ALKALINITY	POUND	0.	0.	0.
WATERBORNE CHROMIUM	POUND	0.	0.	0.
WATERBORNE IRON	POUND	1.	0.	0.
WATERBORNE ALUMINUM	POUND	1.	0.	0.
WATERBORNE NICKEL	POUND	1.	0.	0.
WATERBORNE MERCURY	POUND	0.	0.	0.
WATERBORNE LEAD	POUND	0.	0.	0.
SUMMARY OF ENVIRONMENTAL IMPACTS				
NAME	UNITS			
RAW MATERIALS	POUNDS	92586.	73620.	42689.
ENERGY	MIL BTU	5936.	2229.	1804.
WATER	THOU GAL	3909.	2204.	1233.
INDUSTRIAL SOLID WASTES	CUBIC FT	676.	615.	435.
ATM EMMISSIONS	POUNDS	22567.	10362.	7771.
WATERBORNE WASTES	POUNDS	6449.	3370.	2901.
POST-CONSUMER SOL WASTE	CUBIC FT	2536.	1078.	1684.

TABLE 32

IMPACTS FOR 1,000 POUNDS ONE-WAY ABS CONTAINERS

NAME	UNITS	CRUDE OIL PROD 107 LB	BENZENE MAN 104 LB	NATURAL GAS PROD 953 LB	NATURAL GAS PROCESS 944 LB	OLEFINS MAN 706 LB	BUTADIEN MAN 122 LB	AMMONIA MAN 217 LB	ACRYLO MAN 761 LB	STYRENE MAN 127 LB	POLY BD MAN 120 LB	ABS RESIN MAN 959 LB	ABS BOTTLE FAB 951 LB	ABS CONT SYS TRANS 1000 LB	STEEL CLOSURE MAN 49 LB	FILLING BOTTLES 1000 LB	PACKAGE	DISPOSA...
INPUTS TO SYSTEMS																		
MATERIAL WOOD FIBER	POUNDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	[illegible]	0.000
MATERIAL LIMESTONE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	20.361	0.000	0.000	0.000
MATERIAL IRON ORE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	71.710	0.000	0.000	0.000
MATERIAL SALT	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL GLASS SAND	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL NAT SODA ASH	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL FELDSPAR	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL BAUXITE ORE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL PROCESS ADD	POUNDS	.201	.520	0.000	0.000	.141	3.172	.976	3.805	.940	3.936	12.224	0.000	0.000	3.431	0.000	54.303	0.000
ENERGY PROCESS	MIL BTU	.008	.734	.040	.802	1.620	.864	.901	.591	.690	.304	5.096	6.682	0.000	1.211	0.000	14.550	0.000
ENERGY TRANSPORT	MIL BTU	.012	0.000	.398	0.000	3.795	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4.762	.023	1.722	1.481	.112
ENERGY OF MATL RESOURCE	MIL BTU	1.926	0.000	21.339	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.439	0.000	0.000	.012	0.000	0.000	0.000
WATER VOLUME	THOU GAL	.008	.449	.037	.278	.936	.568	.666	10.511	1.451	.405	2.814	2.385	.243	1.369	3.739	19.302	.007
OUTPUTS FROM SYSTEMS																		
SOLID WASTES PROCESS	POUND	.064	.104	0.000	0.000	.706	.090	.095	.609	.127	.012	1.050	.951	0.000	20.195	24.092	[illegible]	0.000
SOLID WASTES FUEL COMB	POUND	.023	.156	.124	.038	1.300	.805	.073	1.635	.117	0.000	6.620	18.481	.929	.662	1.591	[illegible]	.020
SOLID WASTES MINING	POUND	.057	.426	.303	.183	3.541	2.193	.200	4.453	.319	0.000	18.027	50.326	0.000	262.236	6.756	[illegible]	0.000
SOLID WASTE POST-CONSUM	CUBIC FT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	31.306
ATMOS PARTICULATES	POUND	.006	.083	.033	.010	.308	.182	.032	.346	.037	.006	1.451	3.913	.535	1.479	.794	27.720	.012
ATMOS NITROGEN OXIDES	POUND	.042	.414	2.089	4.629	23.299	.598	.487	.602	.384	.160	4.742	6.802	13.027	.400	1.134	9.010	.130
ATMOS HYDROCARBONS	POUND	.164	.986	10.148	10.770	8.354	.821	1.271	3.583	1.264	5.207	7.007	2.649	4.390	1.000	1.000	[illegible]	[illegible]
ATMOS SULFUR OXIDES	POUND	.033	.507	.200	.044	1.270	.759	.078	1.529	.117	.003	6.219	17.277	1.939	1.055	2.313	[illegible]	[illegible]
ATMOS CARBON MONOXIDE	POUND	.022	.085	.659	1.239	6.146	.102	.103	.075	.079	.035	.082	.043	11.114	.211	.241	[illegible]	[illegible]
ATMOS ALDEHYDES	POUND	.001	.007	.004	.000	.003	.002	.002	.001	.001	.001	.009	.011	.167	.002	.005	.072	.010
ATMOS OTHER ORGANICS	POUND	.000	.008	.004	.000	.006	.003	.004	.001	.003	.001	.017	.015	.356	.003	.006	.003	.003
ATMOS ODOROUS SULFUR	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.052	0.000	7.003	0.000
ATMOS AMMONIA	POUND	.000	.006	.000	0.000	0.000	0.000	.477	0.000	0.000	0.000	0.000	0.000	.010	.131	.001	.010	.000
ATMOS HYDROGEN FLOURIDE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	[illegible]	0.000
ATMOS LEAD	POUND	.000	0.000	.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.018	.000	.000	[illegible]	.002
ATMOS MERCURY	POUND	.000	.000	.000	.000	.000	.000	.000	.000	.000	0.000	.000	.000	0.000	.000	.000	.000	0.000
ATMOSPHERIC CHLORINE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.000	0.000	.000	.000	.000	0.000
WATERBORNE FLUORIDES	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE DISS SOLIDS	POUND	1.182	.122	3.805	.139	.891	.117	.154	.033	.116	.053	.683	.372	2.115	.103	.380	2.498	.000
WATERBORNE BOD	POUND	.000	.004	.000	.000	1.412	.092	.011	2.283	.372	.049	.573	.001	.005	.000	.000	18.420	.000
WATERBORNE PHENOL	POUND	.000	.001	.000	.000	.000	.000	.000	.000	.000	0.000	.000	.000	.002	.000	.000	.002	.000
WATERBORNE SULFIDES	POUND	.000	.001	.000	.000	.000	.000	.000	.000	.000	0.000	.000	.000	.002	.000	.000	.002	[illegible]
WATERBORNE OIL	POUND	.000	.002	.000	.000	1.271	.006	.011	.061	.060	.008	.077	.000	.003	.026	.000	.003	[illegible]
WATERBORNE COD	POUND	.000	.013	.000	.000	3.671	.402	.050	4.719	.900	.100	2.370	.004	.021	.001	.002	.021	.001
WATERBORNE SUSP SOLIDS	POUND	.000	.007	.000	.000	2.048	.025	.011	.609	.372	.150	.507	.002	.013	.131	.001	16.132	.000
WATERBORNE ACID	POUND	.001	.008	.006	.002	.068	.042	.004	.085	.006	0.000	.345	.964	.004	.230	.009	.512	.000
WATERBORNE METAL ION	POUND	.000	.002	.001	.000	.017	.011	.001	.021	.002	0.000	.086	.241	.001	.060	.022	.120	.000
WATERBORNE CHEMICALS	POUND	0.000	0.000	0.000	0.000	0.000	0.000	.108	0.000	0.000	0.000	0.000	0.000	0.000	.002	0.000	0.000	0.000
WATERBORNE CYANIDE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.001	0.000	0.000	.001	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE ALKALINITY	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.001	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE CHROMIUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.002	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE IRON	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.015	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE ALUMINUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.015	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE NICKEL	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.008	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE MERCURY	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE LEAD	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SUMMARY OF ENVIRONMENTAL IMPACTS																		
RAW MATERIALS	POUNDS	.201	.520	0.000	0.000	.141	3.172	.976	3.805	.940	3.936	12.224	0.000	0.000	95.502	0.000	819.767	0.000
ENERGY	MIL BTU	1.946	.734	21.777	.802	5.416	.864	.901	.591	.690	.304	5.536	6.682	4.762	1.246	1.722	16.031	.112
WATER	THOU GAL	.008	.449	.037	.278	.936	.568	.666	10.511	1.451	.405	2.814	2.385	.243	1.369	3.739	19.302	.007
INDUSTRIAL SOLID WASTES	CUBIC FT	.002	.009	.006	.002	.075	.042	.005	.090	.008	.000	.347	.942	.013	3.022	.446	2.120	.000
ATM EMMISSIONS	POUNDS	.260	2.095	13.136	16.691	39.307	2.467	2.455	6.137	1.885	5.413	20.247	31.510	31.556	4.421	5.495	72.480	4.732
WATERBORNE WASTES	POUNDS	1.183	.160	3.813	.141	9.376	.693	.350	7.812	1.828	.360	4.682	1.566	2.165	.561	.414	37.719	.062
POST-CONSUMER SOL WASTE	CUBIC FT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	31.306

TABLE 33

IMPACTS FOR 1,000 POUNDS OF EACH PROCESS FOR ABS CONTAINERS

NAME	UNITS	CRUDE OIL PROD	BENZENE MAN	NATURAL GAS PROD	NATURAL GAS PROCESS	ETHYLENE MAN	BUTADIEN MAN	AMMONIA MAN	ACRYLO MAN	STYRENE MAN	POLY BD MAN	ABS RESIN MAN	ABS BOTTLE FAB	ABS RECYCLE
INPUTS TO SYSTEMS														
MATERIAL WOOD FIBER	POUNDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL LIMESTONE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL IRON ORE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL SALT	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL GLASS SAND	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL NAT SODA ASH	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL FELDSPAR	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL BAUXITE ORE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL PROCESS ADD	POUNDS	1.880	5.000	0.000	0.000	.200	26.000	4.500	5.000	7.400	32.800	12.800	0.000	5.000
ENERGY PROCESS	MIL BTU	.070	7.060	.042	.850	2.295	7.086	4.151	.777	5.433	2.530	5.336	7.026	.414
ENERGY TRANSPORT	MIL BTU	.116	0.000	.418	0.000	5.376	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ENERGY OF MATL RESOURCE	MIL BTU	18.000	0.000	22.391	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.460	0.000	0.000
WATER VOLUME	THOU GAL	.078	4.316	.039	.294	1.326	4.659	3.069	13.812	11.422	3.372	2.946	2.508	.106
OUTPUTS FROM SYSTEMS														
SOLID WASTES PROCESS	POUND	.600	1.000	0.000	0.000	1.000	.740	.440	.800	1.000	.100	1.100	1.000	11.000
SOLID WASTES FUEL COMB	POUND	.211	1.504	.130	.040	1.842	6.600	.338	2.149	.921	0.000	6.932	19.433	1.145
SOLID WASTES MINING	POUND	.530	4.096	.318	.109	5.016	17.974	.920	5.852	2.508	0.000	18.077	52.919	3.118
SOLID WASTE POST-CONSUM	CUBIC FT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ATMOS PARTICULATES	POUND	.052	.794	.035	.011	.436	1.488	.149	.455	.294	.049	1.520	4.114	.442
ATMOS NITROGEN OXIDES	POUND	.388	3.980	2.192	4.903	33.002	4.900	2.243	.791	3.020	1.330	4.965	7.153	.421
ATMOS HYDROCARBONS	POUND	1.535	9.478	10.648	11.408	11.833	6.730	5.859	4.708	9.955	43.393	7.337	2.785	.164
ATMOS SULFUR OXIDES	POUND	.306	4.878	.218	.047	1.799	6.222	.360	2.809	.917	.028	6.512	18.167	1.071
ATMOS CARBON MONOXIDE	POUND	.210	.813	.692	1.312	8.705	.838	.475	.098	.624	.289	.892	.886	.052
ATMOS ALDEHYDES	POUND	.005	.063	.004	.008	.004	.013	.008	.001	.010	.005	.009	.012	.001
ATMOS OTHER ORGANICS	POUND	.004	.081	.004	.000	.009	.027	.019	.002	.024	.012	.018	.016	.001
ATMOS ODOROUS SULFUR	POUND	0.000	0.000	0.000	0.000	0.090	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ATMOS AMMONIA	POUND	.000	.060	.000	0.000	0.000	0.000	2.200	0.000	0.000	0.000	0.000	0.000	0.000
ATMOS HYDROGEN FLOURIDE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ATMOS LEAD	POUND	.000	0.000	.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ATMOS MERCURY	POUND	.000	.000	.000	.000	.000	.000	.000	.000	.000	0.000	.000	.000	.000
ATMOSPHERIC CHLORINE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE FLUORIDES	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE DISS SOLIDS	POUND	11.045	1.170	3.993	.147	1.263	.955	.712	.043	.911	.443	.715	.391	.023
WATERBORNE BOD	POUND	.000	.035	.000	.000	2.000	.750	.050	3.000	2.930	.410	.600	.001	.100
WATERBORNE PHENOL	POUND	.000	.010	.000	.000	.000	.000	.000	.000	.000	0.000	.000	.000	.000
WATERBORNE SULFIDES	POUND	.000	.013	.000	.000	.000	.000	.000	.000	.000	0.000	.000	.000	.000
WATERBORNE OIL	POUND	.000	.020	.000	.000	1.800	.050	.050	.080	.470	.070	.080	.001	.000
WATERBORNE COD	POUND	.000	.120	.000	.000	5.200	3.291	.230	6.200	7.090	.830	2.481	.004	.200
WATERBORNE SUSP SOLIDS	POUND	.000	.070	.000	.000	2.900	.201	.050	.800	2.930	1.250	.531	.003	.200
WATERBORNE ACID	POUND	.010	.078	.006	.002	.096	.344	.018	.112	.048	0.000	.362	1.014	.060
WATERBORNE METAL ION	POUND	.003	.020	.002	.001	.024	.086	.004	.028	.012	0.000	.090	.253	.015
WATERBORNE CHEMICALS	POUND	0.000	0.000	0.000	0.000	0.000	0.000	.500	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE CYANIDE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.001	0.000	0.000	.001	0.000	0.000
WATERBORNE ALKALINITY	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE CHROMIUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.002	0.000	0.000
WATERBORNE IRON	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.016	0.000	0.000
WATERBORNE ALUMINUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.016	0.000	0.000
WATERBORNE NICKEL	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.008	0.000	0.000
WATERBORNE MERCURY	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE LEAD	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SUMMARY OF ENVIRONMENTAL IMPACTS														
RAW MATERIALS	POUNDS	1.880	5.000	0.000	0.000	.200	26.000	4.500	5.000	7.400	32.800	12.800	0.000	5.000
ENERGY	MIL BTU	18.186	7.060	22.851	.850	7.671	7.086	4.151	.777	5.433	2.530	5.796	7.026	.414
WATER	THOU GAL	.078	4.316	.039	.294	1.326	4.659	3.069	13.812	11.422	3.372	2.946	2.508	.106
INDUSTRIAL SOLID WASTES	CUBIC FT	.014	.089	.006	.002	.106	.342	.023	.119	.060	.001	.363	.990	.206
ATM EMMISSIONS	POUNDS	2.500	20.147	13.784	17.681	55.789	20.218	11.313	8.064	14.845	45.105	21.253	33.134	2.152
WATERBORNE WASTES	POUNDS	11.059	1.537	4.001	.150	13.264	5.678	1.614	10.265	14.391	3.003	4.902	1.667	.598
POST-CONSUMER SOL WASTE	CUBIC FT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

For the ABS bottle we will use glass bottle filling and distribution numbers. The disposal data will also be based on the glass system data in Chapter II.

The ABS resin manufacture described in this chapter is a hypothetical case. The quantities of materials used are estimates. The actual materials balance used in industry is proprietary. Our purpose in choosing the ABS system, with estimated values, is to present a typical plastics manufacturing process, which hopefully will approximate the impacts of various barrier bottle manufacturing processes.

Figure 5 shows a flow diagram for manufacturing 1,000 pounds of the ABS system. The values represent pounds of materials required from each process. In the computer generated tables, crude oil and natural gas quantities have been counted as their energy equivalent rather than as pounds of raw materials. The raw materials listed in the tables refer to additives such as catalysts, material packaging, etc.

B. Crude Oil Production

In drilling a well, a petroleum engineer must select a location compatible with property boundaries and reservoir engineering analyses. Provisions must be made for fuel and water supplies, and mud pits for storage of drilling muds and settling of cuttings from used muds.

More than 80 percent of modern wells and all deep wells are drilled by the rotary process. In this process, a bit is turned at the bottom of the hole. Drilling mud is pumped through the drill pipe to cool the bit and flush drill cuttings to the surface. The mud also provides pressure to prevent collapse of the sides of the hole before casing is inserted, and it must be heavy enough to block the flow of gas, oil and brine into the drill hole to prevent expensive and dangerous eruptions from the well.[3/]

After drilling to an intrusion area, the hole is protected by inserting a casing. The casing is normally protected by pumping cement through it, and permitting the cement to rise along the outside of the casing toward the ground surface. In some instances, the casing must be set prior to completion of the well. This occurs when the normal hydrostatic pressure of 0.465 psi per foot of depth is exceeded. Proper setting of the casing is mandatory to prevent sloughing off around the casing in high pressure zones. If the hydrocarbons and brine were allowed to work their way along the outside of the casing, pollution of an upper zone could occur, and result in contamination of a water supply or the surface of the ground at the point where the pollutants break through.

Upon completion of the well construction, production can begin. Oil pools produce primarily under four mechanisms: gas expansion, gas-cap drive, water drive, and gravity drainage. The rates at which the hydrocarbon fluids can be withdrawn from a reservoir depend on the number of wells draining the reservoir, the average thickness of the formation, and the permeability of the reservoir rock for these fluids. Secondary methods such as acid treatment, miscible displacement, addition of surface active agents, and in-situ combustion, can improve recovery efficiency.

Once production is started, the products are transported mainly by pipelines to oil field tank batteries or refinery storage vessels. Preliminary treatment involves separation of hydrocarbons from brine and settleable solids. The hydrocarbons are then processed by a gas plant or refinery.

Detailed information is scarce concerning the ways in which drilling fluids, drilling muds, well cuttings, and well treatment chemicals may contribute to pollution. Studies have been made about well blowout and communication between fresh water aquifers and oil bearing sands. Several publications are available about oil field brine disposal by subsurface injection.[56]

The data below list the approximate amounts of acids used in the U.S. in 1 year for oil and gas well treatment.[20]

ACIDS USED FOR WELL TREATMENT

Acid	Gal/yr	Gal/BBL Crude Produced
Hydrochloric	8.7×10^7	2.2×10^{-2}
Formic	2.0×10^6	5.2×10^{-5}
Acetic	1.0×10^6	2.6×10^{-5}

Also approximately 30×10^5 pounds of inhibitor and 37×10^5 pounds of additives are used per year in well treatment. The total domestic crude production in 1971 was 3,296,612,000 barrels.[93] The quantity of inhibitors per barrel of crude was 9.0×10^{-4} pounds, the quantity of additives, 11.2 $\times 10^{-4}$ pounds per barrel. Since these products are injected into the subsurface reservoir, the amount of pollution to fresh water aquifers is probably very small. The drilling muds used prior to production are usually expensive and therefore merit special handling to prevent excessive losses. However, most spent muds are left in open slush pits to permit evaporation of liquids. Most pits are earth filled when evaporation is complete. Some remain in limited service to contain the effluents from well servicing.

Several sources of pollution resulting from oil field operations are:

1. Well blowout - resulting in surface and subsurface contamination.

2. Dumping of oil based drilling muds, oil soaked cuttings and treatment chemicals.

3. Crude oil escape from pipeline leaks, overflow of storage vessels and rupture of storage and transport vessels.

4. Discharge of bottom sediment from storage vessels.

5. Subsurface disposal of brine into a formation which would permit migration of the brine into area which could result in pollution of fresh water or contribute toward other natural disasters.

6. Escape of natural gas containing hydrogen sulfide could pollute fresh water supplies and local atmosphere.

A significant waste product resulting from oil and gas production is brine. The amount of brine produced can vary from zero to 95 percent of production. It is estimated by the American Petroleum Institute that 2.5 barrels of brine per barrel of oil is typical. However, 90 percent of this is disposed of in some acceptable manner such as subsurface disposal, or evaporation. The remainder is allowed to contaminate surface or subsurface fresh water streams.

Since 25 percent by weight of the average production from an oil well is natural gas, 75 percent of the total brine production was allocated to oil production.

The process loss pollutants are evaporated hydrocarbons, and were estimated from data obtained from the Los Angeles County Air Pollution Control District.[40/]

See Table 34 for environmental impacts related to crude oil production. Note that the crude oil has been counted as its energy equivalent rather than pounds of raw materials. The resource energy accounts for 98.9 percent of the total energy for production of 1,000 pounds of crude oil.

TABLE 34

DATA FOR PRODUCTION OF 1,000 POUNDS OF CRUDE OIL

		Sources
Energy of Material Resource	18.0 million Btu	10
Raw Materials		3
Material process additions (chemicals 0.29, cement 1.0, muds 0.59)	1.88 lb	
Energy		47
Electric	6.34 kwhr	
Fuel oil mobile source	0.36 gal.	
Gasoline mobile source	0.08 gal.	
Natural gas internal combustion	40.0 cu ft	
Water Volume	72.0 gal.	47
Solid Wastes	0.60 lb	3
Process Atmospheric Emissions		47
Hydrocarbons	1.4 lb	
Waterborne Wastes		47
Dissolved solids	11.0 lb	
Transportation		47
Barge	28.0 ton-miles	
Truck	10.0 ton-miles	
Pipeline	110.0 ton-miles	

C. Benzene Manufacture

Figure 6 shows an outline for processes typical of refinery treatment of crude oil.[10] The oil enters the refinery and passes through an initial purification step where water soluble salts and some "heavies" are removed. It then is sent to a distillation unit where the components of the crude are separated according to their boiling points. The light gases go overhead to a gas processing plant or serve as process fuels. The other cuts are routed to hydrotreating, cracking, reformer, or other units to undergo the desired transformations.

The benzene needed for styrene manufacture can be produced in a refinery. With reference to Figure 7, the steps for obtaining benzene are: crude distillation, catalytic reforming, and aromatics separation. The toluene from the separation unit can be dealkylated to produce more benzene.[7] Table 35 lists the environmental impacts for production of 1,000 pounds of benzene. Crude oil is the virgin raw material. A material loss of about 3 percent occurs between the point the crude enters the plant and benzene storage.[47] Much of the loss, such as CO_2 and water vapor, is not accounted for in the impact analysis since they are not considered to be critical pollutants. The BOD and COD tests do not reflect the benzene concentration in the wastewater effluent. The 5-day BOD for pure benzene is zero.[53] The solubility of benzene in water is around 0.08 percent. Instrumental methods such as gas chromatography or total organic carbon analysis could be used to determine the amount of organics, when the standard methods are limited in their analytical scope.

D. Natural Gas Production

The basic data for natural gas were taken from the 1967 Census of Mineral Industries.[84] The data pertaining to natural gas production are presented in Table 36. The quantity of production necessary to achieve 1,000 pounds of product gas is counted as its energy equivalent, rather than as pounds of raw materials. Therefore the energy requirement is large but 97.6 percent of this quantity represents the energy equivalent of the natural gas. Another large impact is atmospheric emissions of hydrocarbons, mainly methane.

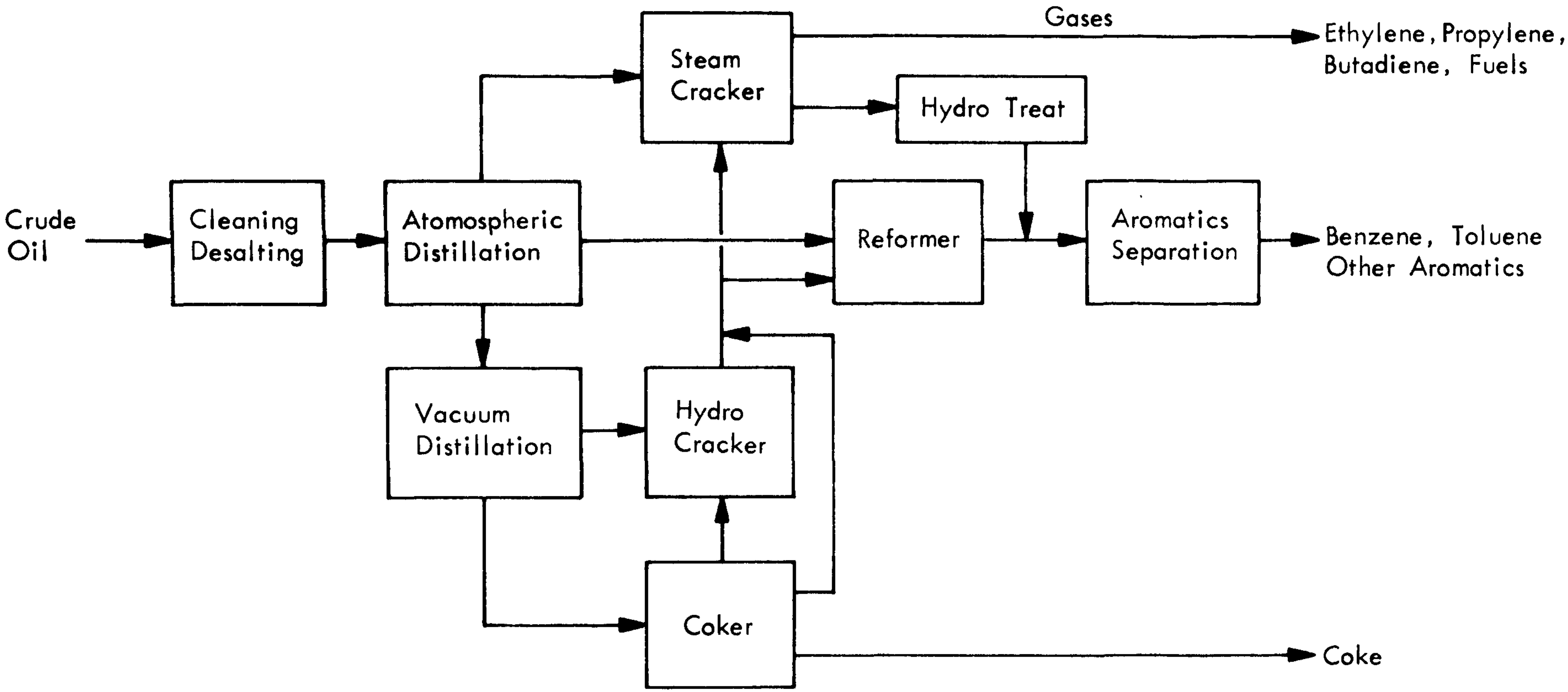

Figure 6 - Flow Diagram for Typical Petrochemical Refinery

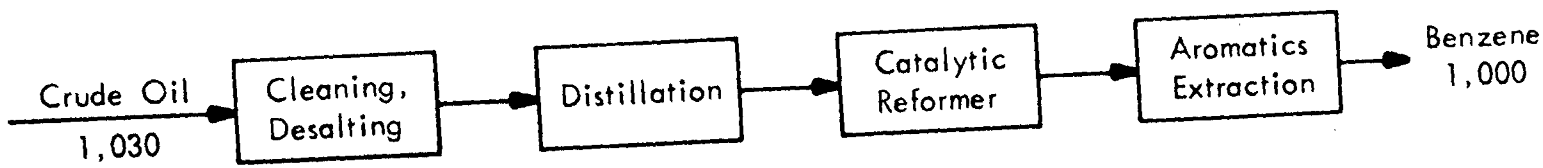

Figure 7 - Processes for Manufacture of 1,000 Pounds of Benzene (lb)

TABLE 35

DATA FOR MANUFACTURE OF 1,000 POUNDS OF BENZENE

		Sources
Raw Materials		68
Catalyst	5.0 lb	
Energy		47
Electric	49.0 kwhr	
Natural gas	6,000.0 cu ft	
Water Volume	4,200 gal.	47
Process Solid Wastes	1.0 lb	68
Process Atmospheric Emissions		47,70
Particulates	0.35 lb	
Hydrocarbons	3.10 lb	
Sulfur oxides	3.40 lb	
Aldehydes	0.05 lb	
Other organics	0.05 lb	
Ammonia	0.06 lb	
Waterborne Wastes		21,51,71
BOD	0.035 lb	
COD	0.120 lb	
Oil	0.020 lb	
Suspended solids	0.070 lb	
Sulfides	0.013 lb	
Phenols	0.0097 lb	
Transportation		
Pipeline	3 ton-miles	68
Barge	12 ton-miles	
Truck	15 ton-miles	

TABLE 36

DATA FOR PRODUCTION OF 1,000 POUNDS OF NATURAL GAS

		Sources
Energy of Material Resource	22.391 million Btu[a]	9
Energy		47
Electric	3.8 kwhr	
Fuel oil mobile source	0.28 gal.	
Gasoline mobile source	0.08 gal.	
Natural gas internal combustion	330.0 cu ft	
Water Volume	29.0 gal.	47
Process Atmospheric Emissions		40,44
Hydrocarbons	10.0 lb	
Waterborne Wastes		47
Dissolved solids	3.9	

a/ $\left(1{,}000 \text{ lb NG} \div 0.046 \frac{\text{lb}}{\text{cu ft}}\right) \times 1{,}030 \frac{\text{Btu}}{\text{cu ft}} = 22{,}391 \text{ million Btu}$

E. Natural Gas Processing

Light straight chain hydrocarbons are normal products of a gas processing plant. The plant uses compression, refrigeration and oil absorption to extract these products.[7] Heavy hydrocarbons are removed first. The remaining components are extracted and kept under controlled conditions, until transported in high pressure pipelines, in insulated railcars or in barges. The primary nonsalable residues coming from the natural gas stream are volatile hydrocarbons leaking into the atmosphere.

Table 37 contains a summary of processing impacts. The large natural gas fueled compressor engines use 92 percent of the process energy attributed to the whole industry, and contribute 80 percent of the air pollution. Table 33 shows that atmospheric emissions are quite large.

TABLE 37

DATA FOR PROCESSING 1,000 POUNDS OF NATURAL GAS

		Sources
Energy		47
Electric	1.3 kwhr	
Natural gas	769.0 cu ft	
Water Volume	280.0 gal.	47
Process Atmospheric Emissions		40,44
Hydrocarbons	10.0 lb	
Transportation		47
Rail	42 ton-miles	
Truck	14 ton-miles	
Barge	14 ton-miles	
Pipeline	70 ton-miles	

F. Ethylene Manufacture

Ethylene is produced by cracking natural gas liquids, and petroleum feedstocks and as a refinery coproduct. Figure 8 shows a typical ethylene plant flow diagram. The feedstock enters the reactors along with steam to lessen coke formation. The cracked gases are quenched with water and compressed. Carbon dioxide, acetylene and water are removed. The clean dry hydrocarbons are sent to fractionation columns to separate ethylene from by-products and uncracked feedstock.

Data for the environmental impacts of ethylene (olefin) production are presented in Table 38. Most of the energy used in the process is for running large compressors. The water volume used is typical for dehydrogenation and cracking units. Solid wastes from the process are negligible. Process atmospheric emissions are reported to be around 0.1 percent of throughput.

ETHYLENE MANUFACTURE

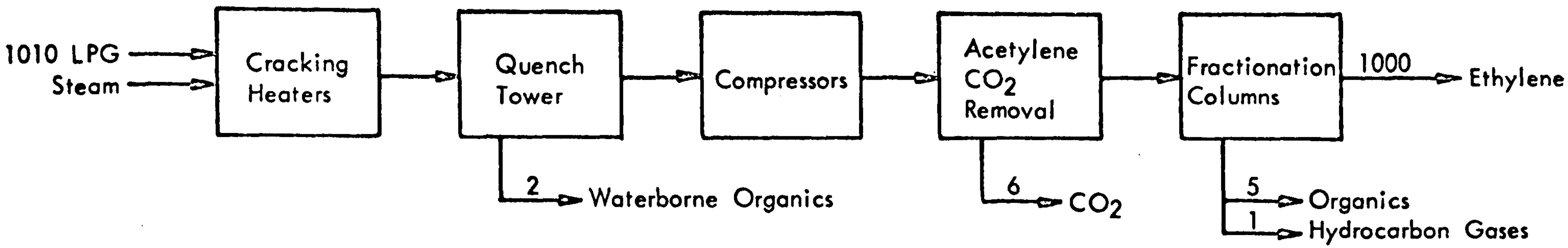

Figure 8 - The Manufacture of 1,000 Pounds of Ethylene

TABLE 38

DATA FOR MANUFACTURE OF 1,000 POUNDS OF ETHYLENE

		Sources
Raw Materials		
Catalysts	0.2 lb	33
Energy		24,47
Electric	60.0 kwhr	
Natural gas internal combustion	4,950.0 cu ft	
Natural gas industrial heat	1,500.0 cu ft	
Water Volume	1,200.0 gal.	24,71
Process solid wastes	1.00 lb	
Process Atmospheric Emissions		68
Hydrocarbons	1.00 lb	
Waterborne wastes		47
BOD	2.0 lb	
COD	5.2 lb	
Oil	1.8 lb	
Suspended solids	2.9 lb	

G. 1,3-Butadiene Manufacture

The principal commercial routes to butadiene are dehydrogenation of n-butane and n-butenes, and as a by-product during the manufacture of olefins.[68] A typical butane dehydrogenation process is shown in Figure 9. The butanes feed stream is preheated, and passed through the reactor catalyst bed to achieve dehydrogenation. The reaction products are quenched in oil, compressed and scrubbed with absorber oil to remove most of the C_4's. The C_4 mixture is recovered in a stripping column. After further separation, the remaining butadiene is recovered by extractive distillation with furfural. The butadiene rerun tower removes polymer, 2-butene, acetylenes, and 1,2-butadiene. The final product is generally greater than 98.7 percent 1,3 butadiene.

The data for environmental impacts are shown in Table 39 with the resulting impacts in Table 33.

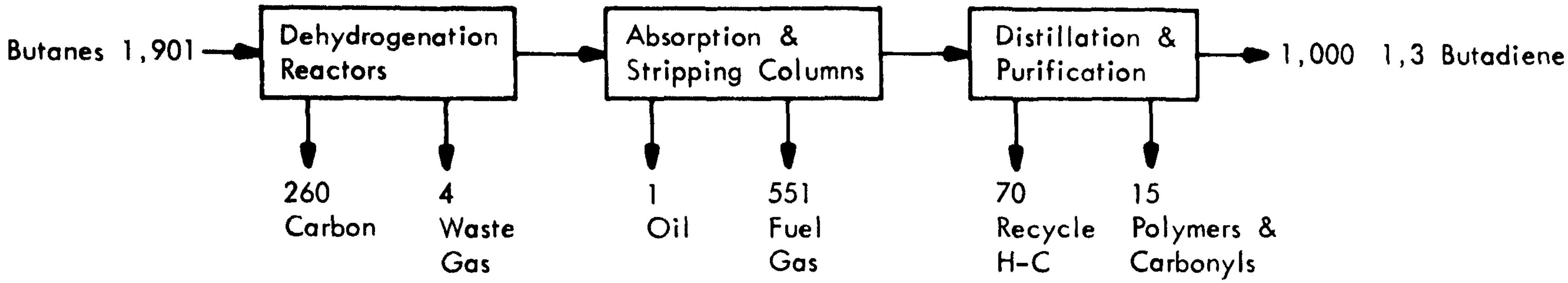

Figure 9 - The Manufacture of 1,000 Pounds of 1,3-Butadiene

TABLE 39

DATA FOR MANUFACTURE OF 1,000 POUNDS OF 1,3 BUTADIENE

		Sources
Raw Materials		68
Material process additions	26.0 lb	
Energy		68
Electric	215.0 kwhr	
Natural gas	4,327.0 cu ft	
Water Volume	4,545 gal.	68
Process Solid Wastes	0.74 lb	68
Process Atmospheric Emissions		40
Hydrocarbons	1.34 lb	
Waterborne Wastes		68,71
BOD	0.75 lb	
COD	3.29 lb	
Oil	0.05 lb	
Suspended solids	0.20 lb	

The electric and natural gas values are averages derived from combining the energy inputs for three separate methods of production. The tabulation below shows the breakdown for each process.68/ These values have been adjusted to reflect by-product credit.

Process	Percent of Total Production	Total For 1,000 lb of Butadiene Elec.-kwhr	Total For 1,000 lb of Butadiene NG-cu ft	Adjusted for Percent Elec.-kwhr	Adjusted for Percent NG-cu ft
Butanes	30	327	8,656	98.1	2,597
Butenes	47	216	2,684	101.6	1,261
Naphtha	23	67	2,040	15.3	469
Total				215.0	4,327

For the production of 1,000 pounds of butadiene, the energy requirements are calculated to be 215 kwhr of electricity and 4,327 cubic feet of natural gas. This amounts to about 8 million Btu of energy. The large energy requirements for the butanes route is due to the dehydrogenation step.

The process solid wastes were estimated to be 0.1 percent of butadiene production. The solids figure would probably be higher if cuprous ammonium acetate was used to extract butadiene from the C_4 product stream. The solids disposal problem would involve copper salts and spent charcoal, which serves to extract polymers and acetylene compounds from the CAA. Atmospheric hydrocarbon emissions are estimated to be 0.1 percent of the starting raw materials.[40] Waterborne waste data were derived from information describing pollutants from three separate plants located in Texas.

H. Ammonia Manufacture

Ammonia is a colorless gas with a characteristic odor that is perceptible at great dilutions. Its boiling point is -33°C. Ammonia weighs 5.14 pounds per gallon at 60°F, or 38.45 pounds per cubic foot at 60°F. It is prepared on a large scale by direct union of hydrogen and nitrogen: $3H_2 + N_2 = 2NH_3 + 22$ kcal. The percent yield is controlled by temperature, pressure and type of catalyst. Satisfactory conditions for reaction are pressures of 100-200 atmospheres and temperatures of 550°-600°C.[9] A diagram for the production ammonia is presented in Figure 10. Natural gases, or other light hydrocarbons, are steam reformed over a nickel catalyst in a tubular furnace. The hydrocarbons are converted into carbon oxides and hydrogen (generally referred to as synthesis gas). Carbon monoxide is reacted in a shift converter to form carbon dioxide and hydrogen. The carbon dioxide is removed by an absorber, and generally used in the production of urea in an adjacent plant. The absorber off-gas goes through a methanator to convert traces of carbon oxides which would poison the synthesis catalyst. The hydrogen and nitrogen combine in the synthesis loop to form ammonia.

For a typical 1,000 tons per day ammonia plant, 300 gallons of condensate per ton of ammonia are produced.[54] This condensate is either sent directly to a wastewater drain or processed through a stripping tower. A typical untreated condensate will contain the following impurities:

Impurity	Concentration (per 300 gal. of condensate)
NH_3	0.1 lb
NH_4HCO_3	0.1 lb
MEA	0.2 lb

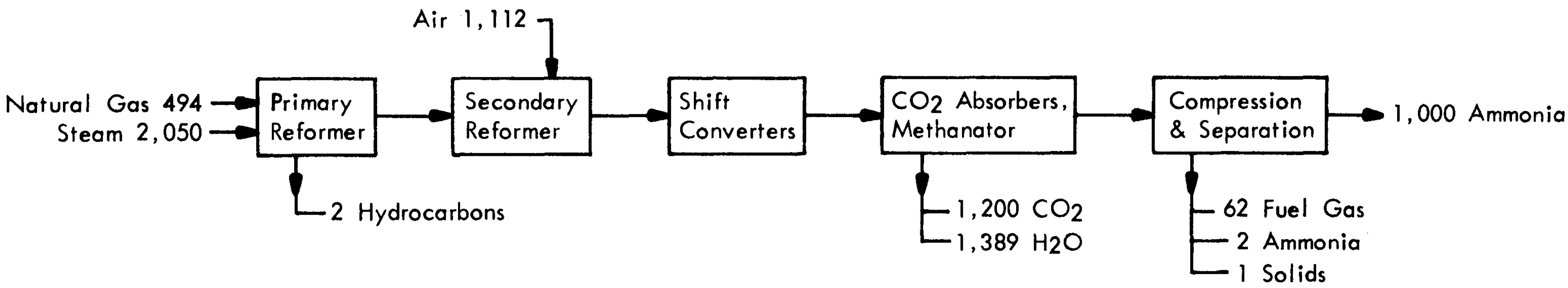

Figure 10 - Process for the Manufacture of 1,000 Pounds of Ammonia

Treatment in a stripping tower should reduce the NH_3 content to less than 20 parts per million.

The environmental impacts for ammonia production are presented in Table 40. The raw materials, energy, and water volume figures are typical for the industry.68/ Process solid wastes were estimated at 0.1 percent of output.68/ Primary atmospheric emissions were derived from values pertaining to plants without controls. It was assumed that controls are the rule and emissions were reduced by an estimated 90-95 percent.44/ Water effluents from ammonia production contributed the following concentrations of pollutants.73/

BOD	36 ppm
COD	166 ppm
Oil	40 ppm
Suspended Solids	15 ppm

TABLE 40

DATA FOR MANUFACTURE OF 1,000 POUNDS OF AMMONIA

		Sources
Raw Materials		5
Material Process Additions	4.55 lb	
(Catalyst 0.4, Caustic 4.0, MEA 0.15)		
Energy		68
Electric	11.0 kwhr	
Natural Gas	3,710.0 cu ft	
Water Volume	3,000.0 gal.	5,71
Process Solid Wastes	0.44 lb	68
Process Atmospheric Emissions		44,70
Hydrocarbons	2.00 lb	
Ammonia	2.20 lb	
Waterborne Wastes		68,73
BOD	0.05 lb	
COD	0.23 lb	
Oil	0.05 lb	
Suspended Solids	0.05 lb	
Ammonia	0.50 lb	

The plant used as a primary data source also produced three other products. Ammonia production was 38.6 percent of the total output. Emissions from ammonia production were assumed to be 38.6 percent of the quantities present in the final plant effluent.

I. Acrylonitrile Manufacture

Several methods exist for production of acrylonitrile; these processes are:[13/]

1. Reacting acetylene with hydrogen cyanide.

2. Dehydration of ethylene cyanohydrin.

3. Ammonia--propylene ammoxidation.

4. Ammonia--propane ammoxidation.

5. Nitric acid--propylene cyanization.

Methods 3, 4, and 5 are the most common commercial processes. The ammonia-propylene ammoxidation process was used as the data source for acrylonitrile production, due to its extensive commercial use and the availability of reliable data. The reaction follows the equation:

$$CH_2{=}CH{-}CH_3 + NH_3 + 1.5O_2 \longrightarrow CH_2{=}CH{-}C{\equiv}N + 3H_2O.$$

The ammonia-propylene route is shown in Figure 11. Propylene may be obtained from refinery catalytic cracking operations or as a co-product in ethylene manufacture. Ammonia is prepared by steam reforming natural gas.

Excluding steam and air, 1,154 pounds of propylene and 373 pounds of ammonia are required to produce 1,000 pounds of acrylonitrile. Also produced in the process are 50 pounds of hydrogen cyanide, 50 pounds of acetonitrile, 108 pounds of fuel gas, 100 pounds of recycle propylene, and 237 pounds of waste carbon, carbon gases, and hydrocarbons. The amount of "useful" by-products is 23 percent of the total useful output of 1,308 pounds. The following example shows how the materials required to produce the by-products are deducted from the total materials requirements, leaving 879 pounds of propylene and 285 pounds of ammonia allocated to the production of 1,000 pounds of acrylonitrile.

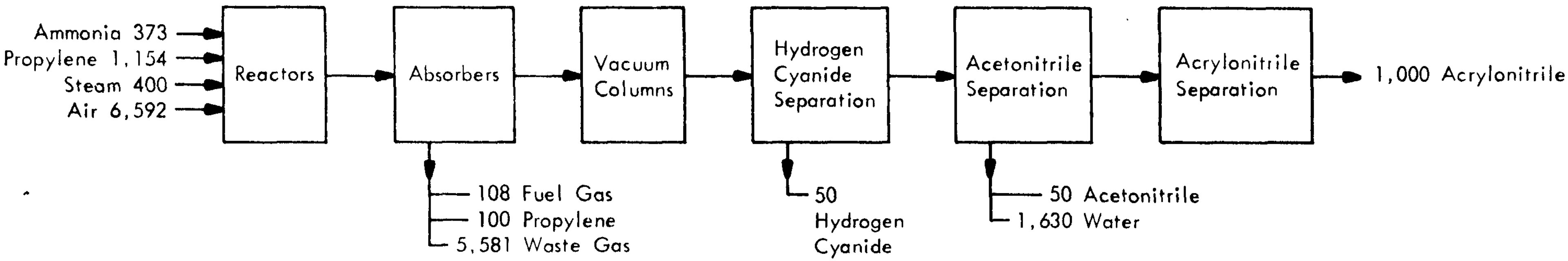

Figure 11 - The Manufacture of 1,000 Pounds of Acrylonitrile (lb)

Example:

Acrylonitrile Manufacture

	Plant Output	Starting Raw Materials	
Acrylonitrile	1,000	Propylene	1,154
Hydrogen cyanide	50	Ammonia	373
Acetonitrile	50	Total	1,527 lb
Fuel	108		
Propylene	100		
Waste (as carbon)	237		
Total	1,545 lb		

By-products and wastes represent 35.3 percent of the total output $\left(\frac{545}{1,545} \times 100\right)$. The materials required to manufacture the by-products--and wastes attributable to them--can be deducted from the starting raw materials. The waste attributable to the useful by-products equals 23 percent of 237 pounds, or 55 pounds $\left(\frac{308}{1,308} \times 237 = 55 \text{ lb}\right)$. Therefore, the deductions are:

Deductions

Hydrogen cyanide	50
Acetonitrile	50
Fuel	108
Propylene	100
Waste (carbon)	55
	363 lb

The deductions can be accomplished by proportioning the 363 pounds on the basis of quantity of starting raw materials:

$$\frac{1,154}{1,527} \times 363 = 275 \text{ lb for propylene deduction}$$

$$363 - 275 = 88 \text{ lb for ammonia deduction}$$

leaving:

$$1,154 - 275 = 879 \text{ lb propylene}$$

$$373 - 88 = 285 \text{ lb ammonia}$$

Since the amount of useful by-products is 23 percent of the usable total output, the requirements for utilities, and allocations for air emissions, and water and solid wastes for acrylonitrile production, can be reduced 23 percent. The values appearing in Table 40 have been adjusted to reflect by-product credit.

Table 41 summarizes the data for the raw impacts attributed to the production of 1,000 pounds of acrylonitrile. The raw materials are considered to be ammonia and propylene. The energy values represent the sum of Btu's from primary and secondary electrical and fuel gas power used to convert ammonia and propylene into acrylonitrile. The water volume represents the amount of water discharged in manufacturing. This figure will vary, depending on the process and location. The process solid wastes have been estimated at 0.1 percent of output, based on literature sources and derived estimates.[68/] The process atmospheric wastes are based on the estimate that about 0.5 percent of the incoming hydrocarbons are lost to the atmosphere due to leaks, spills, turnarounds, etc.[40/] Waterborne wastes refer to pounds of pollutants present in the process wastewater effluent (not in the water volume required during manufacture). Under present controls, about 10 percent of the manufacturing water volume leaves the plant as wastewater. This ratio will vary widely between companies, processes, and locations.[21/] Additional water is lost as a result of evaporation from cooling towers.

The quantity of BOD, COD, etc., in the wastewater stream is dependent upon the efficiency of the plant waste treatment facility.[2,20,32/] Generally, waste streams throughout a plant are combined and are treated as one flow.

The amount of contaminants attributable to each process can be calculated if complete data are available for each stream entering the treatment facility, and if the treatment efficiency for each stream is known.[21/] Generally, quantitative data for each stream are not available. Most plants report pollutants as the quantity present in their final effluent. The waste treatment facility is designed to reduce total plant contaminants to an acceptable level. State and federal agencies may require that maximum BOD

TABLE 41

DATA FOR MANUFACTURE OF 1,000 POUNDS OF ACRYLONITRILE

		Sources
Raw Materials		68
Material Process Addition (Catalyst 1.5, Oxalic Acid 0.5, Sulfuric Acid 3.5)	5.0 lb	
Energy		68
Electric	70.0 kwhr	
Water Volume	13,800.0 gal.	68
Process Solid Wastes	0.8 lb	68
Process Atmospheric Emissions		40,70
Hydrocarbons	4.40 lb	
Waterborne Wastes		68,71
BOD	3.00 lb	
COD	6.20 lb	
Oil	0.08 lb	
Suspended Solids	0.80 lb	
Cyander	0.0008 lb	
Transportation		68
Rail	400 ton-miles	
Truck	100 ton-miles	

concentrations not be exceeded. An example is 100 milligrams per liter for the plant effluent. If the plant produces 10 different products, the amount of BOD assignable to one of the processes could be allocated on the basis of percentage input and treatment efficiency. If complete data are not available, the amount of BOD contributed by each process generally is estimated from available information. Table 41 shows that water values as well as air and water pollution are important environmental impacts.

J. Styrene Manufacture

A diagram for styrene production is presented in Figure 12.[28/] Ethylbenzene and steam react in the presence of a catalyst to form styrene, which is separated from unreacted ethylbenzene, toluene, and polymers by distillation.

Ethylbenzene is commonly made using a Friedel-Crafts type reaction between benzene and ethylene with aluminum chloride as the catalyst. Another catalyst, boron trifluoride-alumina, is also used and results in an overall yield of ethylbenzene of 99 percent from benzene and 93 percent from ethylene.[68/]

Table 42 gives the raw impacts for producing styrene. The values are a combination of ethylbenzene and styrene manufacturing impacts.

The process solid wastes are mostly tars and catalyst residues. Atmospheric hydrocarbon emissions were estimated to be 0.6 percent of the raw materials used. Losses occur in leaks, spills, by-product and product loading, etc. By-product credit can be taken for the amounts of benzene and toluene recovered from the process.

K. Polybutadiene Manufacture

Polybutadiene may be manufactured according to the diagram in Figure 13. Butadiene is treated with compounds to remove inhibitors and oxygen. It is then mixed with a solvent and passed through a drying column and solid absorbents to remove water and other catalyst consumers. The purified mixed feed is fed to the reactors, where various terminators, cross-linking agents, modifiers, and catalysts are added. A typical catalyst used for solution polymerization is n-butyllithium. The cement or reactor effluent, is routed to blend tanks where mixing of antioxidants into the polymer solution is effected. The solvent can be removed by several drying methods. Data for polybutadiene manufacture are presented in Table 43.

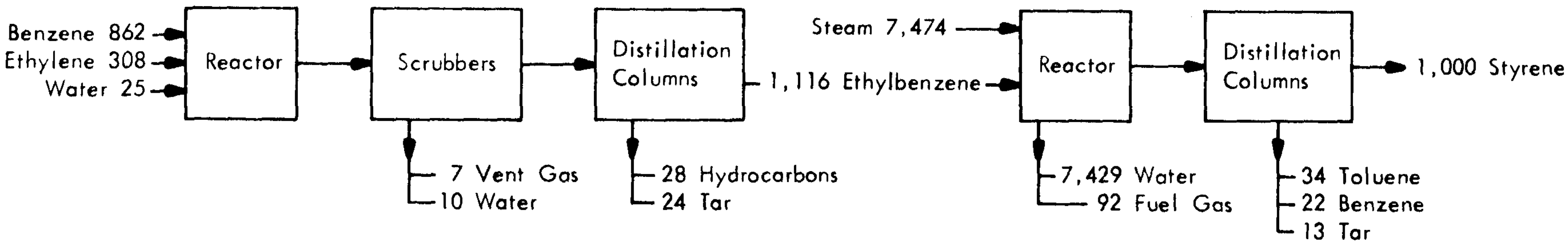

Figure 12 - The Manufacture of 1,000 Pounds of Styrene

TABLE 42

DATA FOR MANUFACTURE OF 1,000 POUNDS OF STYRENE

		Sources
Raw Materials		
Catalyst	7.4 lb	38
Energy		
Electric	30.0 kwhr	38
Natural gas	4,696.0 cu ft	
Water Volume	11,332.0 gal.	38
Process Solid Wastes	1.0 lb	68
Process Atmospheric Emissions		
Hydrocarbons	5.0 lb	40, 70
Waterborne Wastes		
BOD	2.93 lb	48, 71
COD	7.09 lb	
Oil	0.47 lb	
Suspended solids	2.93 lb	
Transportation		
Rail	400 ton-miles	68
Truck	100 ton-miles	

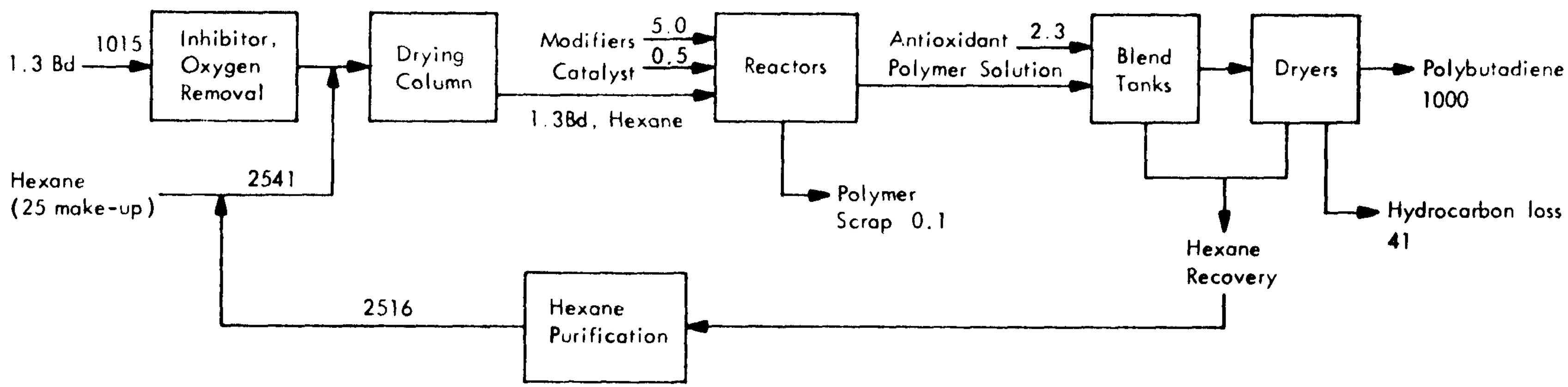

Figure 13 - Manufacture of 1,000 Pounds of Polybutadiene

TABLE 43

DATA FOR MANUFACTURE OF 1,000 POUNDS OF POLYBUTADIENE

		Source
Raw Materials		
Material process additions (solvent 25, catalyst 0.5, modifier 5.0, antioxidant 2.3)	32.8 lb	68
Energy		
Natural gas	2,330.0 cu ft	68
Water Volume	3,330.0 gal.	71
Process Solid Wastes	0.10 lb	68
Process Atmospheric Emissions		
Hydrocarbons	41.0 lb	40, 70
Waterborne Wastes		
BOD	0.41 lb	71
COD	0.83 lb	
Oil	0.07 lb	
Suspended solids	1.25 lb	
Transportation		
Rail	400 ton-miles	68
Truck	100 ton-miles	

The principal contaminant from the process is the hydrocarbon solvent lost to the atmosphere during polymer drying.

L. ABS Resin Manufacture

ABS resins are thermoplastic mixtures generally made by:[68]

1. Copolymerizing styrene with a copolymer of acrylonitrile and butadiene.

2. Blending acrylonitrile-butadiene and acrylonitrile-styrene copolymers.

3. Grafting styrene and acrylonitrile onto a preformed polybutadiene matrix.

The ABS resins used for beverage containers usually contain about 75 percent acrylonitrile. The exact formulations are generally proprietary. In this report, the quantitative values for input materials and energy, were derived from open literature sources, which describe manufacturing processes similar to the high nitrile barrier resin. The estimates we have used should provide a set of data which will be representative of the various industrial processes used to produce resin for fabrication of barrier bottles.

Figure 14 shows a flow diagram for the manufacture of an ABS resin. We have chosen acrylonitrile, styrene, and polybutadiene as raw materials. (The Barex bottle is a copolymer of acrylonitrile and methyl acrylate, while the Lopac is made from methyacrylonitrile and styrene.)[37]

The data pertaining to manufacturing are shown in Table 44. The energy and water volume data were taken from a process which produces an ABS resin containing 70 percent styrene, 23 percent acrylonitrile and 7 percent polybutadiene.[67] The values should approximate a process producing a high nitrile resin.

The solid waste from manufacturing is estimated to be 0.5 percent of production. Also, incineration is assumed for 80 percent of the wastes, leaving 1 pound as solid wastes.

The atmospheric hydrocarbon losses are estimated to be 0.3 percent of the incoming acrylonitrile and styrene.

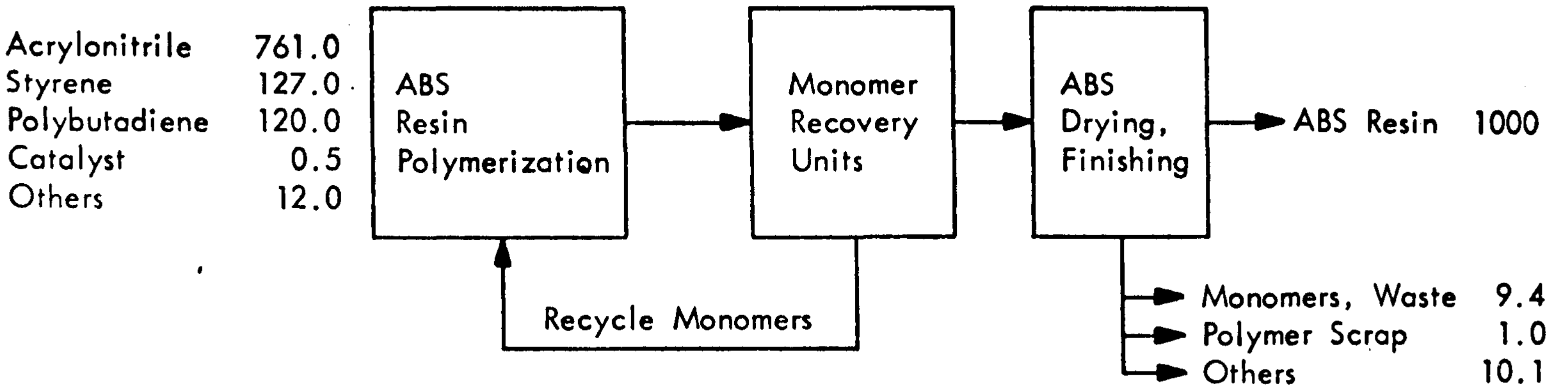

Figure 14 - Manufacture of 1,000 Pounds of ABS Resin

TABLE 44

DATA FOR MANUFACTURE OF 1,000 POUNDS OF ABS RESIN

		Sources
Raw materials		
Material process addition (catalysts 0.5, additives 11.5)	12.0 lb	50,68
Packaging materials (polyethylene)	20.0 lb	
Energy		
Electric	206.0 kwhr	68
Natural gas	2,386.0 cu ft	
Water volume	2,841.0 gal.	50,68
Process solid wastes	1.0 lb	46,68
Process atmospheric emissions		
Hydrocarbons	2.7 lb	40, 70
Waterborne wastes		
BOD	0.46 lb	50,68
COD	2.36 lb	
Oil	0.02 lb	
Suspended solids	0.49 lb	
Tot chromium	0.0016 lb	
Iron	0.016 lb	
Aluminum	0.016 lb	
Nickel	0.008 lb	
Cyanide	0.0008 lb	
Transportation		
Rail	125 ton-miles	
Truck	125 ton-miles	

Waterborne waste represents the present effluent guidelines set by EPA in March of 1973. The quantities are in close agreement with published data for ABS plant effluents.[50]

M. Bottle Fabrication

The data in Table 45 show the impacts pertaining to fabrication of 12-ounce bottles from an ABS resin. The energy required in the process is the largest impact. The following basic assumptions were made:[31]

1. Basic extrusion line producing 150 lb/hr
2. Electrical requirements - 95 kw
3. Water volume - 1,800 gal. per hour

The requirements for processing 1,000 pounds of resin are: 633 kilowatts and 12,000 gallons of water. The water is assumed to be used five times reducing the make up requirement to 2,400 gallons per 1,000 pounds. The energy requirements will vary with production methods and equipment. Values as low as about 325 kilowatts per 1,000 pounds have been reported.[67]

For a description of bottle filling, refer to Chapter II, section M. The same data used for glass bottles will be used for the ABS bottle. In like manner, Chapter II, section L discusses bottle packaging, Chapter IV, section I describes the steel closure, and Chapter II, section N discusses solids disposal. Impacts for filling, packaging, closures, and solids disposal have been included in the computer printouts.

TABLE 45

DATA FOR FABRICATION OF 1,000 POUNDS OF ABS BOTTLES

		Source
Raw materials		
Material packaging (corrugated)	26.0 lb	31
Energy		
Electric	633.0 kwhr	31
Water volume	2,400.0 gal.	31
Process solid wastes	1.0 lb	67
Transportation	100 ton-miles	67

N. Container Options

The options available to the plastic bottle system are return and recycle. The impacts for a returnable container should approximate those for a glass container described in Chapter II.

Table 46 shows the data pertinent to the manufacture of 1,000 pounds of ABS resin from recycled bottles. The data were derived from the following assumptions:[68]

1. Energy for cleaning and grinding - 50 HP
2. Cleaning compounds - 5 lb
3. Water volume - 100 gal.

TABLE 46

DATA FOR MANUFACTURE OF 1,000 POUNDS OF ABS RESIN FROM RECYCLE MATERIAL

		Source
Raw Materials		
Used bottles	1,053 lb	68
Cleaning compounds	5.0 lb	
Energy		
Electric	37.3 kwhr	68
Water Volume	100.0 gal.	68
Process Solid Wastes	11.0 lb	68
Process Atmospheric Emissions		
Particulates	0.2 lb	68
Waterborne Wastes		
BOD	0.1 lb	
COD	0.2 lb	
Suspended solids	0.2 lb	
Transportation		
Rail	125 ton-miles	68
Truck	125 ton-miles	

The transportation distance was estimated to be 500 miles from consumer disposal to resin plant. Ninety-five percent of the bottles were assumed to be usable as recycle material. Thus, 1,053 pounds of used bottles must be returned to produce 1,000 pounds of resin. Eighty percent of the off-spec material is assumed to be incinerated, leaving 11 pounds as solid wastes.

CHAPTER IV

STEEL CANS

This chapter contains the basic data and outlines the calculations made to determine the total environmental profile for steel beverage cans. Three steel systems were studied. Two of the systems are conventional three-piece steel cans with either aluminum or steel closures. The third system is a hypothetical three-piece steel can made of recycled metal.

Figures 15 and 16 outline the operations which are considered for ferrous strip manufacture. Figure 17 outlines the can fabrication operations. For conventional steel cans there are four major virgin raw materials entering the steel strip system as well as manufactured lime and scrap obtained from outside the steel mill. Thus, counting steel strip manufacture, can fabrication and solvent manufacture, a total of nine operations plus intervening transportation are included. For a hypothetical recycled container, the major material used is postconsumer scrap. Thus, the only operations differing from the conventional system are solid waste processing and electric furnace manufacturing operations.

For analysis of these container systems, this chapter is divided into the following 11 sections. Packaging and disposal basic data are included in Chapter II.

A. Overview of Systems
B. Iron Ore Mining
C. Coal Mining
D. Oxygen Manufacture
E. External Scrap Procurement
F. Steel Strip Manufacture
G. Ferrous Can Fabrication
H. Electric Furnace Steel Manufacture
I. Steel Closures for Cans
J. Can Filling
K. Petroleum Products

A. Overview of Systems

On the following pages is a set of tables numbered 47 through 51. These tables are computer generated reports which provide an overview of the steel can systems. Table 47 summarizes the relative impacts for 1 million, 12-ounce beer cans fabricated from each steel system.

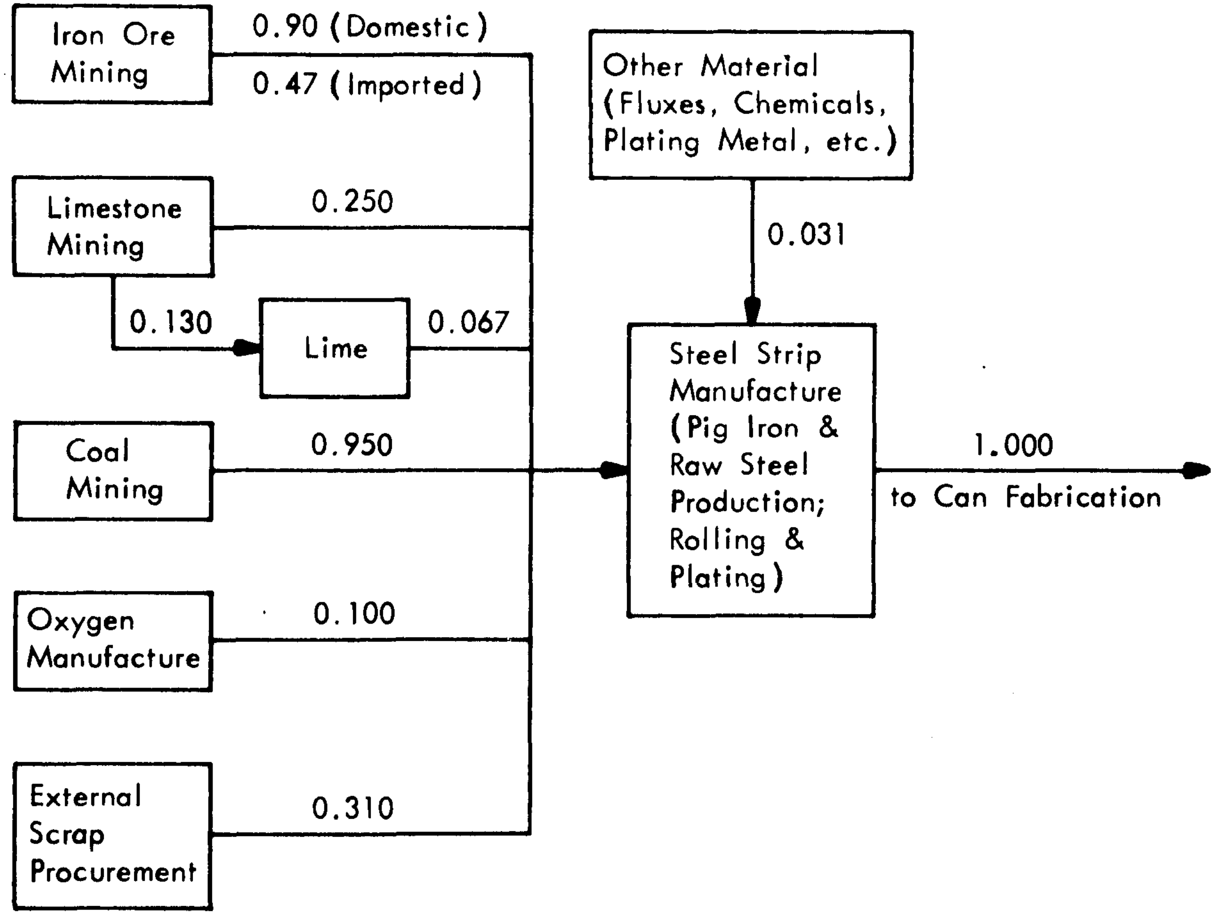

Figure 15 - Materials Flow for the Manufacture of One Ton of Steel Strip Using Primarily Virgin Materials (in tons)

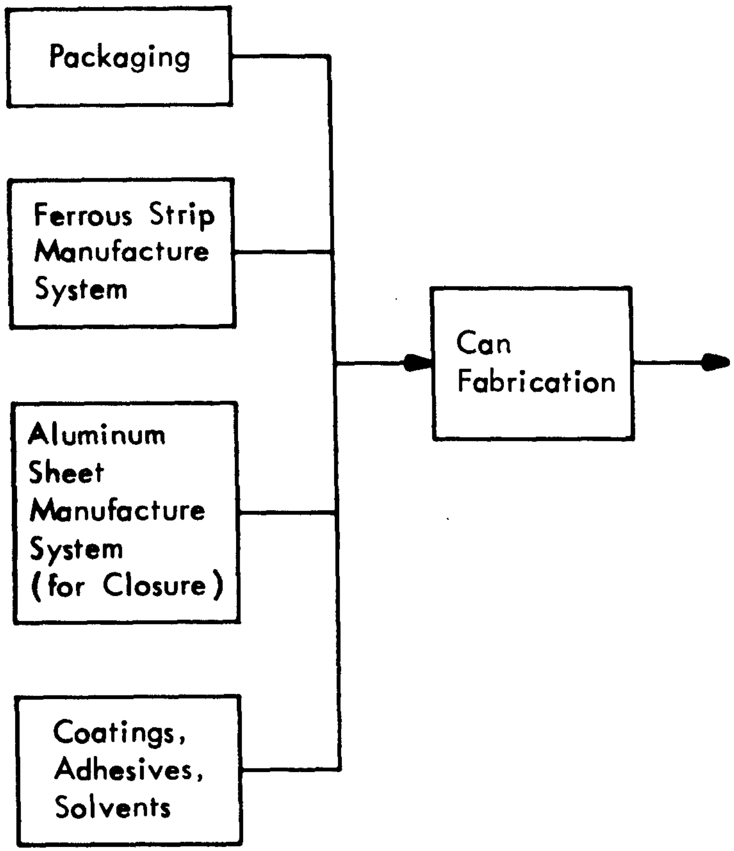

Figure 16

SUMMARY OF MATERIALS REQUIREMENTS FOR STEEL CAN FABRICATION

Materials Requirements for 1-Ton Finished Cans	Bimetal: Cylinder and Bottom	Bimetal: Aluminum Closure	All Steel: Cylinder and Bottom	All Steel: Steel Closure
Packaging - lb	50	1.3	48	10
Steel Strip - lb	1,840	--	1,886	360
Aluminum Sheet - lb	--	256	--	--
Coatings and Adhesives				
Solvents - lb	20	10	19	4
Solids - lb	14	9	13	3
Solder - lb	32	--	30	-
Number of Containers/Ton	18,000		16,700	
Weight of 1 Million Containers - Ton	55.4		60.0	

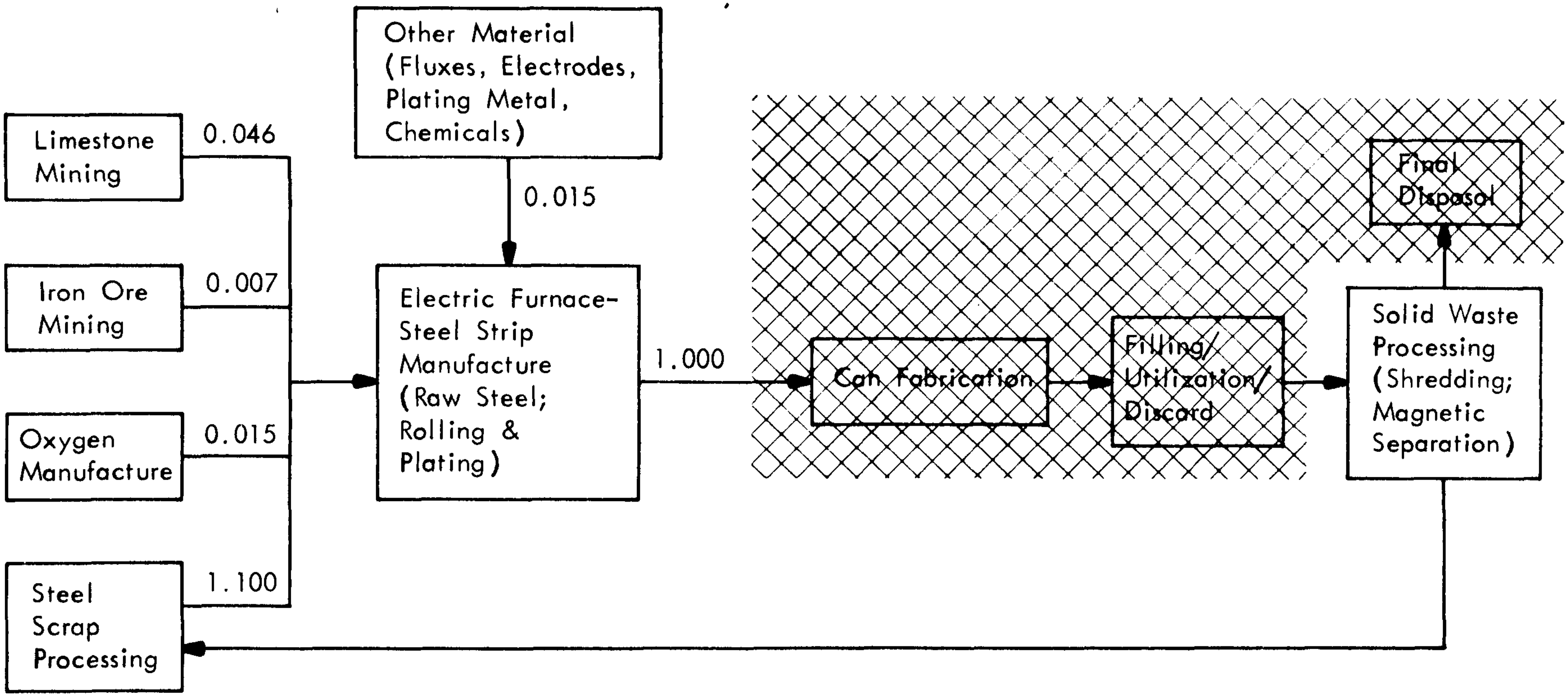

Figure 17 - Materials Flow for the Manufacture of One Ton of Steel Strip by Melting Scrap in an Electric Furnace (in tons)

TABLE 47

IMPACTS FOR 1 MILLION STEEL CANS

NAME	UNITS	BIMETAL CAN	ALL STL 100 PCT RECYCLED CAN	ALL STEEL CAN
INPUTS TO SYSTEMS				
MATERIAL WOOD FIBER	POUNDS	2703.	2631.	2928.
MATERIAL LIMESTONE	POUND	43021.	10037.	53682.
MATERIAL IRON ORE	POUND	139652.	1557.	189060.
MATERIAL SALT	POUND	3335.	0.	0.
MATERIAL GLASS SAND	POUND	0.	0.	0.
MATERIAL NAT SODA ASH	POUND	0.	0.	0.
MATERIAL FELDSPAR	POUND	0.	0.	0.
MATERIAL BAUXITE ORE	POUND	57232.	0.	0.
MATERIAL PROCESS ADD	POUNDS	11491.	5840.	9483.
ENERGY PROCESS	MIL BTU	4526.	1958.	3379.
ENERGY TRANSPORT	MIL BTU	235.	380.	188.
ENERGY OF MATL RESOURCE	MIL BTU	276.	88.	55.
WATER VOLUME	THOU GAL	3196.	964.	3657.
OUTPUTS FROM SYSTEMS				
SOLID WASTES PROCESS	POUND	46459.	28213.	56508.
SOLID WASTES FUEL COMB	POUND	5383.	3102.	2088.
SOLID WASTES MINING	POUND	594022.	11833.	692039.
SOLID WASTE POST-CONSUM	CUBIC FT	302.	45.	327.
ATMOS PARTICULATES	POUND	4825.	2367.	4068.
ATMOS NITROGEN OXIDES	POUND	3215.	2367.	1793.
ATMOS HYDROCARBONS	POUND	4229.	3681.	3206.
ATMOS SULFUR OXIDES	POUND	6302.	3150.	3176.
ATMOS CARBON MONOXIDE	POUND	1769.	1923.	887.
ATMOS ALDEHYDES	POUND	18.	25.	12.
ATMOS OTHER ORGANICS	POUND	32.	59.	18.
ATMOS ODOROUS SULFUR	POUND	124.	29.	162.
ATMOS AMMONIA	POUND	257.	2.	346.
ATMOS HYDROGEN FLOURIDE	POUND	19.	0.	0.
ATMOS LEAD	POUND	1.	3.	0.
ATMOS MERCURY	POUND	0.	0.	0.
ATMOSPHERIC CHLORINE	POUND	13.	0.	0.
WATERBORNE FLUORIDES	POUND	82.	0.	0.
WATERBORNE DISS SOLIDS	POUND	656.	489.	358.
WATERBORNE BOD	POUND	121.	60.	74.
WATERBORNE PHENOL	POUND	1.	0.	0.
WATERBORNE SULFIDES	POUND	1.	0.	0.
WATERBORNE OIL	POUND	175.	156.	75.
WATERBORNE COD	POUND	718.	16.	14.
WATERBORNE SUSP SOLIDS	POUND	398.	853.	379.
WATERBORNE ACID	POUND	669.	446.	637.
WATERBORNE METAL ION	POUND	172.	37.	159.
WATERBORNE CHEMICALS	POUND	226.	3.	4.
WATERBORNE CYANIDE	POUND	0.	0.	0.
WATERBORNE ALKALINITY	POUND	0.	0.	0.
WATERBORNE CHROMIUM	POUND	0.	0.	0.
WATERBORNE IRON	POUND	0.	0.	0.
WATERBORNE ALUMINUM	POUND	0.	0.	0.
WATERBORNE NICKEL	POUND	0.	0.	0.
WATERBORNE MERCURY	POUND	0.	0.	0.
WATERBORNE LEAD	POUND	0.	0.	0.
SUMMARY OF ENVIRONMENTAL IMPACTS				
RAW MATERIALS	POUNDS	257434.	20066.	255153.
ENERGY	MIL BTU	5037.	2426.	362[illegible].
WATER	THOU GAL	3196.	964.	3657.
INDUSTRIAL SOLID WASTES	CUBIC FT	8719.	583.	10134.
ATM EMMISSIONS	POUNDS	20804.	13606.	13667.
WATERBORNE WASTES	POUNDS	3221.	2061.	1701.
POST-CONSUMER SOL WASTE	CUBIC FT	302.	45.	327.

TABLE 48

IMPACTS FOR 1 TON BIMETAL CANS

NAME	UNITS	IRON ORE MINING 1660 LBS	LIMESTON MINING 700 LBS	COAL MINING 1740 LBS	LIME MFG 124 LBS	OXY MFG 182 LBS	EXTERNAL SCRAP 580 LBS	STEEL STRIP MFG 1840 LBS	PETROL PROD SYS 27 LB	3 PIECE CAN FAB 2000 LBS	ALUM CLOSURE SYS 252 LBS	TRANS	DISPOSAL	FILLING 2000 LBS	PAPER PACKAGE 49 LB	PLASTIC PACKAGE 36 LBS
INPUTS TO SYSTEMS																
MATERIAL WOOD FIBER	POUNDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	48.797	0.00
MATERIAL LIMESTONE	POUND	0.000	0.000	0.000	248.000	0.000	0.000	469.200	0.000	0.000	59.353	0.000	0.000	0.000	0.000	0.00
MATERIAL IRON ORE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	2520.800	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0
MATERIAL SALT	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	60.191	0.000	0.000	0.000	0.000	0.0
MATERIAL GLASS SAND	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
MATERIAL NAT SODA ASH	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
MATERIAL FELDSPAR	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0
MATERIAL BAUXITE ORE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1033.064	0.000	0.000	0.000	0.000	0.0
MATERIAL PROCESS ADD	POUNDS	0.000	0.000	0.000	0.000	0.000	0.000	75.440	.052	52.000	75.056	0.000	0.000	.036	3.444	1.3
ENERGY PROCESS	MIL BTU	.884	.013	.123	.288	.580	.253	35.625	.105	5.419	34.491	0.000	0.000	2.412	.702	.8
ENERGY TRANSPORT	MIL BTU	.138	.011	.039	.002	.009	0.000	.614	.007	0.000	.584	2.488	.121	0.000	.085	0.0
ENERGY OF MATL RESOURCE	MIL BTU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.501	0.000	3.683	0.000	0.000	0.000	0.000	.8
WATER VOLUME	THOU GAL	4.432	.033	.044	.020	.520	.007	42.612	.134	.406	8.497	.140	.008	.050	.728	.04
OUTPUTS FROM SYSTEMS																
SOLID WASTES PROCESS	POUND	0.000	0.000	0.000	22.630	0.000	0.000	644.000	.017	50.000	65.519	0.000	0.000	54.000	2.264	.17
SOLID WASTES FUEL COMB	POUND	1.113	.027	.330	.401	1.164	.371	12.568	.048	8.381	65.626	.562	.030	2.319	3.132	1.06
SOLID WASTES MINING	POUND	8822.949	.074	331.658	2.266	3.157	.970	33.072	.128	22.823	1490.505	0.000	0.000	9.850	1.991	2.8?
SOLID WASTE POST-CONSUM	CUBIC FT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	5.452	0.000	0.000	0.00
ATMOS PARTICULATES	POUND	15.379	4.558	3.494	2.442	.251	.084	24.198	.022	1.821	31.619	.357	.013	1.156	1.444	.22
ATMOS NITROGEN OXIDES	POUND	.851	.036	.812	.195	.527	.206	10.669	.088	4.341	30.648	4.851	.129	1.602	.502	2.22
ATMOS HYDROCARBONS	POUND	.680	.015	.677	.129	.321	.131	9.164	.220	27.461	31.603	1.744	.131	1.366	.255	2.21
ATMOS SULFUR OXIDES	POUND	1.216	.029	2.259	.551	1.104	.404	24.580	.142	7.661	67.222	2.007	.031	3.372	1.896	.99
ATMOS CARBON MONOXIDE	POUND	.251	.033	3.933	.062	.122	.029	2.386	.025	.655	17.507	4.631	1.010	.340	.215	.53
ATMOS ALDEHYDES	POUND	.008	.000	.002	.001	.002	.001	.049	.002	.010	.118	.110	.010	.007	.004	.08
ATMOS OTHER ORGANICS	POUND	.004	.001	.003	.001	.004	.001	.060	.002	.018	.244	.152	.064	.008	.005	.00
ATMOS ODOROUS SULFUR	POUND	0.000	0.000	0.000	0.000	0.000	0.000	1.840	0.000	0.000	0.000	0.000	0.000	0.000	.396	0.00
ATMOS AMMONIA	POUND	.000	.000	.000	.000	.000	.000	4.605	.002	0.000	.016	.006	.000	.001	.000	0.00
ATMOS HYDROGEN FLOURIDE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.346	0.000	0.000	0.000	0.000	0.00
ATMOS LEAD	POUND	.000	.000	.000	.000	.000	.000	.001	.000	0.000	.009	.007	.003	.000	.002	0.00
ATMOS MERCURY	POUND	.000	.000	.000	.000	.000	.000	.000	.000	.000	.002	0.000	0.000	.000	.000	.0
ATMOSPHERIC CHLORINE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.239	0.000	0.000	0.000	0.000	0.00
WATERBORNE FLUORIDES	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.486	0.000	0.000	0.000	0.000	0.00
WATERBORNE DISS SOLIDS	POUND	.172	.007	.025	.026	.059	.049	2.504	.325	.587	5.968	1.202	.065	.419	.122	.23
WATERBORNE BOD	POUND	.000	.000	.000	.000	.000	.000	.003	.001	.000	.934	.003	.000	.001	.997	.24
WATERBORNE PHENOL	POUND	.000	.000	.000	.000	.000	.000	.001	.000	.000	.015	.001	.000	.000	.000	.00
WATERBORNE SULFIDES	POUND	.000	.000	.000	.000	.000	.000	.002	.000	.000	.006	.001	.000	.000	.000	.00
WATERBORNE OIL	POUND	.000	.000	.000	.000	.000	.000	.922	.001	.000	2.134	.002	.000	.000	.000	.10
WATERBORNE COD	POUND	.001	.000	.000	.000	.000	.000	.013	.004	.002	12.715	.012	.001	.002	.001	.21
WATERBORNE SUSP SOLIDS	POUND	.001	.000	.000	.000	.000	.000	4.608	.002	.001	2.024	.008	.000	.001	.472	.07
WATERBORNE ACID	POUND	.057	.001	3.497	.025	.060	.019	4.315	.002	.437	3.439	.002	.000	.130	.027	[illegible]
WATERBORNE METAL ION	POUND	.014	.000	.874	.006	.015	.005	1.079	.001	.109	.953	.001	.000	.033	.007	.01
WATERBORNE CHEMICALS	POUND	0.000	0.000	0.000	0.000	0.000	0.000	.055	0.000	0.000	4.030	0.000	0.000	0.000	0.000	0.00
WATERBORNE CYANIDE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.001	0.000	0.000	0.000	0.000	0.00
WATERBORNE ALKALINITY	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
WATERBORNE CHROMIUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
WATERBORNE IRON	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
WATERBORNE ALUMINUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
WATERBORNE NICKEL	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
WATERBORNE MERCURY	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.000	0.000	0.000	0.000	0.000	0.00
WATERBORNE LEAD	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.000	0.000	0.000	0.000	0.000	0.00
SUMMARY OF ENVIRONMENTAL IMPACTS																
RAW MATERIALS	POUNDS	0.000	0.000	0.000	248.000	0.000	0.000	3065.440	.052	52.000	1227.665	0.000	0.000	.036	52.242	1.39
ENERGY	MIL BTU	1.022	.025	.163	.290	.589	.253	36.239	.613	5.419	38.758	2.488	.121	2.412	.787	1.60
WATER	THOU GAL	4.432	.033	.044	.020	.520	.007	42.612	.134	.406	8.497	.140	.008	.050	.728	.04
INDUSTRIAL SOLID WASTES	CUBIC FT	119.125	.001	4.482	.342	.058	.018	9.310	.003	1.096	21.693	.008	.000	.893	.100	.05
ATM EMMISSIONS	POUNDS	18.388	4.672	11.179	3.380	2.330	.857	77.552	.502	42.166	179.734	13.865	1.392	7.852	4.718	6.22
WATERBORNE WASTES	POUNDS	.245	.009	4.398	.057	.135	.073	13.403	.338	1.137	33.730	1.232	.066	.587	1.626	[illegible]
POST-CONSUMER SOL WASTE	CUBIC FT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	5.452	0.000	0.000	0.00

TABLE 49

IMPACTS FOR 1 TON ALL STEEL CANS

NAME	UNITS	IRON ORE MINING 1697 LBS	LIMESTON MINING 717 LBS	COAL MINING 1792 LBS	LIME MFG 126 LBS	OXYGEN MFG 187 LBS	EXTERNAL SCRAP 585 LBS	CLOSURE 360 LBS	STEEL STRIP MFG 1886 LBS	3 PIECE CAN FAB 1886 LBS	TRANS	DISPOSAL 2000 LBS	FILLING CANS 2000 LBS	PAPER PACKAGE 49 LBS	PLASTIC PACKAGE 34 LBS
INPUTS TO SYSTEMS															
MATERIAL WOOD FIBER	POUNDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	48.797	0.000
MATERIAL LIMESTONE	POUND	0.000	0.000	0.000	252.000	0.000	0.000	161.046	480.938	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL IRON ORE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	567.180	2583.820	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL SALT	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL GLASS SAND	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL NAT SODA ASH	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL FELDSPAR	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL BAUXITE ORE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL PROCESS ADD	POUNDS	0.000	0.000	0.000	0.000	0.000	0.000	26.890	77.326	49.036	0.000	0.000	.034	3.444	1.360
ENERGY PROCESS	MIL BTU	.596	.013	.127	.293	.592	.255	8.769	36.516	5.111	0.000	0.000	2.278	.702	.780
ENERGY TRANSPORT	MIL BTU	.093	.012	.041	.002	.010	0.000	.185	.629	0.000	1.463	.121	.450	.085	0.000
ENERGY OF MATL RESOURCE	MIL BTU	0.000	0.000	0.000	0.000	0.000	0.000	.150	0.000	0.000	0.000	0.000	0.000	0.000	.782
WATER VOLUME	THOU GAL	2.985	.033	.045	.020	.531	.007	10.769	43.678	.383	.082	.008	.073	.720	.046
OUTPUTS FROM SYSTEMS															
SOLID WASTES PROCESS	POUND	0.000	0.000	0.000	22.995	0.000	0.000	158.067	660.100	47.150	0.000	0.000	51.000	2.264	.170
SOLID WASTES FUEL COMB	POUND	.750	.028	.340	.408	1.189	.373	3.734	12.882	7.903	.328	.030	2.295	3.132	1.033
SOLID WASTES MINING	POUND	5942.887	.076	341.512	2.302	3.227	.976	2070.035	33.899	21.522	0.000	0.000	9.302	1.991	2.814
SOLID WASTE POST-CONSUM	CUBIC FT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	5.452	0.000	0.000	0.000
ATMOS PARTICULATES	POUND	10.359	4.662	3.598	2.481	.256	.085	11.375	24.803	1.717	.226	.013	1.151	1.444	.222
ATMOS NITROGEN OXIDES	POUND	.573	.037	.836	.198	.538	.207	4.209	10.935	4.094	2.711	.129	2.508	.502	2.160
ATMOS HYDROCARBONS	POUND	.458	.015	.697	.132	.328	.132	11.014	9.393	25.895	.976	.131	1.651	.255	2.177
ATMOS SULFUR OXIDES	POUND	.819	.030	2.326	.559	1.128	.407	6.946	25.194	7.413	1.436	.031	3.366	1.896	.971
ATMOS CARBON MONOXIDE	POUND	.169	.034	4.050	.063	.125	.029	1.057	2.440	.618	2.084	1.010	1.485	.215	.523
ATMOS ALDEHYDES	POUND	.006	.000	.002	.001	.002	.001	.015	.050	.009	.066	.010	.025	.004	.001
ATMOS OTHER ORGANICS	POUND	.003	.001	.003	.001	.004	.001	.017	.062	.017	.065	.064	.050	.005	.001
ATMOS ODOROUS SULFUR	POUND	0.000	0.000	0.000	0.000	0.000	0.000	.414	1.886	0.000	0.000	0.000	0.000	.396	0.000
ATMOS AMMONIA	POUND	.000	.000	.000	.000	.000	.000	1.037	4.728	0.000	.004	.000	.002	.000	0.000
ATMOS HYDROGEN FLOURIDE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ATMOS LEAD	POUND	.000	.000	.000	.000	.000	.000	.000	.001	0.000	.002	.003	.002	.000	0.000
ATMOS MERCURY	POUND	.000	.000	.000	.000	.000	.000	.000	.000	.000	0.000	0.000	.000	.000	.000
ATMOSPHERIC CHLORINE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE FLUORIDES	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE DISS SOLIDS	POUND	.116	.007	.026	.026	.060	.049	.774	2.567	.553	.700	.065	.619	.122	.228
WATERBORNE BOD	POUND	.000	.000	.000	.000	.000	.000	.001	.003	.000	.002	.000	.001	.997	.238
WATERBORNE PHENOL	POUND	.000	.000	.000	.000	.000	.000	.000	.001	.000	.001	.000	.000	.000	.000
WATERBORNE SULFIDES	POUND	.000	.000	.000	.000	.000	.000	.001	.002	.000	.001	.000	.001	.000	.000
WATERBORNE OIL	POUND	.000	.000	.000	.000	.000	.000	.208	.945	.000	.001	.000	.001	.000	.102
WATERBORNE COD	POUND	.001	.000	.000	.000	.000	.000	.005	.014	.002	.007	.001	.005	.001	.204
WATERBORNE SUSP SOLIDS	POUND	.000	.000	.000	.000	.000	.000	1.038	4.724	.001	.005	.000	.003	.472	.068
WATERBORNE ACID	POUND	.038	.001	3.601	.026	.062	.019	1.005	4.423	.412	.001	.000	.123	.027	.054
WATERBORNE METAL ION	POUND	.010	.000	.900	.006	.015	.005	.451	1.106	.103	.000	.000	.031	.007	.013
WATERBORNE CHEMICALS	POUND	0.000	0.000	0.000	0.000	0.000	0.000	.012	.057	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE CYANIDE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE ALKALINITY	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE CHROMIUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE IRON	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE ALUMINUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE NICKEL	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE MERCURY	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE LEAD	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SUMMARY OF ENVIRONMENTAL IMPACTS															
RAW MATERIALS	POUNDS	0.000	0.000	0.000	252.000	0.000	0.000	755.116	3142.076	49.036	0.000	0.000	.034	52.242	1.360
ENERGY	MIL BTU	.689	.025	.167	.295	.602	.255	9.105	37.145	5.111	1.463	.121	2.728	.787	1.562
WATER	THOU GAL	2.985	.033	.045	.020	.531	.007	10.769	43.678	.383	.082	.008	.073	.728	.046
INDUSTRIAL SOLID WASTES	CUBIC FT	80.239	.001	4.615	.347	.060	.018	30.130	9.543	1.034	.004	.000	.845	.100	.054
ATM EMMISSIONS	POUNDS	12.386	4.77[illegible]	11.512	3.434	2.341	.863	36.884	79.491	39.763	7.569	1.392	17.241	4.718	6.062
WATERBORNE WASTES	POUNDS	.165	.009	4.528	.058	.136	.074	4.295	13.841	1.472	.718	.066	.783	1.626	.908
POST-CONSUMER SOL WASTE	CUBIC FT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	5.452	0.000	0.000	0.000

TABLE 50

IMPACTS FOR 1 TON 100 PERCENT RECYCLED ALL STEEL CAN

		EXTERNAL SCRAP 1.11 TON	OXYGEN IRON ORE LIME AND LIMESTON	ELECTRIC FURNACE STL STRP 1.24 TON	THREE PC CAN FAB 1.11 TON	PETRO PROD SYSM 30 LB	CLOSURE FAB 0.18 TON	FILLING AND PLAS PACKAGE	PAPER PACKAGE 45 LB	TRANS	DISPOSAL
INPUTS TO SYSTEMS											
NAME	UNITS										
MATERIAL WOOD FIBER	POUNDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	43.857	0.000	0.000
MATERIAL LIMESTONE	POUND	0.000	52.808	114.448	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL IRON ORE	POUND	0.000	0.000	25.950	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL SALT	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL GLASS SAND	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL NAT SODA ASH	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL FELDSPAR	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL BAUXITE ORE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL PROCESS ADD	POUNDS	0.000	0.000	24.880	57.720	.058	9.916	1.353	3.259	0.000	0.000
ENERGY PROCESS	MIL BTU	.969	.166	20.939	6.016	.117	.273	3.035	.658	.221	0.000
ENERGY TRANSPORT	MIL BTU	0.000	.005	0.000	0.000	.008	.002	.450	.086	2.932	.003
ENERGY OF MATL RESOURCE	MIL BTU	0.000	0.000	0.000	0.000	.556	.150	.759	0.000	0.000	0.000
WATER VOLUME	THOU GAL	.025	.128	14.093	.451	.148	.044	.118	.716	.175	.000
OUTPUTS FROM SYSTEMS											
NAME	UNITS										
SOLID WASTES PROCESS	POUND	0.000	4.819	348.320	55.500	.019	8.105	51.165	2.070	0.000	0.000
SOLID WASTES FUEL COMB	POUND	1.419	.290	32.340	9.303	.053	.141	3.297	3.469	.687	.001
SOLID WASTES MINING	POUND	3.712	67.048	86.839	25.333	.142	.384	12.832	1.641	0.000	0.000
SOLID WASTE POST-CONSUM	CUBIC FT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.742
ATMOS PARTICULATES	POUND	.323	1.303	32.111	2.021	.024	.034	1.366	1.500	.380	.000
ATMOS NITROGEN OXIDES	POUND	.788	.140	16.901	4.819	.098	1.217	4.611	.452	5.277	.003
ATMOS HYDROCARBONS	POUND	.501	.088	12.182	30.481	.245	8.513	3.763	.216	2.674	.003
ATMOS SULFUR OXIDES	POUND	1.547	.313	33.397	8.726	.158	.164	4.308	.739	1.583	.001
ATMOS CARBON MONOXIDE	POUND	.112	.040	7.454	.727	.027	.320	1.093	.203	10.696	.091
ATMOS ALDEHYDES	POUND	.005	.001	.051	.011	.002	.001	.026	.004	.163	.000
ATMOS OTHER ORGANICS	POUND	.003	.001	.066	.020	.002	.001	.051	.005	.419	.014
ATMOS ODOROUS SULFUR	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.478	0.000	0.000
ATMOS AMMONIA	POUND	.001	.000	.005	0.000	.002	.000	.002	.000	.008	.000
ATMOS HYDROGEN FLOURIDE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ATMOS LEAD	POUND	.000	.000	.000	0.000	.000	.000	.002	.000	.025	.000
ATMOS MERCURY	POUND	.000	.000	.001	.000	.000	.000	.000	.000	0.000	0.000
ATMOSPHERIC CHLORINE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE FLUORIDES	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE DISS SOLIDS	POUND	.188	.017	2.880	.651	.361	.134	.040	.105	1.508	.001
WATERBORNE BOD	POUND	.000	.000	.004	.000	.002	.000	.232	.753	.004	.000
WATERBORNE PHENOL	POUND	.000	.000	.001	.000	.000	.000	.000	.000	.001	.000
WATERBORNE SULFIDES	POUND	.000	.000	.002	.000	.001	.000	.001	.000	.002	.000
WATERBORNE OIL	POUND	.000	.000	2.490	.000	.001	.000	.100	.000	.002	.000
WATERBORNE COD	POUND	.002	.000	.017	.002	.005	.001	.203	.001	.015	.000
WATERBORNE SUSP SOLIDS	POUND	.001	.000	13.694	.001	.003	.001	.069	.434	.009	.000
WATERBORNE ACID	POUND	.071	.016	6.641	.485	.003	.007	.176	.023	.003	.000
WATERBORNE METAL ION	POUND	.018	.004	.416	.121	.001	.002	.044	.006	.001	.000
WATERBORNE CHEMICALS	POUND	0.000	0.000	.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE CYANIDE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE ALKALINITY	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE CHROMIUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE IRON	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE ALUMINUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE NICKEL	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE MERCURY	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE LEAD	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SUMMARY OF ENVIRONMENTAL IMPACTS											
NAME	UNITS										
RAW MATERIALS	POUNDS	0.000	52.808	165.278	57.720	.058	9.916	1.353	47.116	0.000	0.000
ENERGY	MIL BTU	.969	.171	20.939	6.016	.681	.425	4.243	.743	3.154	.003
WATER	THOU GAL	.025	.128	14.093	.451	.148	.044	.118	.716	.175	.000
INDUSTRIAL SOLID WASTES	CUBIC FT	.069	.974	6.311	1.217	.003	.117	.898	.097	.009	.000
ATM EMMISSIONS	POUNDS	3.279	1.886	102.167	46.805	.557	10.249	16.121	3.597	21.225	.112
WATERBORNE WASTES	POUNDS	.280	.038	26.196	1.262	.375	.146	1.664	1.322	1.545	.001
POST-CONSUMER SOL WASTE	CUBIC FT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.742

TABLE 51

IMPACTS FOR 1 TON EACH PROCESS IN STEEL SYSTEMS

NAME	UNITS	IRON ORE MINING	COAL MINING	OXYGEN MFG	EXTERNAL SCRAP	STEEL STRIP	1 PIECE CAN FAB	ELECTRIC FURNACE STEEL MAN	STEEL CLOSURE FAB	FILLING MILLION CANS	PETROL PRODUCTS SYSTEM
INPUTS TO SYSTEMS											
MATERIAL WOOD FIBER	POUNDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL LIMESTONE	POUND	0.000	0.000	0.000	0.000	510.000	0.000	92.000	694.700	0.000	0.000
MATERIAL IRON ORE	POUND	0.000	0.000	0.000	0.000	2740.000	0.000	20.860	3151.000	0.000	0.000
MATERIAL SALT	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL GLASS SAND	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL NAT SODA ASH	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL FELDSPAR	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL BAUXITE ORE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL PROCESS ADD	POUNDS	0.000	0.000	0.000	0.000	82.000	52.000	20.000	149.367	2.000	3.873
ENERGY PROCESS	MIL BTU	.702	.142	6.370	.873	36.723	5.419	16.832	48.719	134.015	7.771
ENERGY TRANSPORT	MIL BTU	.110	.045	.104	0.000	.667	0.000	0.000	1.030	26.451	.530
ENERGY OF MATL RESOURCE	MIL BTU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.834	0.000	37.080
WATER VOLUME	THOU GAL	3.517	.050	5.710	.023	46.318	.406	11.329	59.830	4.299	9.895
OUTPUTS FROM SYSTEMS											
SOLID WASTES PROCESS	POUND	0.000	0.000	0.000	0.000	700.000	50.000	280.000	878.151	3000.000	1.236
SOLID WASTES FUEL COMB	POUND	.883	.379	12.788	1.279	13.661	8.381	25.996	29.746	134.988	3.532
SOLID WASTES MINING	POUND	7002.341	381.216	34.694	3.344	35.948	22.823	69.806	11500.193	547.200	9.452
SOLID WASTE POST-CONSUM	CUBIC FT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ATMOS PARTICULATES	POUND	12.205	4.016	2.757	.291	26.302	1.821	25.813	63.196	67.708	1.601
ATMOS NITROGEN OXIDES	POUND	.675	.933	5.788	.710	11.596	4.341	13.586	23.382	147.524	6.513
ATMOS HYDROCARBONS	POUND	.539	.778	3.526	.451	9.961	27.461	9.793	61.188	97.128	16.308
ATMOS SULFUR OXIDES	POUND	.965	2.597	12.131	1.393	26.717	7.861	26.846	38.589	198.000	10.513
ATMOS CARBON MONOXIDE	POUND	.199	4.521	1.340	.101	2.594	.655	5.992	10.319	87.369	1.824
ATMOS ALDEHYDES	POUND	.007	.002	.019	.004	.053	.010	.041	.082	1.465	.130
ATMOS OTHER ORGANICS	POUND	.004	.003	.041	.003	.065	.018	.053	.096	2.939	.147
ATMOS ODOROUS SULFUR	POUND	0.000	0.000	0.000	0.000	2.000	0.000	0.000	2.300	0.000	0.000
ATMOS AMMONIA	POUND	.000	.000	.001	.001	5.005	0.000	.004	5.759	.128	.121
ATMOS HYDROGEN FLOURIDE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ATMOS LEAD	POUND	.000	.000	.001	.000	.001	0.000	.000	.001	.125	.001
ATMOS MERCURY	POUND	.000	.000	.000	.000	.000	.000	.000	.000	.003	.000
ATMOSPHERIC CHLORINE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE FLUORIDES	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE DISS SOLIDS	POUND	.137	.029	.648	.169	2.722	.587	2.315	4.297	36.431	24.045
WATERBORNE BOD	POUND	.000	.000	.001	.000	.004	.000	.003	.007	.067	.103
WATERBORNE PHENOL	POUND	.000	.000	.000	.000	.001	.000	.001	.002	.024	.028
WATERBORNE SULFIDES	POUND	.000	.000	.000	.000	.002	.000	.002	.003	.030	.036
WATERBORNE OIL	POUND	.000	.000	.000	.000	1.002	.000	2.002	1.154	.034	.068
WATERBORNE COD	POUND	.001	.000	.004	.001	.015	.002	.013	.027	.269	.322
WATERBORNE SUSP SOLIDS	POUND	.000	.000	.002	.001	5.009	.001	11.008	5.766	.168	.181
WATERBORNE ACID	POUND	.045	4.020	.665	.064	4.691	.437	5.339	10.029	7.251	.181
WATERBORNE METAL ION	POUND	.011	1.005	.166	.016	1.173	.109	.335	2.507	1.813	.045
WATERBORNE CHEMICALS	POUND	0.000	0.000	0.000	0.000	.060	0.000	.040	.069	0.000	0.000
WATERBORNE CYANIDE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE ALKALINITY	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE CHROMIUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE IRON	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE ALUMINUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE NICKEL	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE MERCURY	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE LEAD	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SUMMARY OF ENVIRONMENTAL IMPACTS											
RAW MATERIALS	POUNDS	0.000	0.000	0.000	0.000	3332.000	52.000	132.860	4195.087	2.000	3.873
ENERGY	MIL BTU	.811	.187	6.474	.873	39.391	5.419	16.832	50.584	160.466	45.381
WATER	THOU GAL	3.517	.050	5.710	.023	46.318	.406	11.329	59.830	4.299	9.895
INDUSTRIAL SOLID WASTES	CUBIC FT	94.544	5.152	.641	.042	10.120	1.046	5.073	167.388	49.710	.192
ATM EMMISSIONS	POUNDS	14.594	12.650	25.604	2.954	84.295	42.166	82.128	204.913	602.397	37.158
WATERBORNE WASTES	POUNDS	.194	5.055	1.487	.252	14.677	1.137	21.058	23.662	46.086	25.002
POST-CONSUMER SOL WASTE	CUBIC FT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 48 summarizes systems for 1 ton of bimetal (CSTL) cans while Table 49 and 50 summarize the all steel and recycled cans. The remaining Table 51, converts raw data to impacts for 1 ton output of each subsystem. These raw data are presented in tables within the text of this chapter.

Table 47 provides an overview of the relative environmental merits of the two virgin can systems and one 100 percent recycled system. The widely used three-piece bimetal can is clearly the most detrimental to the environment, producing more impacts in six of the seven categories. The all steel can is the second most desirable can from an environmental point of view with recycled cans being clearly best, producing the least impact in six of the seven categories.

Tables 48 through 50 summarize the systems for 1 ton of cans showing contributions of various component processes. Several observations can be made by viewing these tables. The most important component accounts for more energy than the manufacture of the steel for the body and bottom. The most important operation for all steel cans is steel strip manufacture, which accounts for more impacts than the other operations in five of the seven categories.

Most other subprocesses contribute very little in each system, but some major processing step, such as steel manufacture or iron ore mining, is typically the second most abundant source of impacts.

Table 51 shows impacts for 1 ton output of each component process. These tables convert the raw data given in this chapter into impact parameters.

B. Iron Ore Mining

The basic raw material for steel can manufacture is iron ore. This material is found for the most part in flat-lying or gently sloping beds not more than 20 feet thick. Open pit mining accounts for about 90 percent of the iron ore extracted at present, with the remainder being recovered from deep vertical shaft mines.

Because of stringent specifications placed on iron ore used in blast furnaces it is necessary to beneficiate the ore. This requires that the ore be crushed to minus 4 inches and screened to remove minus 1/4-inch pieces. The minus 1/4-inch screenings are concentrated into pellets usually about 3/8 inch to 1/2 inch in diameter by an agglomeration procedure. The agglomeration procedure may take place at either the mine or the steel mill. The crushing and screening operations result in generation of particulate air pollution.

Data concerning the total environmental profile of iron ore mining were derived from government data sources. These are summarized in Table 52. Table 51 is a computer generated table which transforms the data from Table 52, and similar tables for the other operations, into environmental impacts per ton of output for that operation. However, tables such as 48 are more meaningful. That table displays the impacts per ton of finished three-piece conventional steel cans, so that each operation is put into proper perspective.

TABLE 52

DATA FOR MINING OF 1 TON IRON ORE

		Source
Energy		84
Natural gas	360 cu ft	
Distillate	0.23 gal.	
Residual	0.43 gal.	
Electric	28 kwhr	
Water Volume	3,500 gal.	85
Mining Wastes	6,500 lb	97
Atmospheric Emissions		
Particulates	12 lb	52
Transportation		
Rail	83 ton-miles	79
Water	316 ton-miles	81

Observing Table 52 we see that the dominant environmental effect of mining iron ore is mining wastes. These wastes are quite sizable and amount to 3.5 tons per ton of marketable ore. This impact is largely one of aesthetics, blight and land use. The problem is not so much how to dispose properly of the waste, but the mechanics of disposing of so much waste.

Currently there is much discussion concerning the adverse affects of waterborne disposal of taconite tailings. This method of disposal is alleged to create a serious water pollution problem in Lake Superior. The magnitude of this problem is staggering, as the ore mine which discharges its wastes is reported to dump nearly 22 million long tons a year, amounting to 500 pounds per short ton of the total iron ore mined in this country. The cessation of this problem would significantly reduce current water pollution of virgin steel systems. We have assumed that these tailings will be impoundedin the very near future, and have included them as solid waste in Table 52.

Table 48 shows that the overall effect of iron ore mining on three-piece can manufacture is large only with respect to industrial solid wastes.

C. Coal Mining

The environmental consequences of mining coal are inherently more serious and more difficult to bring under control than those of most mining industries. As opposed to limestone quarries which are located in highly visible locations scattered throughout the country, coal mines tend to be located far from major population regions. Hence, the environmental damage of mining coal has not been as visible as that due to limestone mining.

Coal mining results in many of the same environmental detriments which normally plague limestone mining as well as some which are unique. Those which are common are the dust and noise associated with mining and beneficiation; general unsightliness; improperly disposed solid residues and open surface mines left abandoned in unsatisfactory condition.

In addition, environmental damage results from coal mining in the form of: (1) burning coal refuse banks; (2) acid mine drainage; and (3) mine subsidence. The burning refuse banks are unique to coal mining and are caused by wasted organic material in mine refuse piles undergoing spontaneous combustion. These fires may burn for many years and may require intensive effort over a period of several years to extinguish permanently. Procedures are now established for proper construction of refuse banks which prevent spontaneous combustion, but extinguishing existing fires will be a problem for many years. The air pollution from these fires is included in Table 53.

Acid mine drainage results primarily from the subsidence of layers of material above deep coal mines as abandoned tunnels collapse. Invariably this subsidence ruptures water bearing structures above the mine level and water eventually fills the mine.

This water leaches minerals from the structure through which it moves. The resultant water pollution (shown in Table 53) usually ends up in the local streams and lakes. This problem grows annually and depends not on the rate of coal extraction as do most impacts, but on the cumulative total of coal mined. One source[65] estimates that to treat acid mine drainage properly to achieve the current water standards of the state of Pennsylvania would require a minimum expenditure of $40 million per year in perpetuity, and this assumes that proper mining techniques are adopted to prevent the problem from growing.

The problem of mine subsidence is important because nearly 5 million acres of land in the U.S. have been undermined by coal production. Included in this total on 158,000 acres of urban lands, often present because of cities whose growth has been stimulated by local coal mining activity. Virtually all of this land will sooner or later be affected adversely by mine subsidence. The magnitude of this problem is reflected in the cost estimates of mine subsidence prevention programs and increased cost of building foundations in potential subsidence areas. The total of these two items is over $1 billion, and this amount represents only a small portion of the total surface damage covered by mine subsidence. Subsidence can be prevented by proper mining techniques, however.

Table 48 shows that coal mining accounts for only a small percent of the impacts of the three-piece bimetal can system.

D. Oxygen Manufacture

The steel industry consumes more oxygen than all other industries combined, using well over one-half of all oxygen produced in this country. Oxygen is used in a variety of iron- and steel-making operations ranging from scrap preparation to basic oxygen process (BOP) steel furnaces. The latter is the most important accounting for 121 billion cubic feet (5 million tons) of oxygen consumption in 1971 which was 58 percent of the total consumed by the steel industry.

Oxygen is manufactured by cryogenic separation of air. This technique is essentially one of liquifying air and then collecting the oxygen by fractionation. The oxygen is produced in the form of a liquid which boils at 300°F below zero at normal atmospheric pressure so that it must be kept under stringent conditions of temperature and pressure for handling. Most oxygen plants are located quite close to their point of consumption to minimize transportation difficulties although there is a small amount of long distance hauling in insulated rail cars.

The environmental data for oxygen manufacture are listed in Table 54. The impacts are in Table 51. The most important impact is energy use. Those of air and water pollution are entirely due to fuel combustion.

TABLE 53

DATA FOR MINING OF 1 TON COAL

		Source
Energy		84
Coal	0.0010 ton	
Distillate	0.22 gal.	
Residual	0.025 gal.	
Natural gas	3.7 cu ft	
Gasoline	0.042 gal.	
Electricity	10 kwhr	
Water Volume		85
Process	46 gal.	65
Mining Wastes	380 lb	41
Atmospheric Emissions		42
Carbon monoxide	4.4 lb	
Sulfur oxide	2.2 lb	
Hydrocarbons	0.7 lb	
Nitrogen oxide	0.7 lb	
Particulates	3.9 lb	52
Waterborne Wastes		65
Sulfuric acid	4 lb	
Iron	1 lb	65,68
Transportation		
Rail	196 ton-miles	79
Water	30 ton-miles	82
Truck	4 ton-miles	68,97

TABLE 54

DATA FOR MANUFACTURE OF 1 TON OXYGEN

		Source
Energy		
Distillate oil	0.21 gal.	83
Residual oil	0.61 gal.	
Natural gas	1,528 cu ft	
Gasoline	0.49 gal.	
Electricity	415 kwhr	
Water	5,600 gal.	83
Transportation		
Rail	54 ton-miles	87
Truck	13 ton-miles	

E. External Scrap Procurement

The recycling of metallic scrap back into iron and steel furnaces has long been an economically viable means of utilizing ferrous waste materials. For instance, one-half of the metallic input to steel furnaces in 1969 was in the form of scrap. Much of the scrap recovered is generated within the mills themselves and the impacts associated with their recovery are included with normal iron and steel mill operations. However, substantial quantities of scrap are transported to iron and steel mills from external sources (including other mills at different sites). In 1971 this amounted to 2.6 million tons for blast furnace use and 26.8 million tons for use in steel furnaces.

The only environmental damage resulting from scrap procurement is related to energy use for preparing, loading and transporting the scrap. Positive effects of scrap usage on the environment include the displacement of virgin materials (and their related environmental effects) in iron and steel manufacture; and alleviation of solid waste disposal problems by diverting scrap from municipal solid waste streams. At the present time, a rapidly growing but still very small percent of scrap used is derived from municipal waste streams.

The environmental impacts of scrap recovery are not well documented, but they are small as compared to virgin raw material procurement. Table 55 contains data from one installation which magnetically separates ferrous scrap from mixed urban refuse. These data are quite close to MRI estimates of conventional scrap recovery and processing from industrial sources. These data were applied to the recycle options recovering scrap from mixed refuse.

Tables 51 and 48 show the impacts are quite small.

TABLE 55

DATA PERTAINING TO THE PROCUREMENT OF 1 TON SCRAP
(By Magnetic Separation of Mixed Municipal Wastes)

Energy	
Electricity	40 kwhr
Natural gas	190 cu ft
Distillate	1.4 gal.
Transportation	
Rail	130 ton-miles
Truck	2 ton-miles
Barge	20 ton-miles

Source: 68

F. Steel Strip Manufacture

The manufacture of steel strip suitable for can fabrication can be considered to consist of three separate steps: (1) pig iron production, (2) steel production, and (3) rolling and plating. These processes form the basic manufacturing step of converting iron ore into steel and are responsible for most of the environmental impact attributed to can manufacture.

Enormous amounts of energy are required to manufacture steel from raw materials. This energy is primarily supplied by coal which is first coked and then mixed with the raw materials. The energy is consumed in the blast and steel furnaces where the iron ore is converted at high temperatures to iron alloys in a series of chemical reactions with coke, fluxing agents and other materials. The raw steel is then worked into steel strip and is plated with tin or chromium for shipment to can fabricators.

Table 56 shows that iron ore is the leading material input to the steel system. In this study we are considering impacts on resources of the world, so that depletion of iron ore in foreign countries is included. Thus, 0.90 ton of domestic and 0.47 imported iron ore per ton steel produced was included in the calculations.

Solid wastes in the form of discarded metallics are generated in each step. Most of these materials are recycled directly on-site and, therefore, are not materials which need to be disposed. However, significant solid wastes which require disposal do appear from three sources: (1) fuel combustion residues; (2) wastewater treatment sludges; and (3) slags from iron and steel furnaces. These are listed in Table 56.

For many years a very serious air pollution problem existed for the steel industry from the use of beehive ovens to convert coal into coke. The air pollution problem resulted because approximately 25 percent of the coal was converted to airborne materials which were not subject to any pollution controls.[61/] Hence, for every ton of coal input to the plant there were 500 pounds of coal dust, ammonia, odorous sulfides and a variety of other materials emitted into the air. Today, almost all of the beehive ovens have been abandoned in favor of chemical by-product ovens which capture almost all of the effluent for recycling purposes or for conversion to by-products. Other pollution controls to reduce dust and fume emissions from the agglomerating, furnace and finishing areas have also been implemented so that air pollution, although still a problem, is less serious than it was in previous years.

The extent of present air pollution is revealed in Table 51. Air pollution is second only to energy in importance as an impact. Another serious environmental problem facing the steel industry is water pollution. Waterborne wastes are generated in every subprocess of iron and steel manufacture. These wastes are primarily suspended solids, oils, waste acids, waste plating solutions, and dissolved chemicals. Proper treatment of these wastes is made difficult by the unusually large volumes of effluent streams.

Table 56

DATA FOR THE MANUFACTURE OF 1 TON STEEL STRIP

		Source
Virgin materials		77
Limestone	0.255 tons	
Iron ore[a]	1.37 tons	
Other	0.041 tons	
Total	1.67 tons	
Energy		77
Coal	0.95 tons	
Distillate oil	4.2 gal.	
Residual oil	8.5 gal.	
Tar and pitch	2.0 gal.	
LPG	0.18 gal.	
Natural gas	6,930 cu ft	
Electricity	430 kwhr	
Water volume	46,000 gal.	83
Solid wastes		
Blast furnace slag	220 lb	55,61
Steel furnace slag	340 lb	55,61
Wastewater treatment sludge	140 lb	58,68
Process atmospheric emissions		
Particulates		61
Agglomerating	5 lb	
Coke manufacture	5 lb	
Blast furnace	2 lb	
Steel furnace	9 lb	
Scarfing	2 lb	
Total	23 lb	
Sulfur oxides	11 lb	
Hydrogen sulfide	2 lb	
Ammonia and organics	5 lb	
Waterborne wastes		49,58
Suspended solids	5.0 lb	
Acids	4 lb	
Oil	1.0 lb	
Metal ions	1.0 lb	
Fluorides	0.04	
Other chemicals	0.02	
Transportation		87
Rail	254 ton-miles	
Truck	76 ton-miles	
Water	93 ton-miles	

a/ About two-thirds (0.90 ton) of the iron ore is domestic.

The primary source of suspended solids is the blast and steel furnace areas. Exit gases from these furnaces are scrubbed to prevent air pollution, and to clean them sufficiently so they may be burned. Some suspended solids are also produced when cleaning the ingots or blooms and during rolling operations.

Waste oils, acids, and plating solutions are produced in the rolling and plating areas. These acids result from cleaning operations, whereas oils and plating solutions result from finishing operations. These solutions typically contain iron salts in addition to other heavy metal ions related to plating operations.

Coke plant wastes generally account for most of the other chemicals found in the waste streams. Coke plant wastes contain phenols as well as ammonia, cyanides, and other chemicals.

Table 48 shows that steel strip manufacture accounts for significant impacts. This category is second only to the aluminum closure system in importance as a subprocess of three-piece can manufacture.

G. Ferrous Can Fabrication

Steel strip is shipped to can fabricators to be converted into beer cans. The steel can is made of electrolytic tin plate (ETP) steel or tin-free steel (TFS). These cans are nearly identical except that the TFS can is coated with a very thin layer of chromium instead of tin. This amounts to less than one-half of 1 percent of the final can weight in either case, so the differences are considered negligible.

The three-piece can is fabricated from a metal blank which is soldered or welded to form the can cylinder. A steel bottom and an aluminum top are attached to the can cylinder by mechanical crimping. The connections are made leak-proof with a sealant (end compound). The can is coated and decorated with inks.

Raw data for can fabrication are included in Table 57, with the impacts displayed in Tables 51 and 48.

TABLE 57

DATA FOR FABRICATION OF CAN BODY AND BOTTOM FOR 1 TON OF THREE-PIECE STEEL CANS

		Sources
Virgin materials		68
Solder	32 lb	
Cement, paint, coatings	20 lb	
Solvent	26 lb	
Packaging (corrugated containers)	49 lb	
Energy		68
Natural gas	2,200 cu ft	
Electricity	273 kwhr	
Water volume	320 gal.	83
Solid waste	50 lb	68
Atmospheric emissions		
Process hydrocarbons	24 lb	68
Transportation		88
Rail	97 ton-miles	
Truck	111 ton-miles	
Water	11 ton-miles	

As shown in Table 51 and 48, impacts from can fabrication are important. These impacts result from the use of electricity to run plant machinery and natural gas for drying ovens. Significant air pollution also occurs from evaporated solvents of which it is estimated that only 9 percent is incinerated to prevent air pollution.

H. Electric Furnace Steel Manufacture

As noted in Section F which describes conventional steel manufacture, large quantities of steel are recycled each year as a normal part of the steel-making process. The scrap is normally high grade industrial waste resulting from metal discarded at various stages in manufacturing. However, the potential exists to obtain much steel from post-consumer ferrous wastes, such as steel cans discarded into municipal waste streams.

In this study we are examining one system which might be used to fabricate ferrous products using post-consumer waste as the primary raw material. This system is the three-piece electric furnace system. Electric furnace technology is well established and presently is being used in many applications. It is typically a small operation compared to large, conventional steel mills. Electric furnaces use scrap as the principal raw material. Most electric furnaces prior to 1960 did not produce carbon steel, but produced various ferroalloys for special purposes. However, in 1971, 71 percent of the output of electric furnaces was carbon steel. These furnaces can produce suitable can steel. Economics dictate the location and choice of output products.

Scrap metal and various additives are charged into an electric furnace through its top. (The materials flow is shown in Figure 17.) These materials are melted by the conversion of electric energy into heat. Current is brought into the furnace through large carbon electrodes and the energy is converted to heat in the furnace. Much less energy is required for this process than for making steel from virgin ore. The electric furnace consumes energy primarily by melting the iron and maintaining a high enough temperature for refining to take place. On the other hand, conventional steel production requires several separate operations: agglomerating, blast furnace operations, and steel furnace operations. The large difference in energy is seen by the fact that an energy requirement of 500 kilowatt-hours per ton of steel for a typical electric furnace translates to a fuel requirement of about 6 million Btu. This quantity may be compared to over 15 million Btu of fuel required for the blast furnace alone to produce 1 ton of pig iron. 1/ For 1 ton of steel strip produced, the energy difference is 41 million Btu for conventional steel as opposed to 19 million Btu for the electric furnace system.

The data for electric furnace steel are given in Table 58. The most troublesome on-site impact of electric steel furnaces is air pollution. This results primarily from fume emission. "Fume" is the term applied to electric furnace emissions of airborne particulates--composed predominantly of metal oxides but also of combusted impurities. These particulates are quite small, usually below 2 microns, and are somewhat difficult to control. These emissions occur mainly during charging operations when the roof of the furnace is opened, and during the "boil" phase.

I. Steel Closures for Cans

In the not-too-distant past, steel beverage cans were closed with a steel lid. However, the advent of the aluminum ring pull top has virtually eliminated the steel can closure from the beer can market, although some steel tops still occur on soft drink cans. As environmental aspects of product manufacture become more important, it may be desirable to replace the aluminum tops on steel cans with steel tops.

The steel tops which could be used would probably be fabricated from tin-free steel. The process is a fairly simple one of stamping the lids from sheet blanks. A polymer coating is required which must be dried in an oven.

Table 59 contains the data for the fabrication. The environmental profile is quite similar to that of the can body and bottom fabrication discussed in Section G.

J. Can Filling

Can filling proceeds in a manner similar to that described for bottle filling in Chapter II. The cans are received in the plant, rinsed, filled, and topped with an appropriate closure. Most commonly used is an aluminum ring pull top, although a steel top is used in some cases. The impacts in the filling plant are similar for both aluminum and steel cans, and for beer or soft drink cans. However, for beer a pasteurization is required which is not present in the soft drink system. Also, the kinds of fuels used by brewers are different from those used by soft drink plants. Table 60 summarizes the impact data.

TABLE 58

DATA FOR MANUFACTURE OF 1 TON STEEL STRIP FROM ELECTRIC FURNACE MILLS

		Sources
Materials		39
Scrap	2,140 lb	
Oxygen	30 lb	
Iron ore	14 lb	
Limestone	92 lb	
Carbon electrodes	10 lb	
Plating metal (chromium or tin)	10 lb	
Energy		
Electricity	500 kwhr (furnace)	1
	335 kwhr (rolling and plating)	68
Natural gas	5,400 cu ft	68
Residual oil	10 gal.	68
Water	11,000 gal.	58,68
Process solid wastes	140 lb (slag)	1
	140 lb (treatment sludge)	68
Process atmospheric emissions		
Particulates	20 lb	61
Carbon monoxide	4 lb	61
Waterborne wastes		58,68
Suspended solids	11 lb	
Acids	4 lb	
Oil	2 lb	
Chemicals	0.04 lb	

TABLE 59

DATA FOR FABRICATION OF ONE TON STEEL CAN CLOSURES

Materials	
Steel	2,300 lb
Coatings	
Solids	55 lb
Solvent	45 lb
Paper packaging	5 lb
Energy	
Natural gas	1,000 cu ft
Electricity	23 kwhr
Industrial Solid Wastes	45 lb
Process Atmospheric Emissions	45 lb
Hydrocarbons	
Transportation	
Rail	97 ton-miles
Truck	111 ton-miles
Water	11 ton-miles

Source: 68

TABLE 60

DATA FOR FILLING 1 MILLION 12-OUNCE CANS

Materials	
Packaging	
Plastic	1,940 lb
Other materials	2 lb
Energy	
Beer	
Coal	1.0 ton
Residual	150 gal.
Natural gas	55,000 cu ft
Electricity	2,000 kwhr
Soft drink	
Natural gas	15,000 cu ft
Electricity	1,700 kwhr
Solid Wastes	3,000 lb
Transportation	
Beer	
Rail	10,000 ton-miles
Truck	7,000 ton-miles
Soft drink	
Truck	125 gal. diesel
	400 gal. gasoline

Source: 68

K. Petroleum Products

Various petroleum products are utilized for solvents, petroleum coke and pitch, and for other uses in this study. For those products, a system has been derived using "refinery average" data. These data are summarized in Table 61, and on Table 51. The impacts of this system on the total can systems is quite small.

TABLE 61

DATA FOR 1,000 POUNDS PETROLEUM PRODUCT MANUFACTURE
(Crude Oil Refinery)

		Source
Energy of Material Resource		
(1,030 pounds crude oil)	18.54 million Btu	10
Energy		47
Electricity	50 kwhr	
Natural gas	3,000 cu ft	
Water	4,800 gal.	47
Atmospheric Emissions		47, 70
Particulates	0.35 lb.	
Hydrocarbons	3.1 lb	
Sulfur oxides	3.4 lb	
Aldehydes	0.05 lb	
Other organics	0.05 lb	
Ammonia	0.06 lb	
Waterborne Wastes		21,51,71
BOD	0.051 lb	
Phenol	0.014 lb	
Sulfides	0.018 lb	
Oil	0.03 lb	
COD	0.16 lb	
Suspended solids	0.09 lb	

CHAPTER V

ALUMINUM CANS

The basic data relating to the manufacture of aluminum beer cans are presented in this chapter. The conventional aluminum can system consists of primary rolled and drawn aluminum alloy cans. In addition, four systems using recycled aluminum cans are considered, at recycling levels of 25, 50, 75 and 100 percent.

Figure 18 shows the principal mining and manufacturing processes which are involved in the production of aluminum sheet and the material inputs. Twelve separate operations, including transportation are analyzed. Data relating to crude oil production and refining may be found in Chapter III, and discussions of limestone mining and lime manufacture appear in Chapter II. This chapter is divided into the following eight sections;

A. Overview
B. Bauxite Mining
C. Caustic Soda Manufacture
D. Refining of Alumina
E. Aluminum Smelting
F. Aluminum Rolling
G. Can Fabrication
H. Recycle Options

Filling and distribution of aluminum cans is essentially the same as for steel cans, so those impacts are found in Chapter IV. Waste disposal and packaging data are in Chapter II.

A. Overview

The computer reports for the aluminum can system are presented here. They are of three kinds. Table 62 compares the results for the four recycling options with the conventional system. Table 63 presents the results for 1 ton of conventional aluminum cans derived 15 percent from recycled cans. Table 64 summarizes the impacts for 1 ton of each operation.

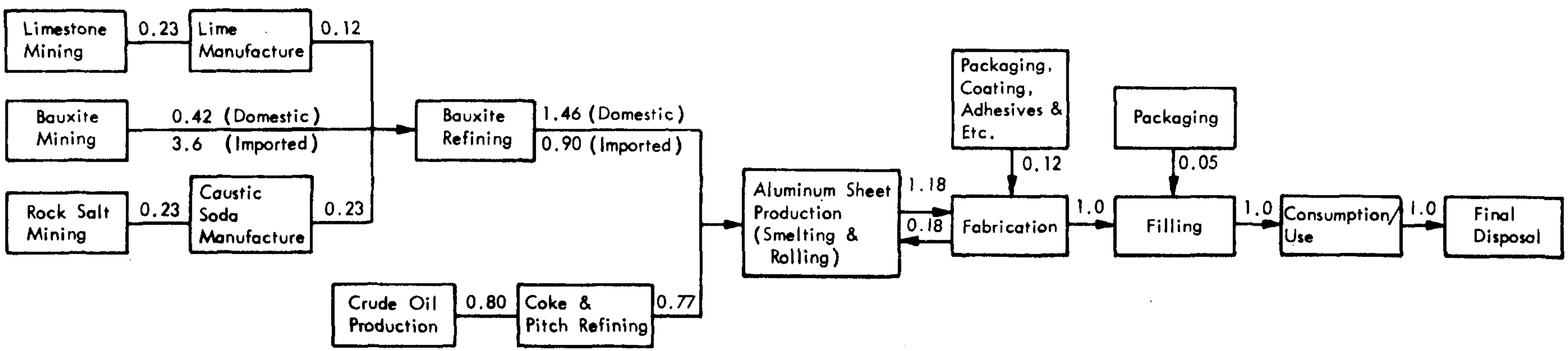

Figure 18 - Materials Flow for 1 Ton Virgin Aluminum Cans

TABLE 62

IMPACTS FOR 1 MILLION ALUMINUM CANS, 6 OPTIONS

NAME	UNITS	VIRGIN ALUMINUM	15 PCNT RECYCLE ALUMINUM	25 PCNT RECYCLE ALUMINUM	50 PCNT RECYCLE ALUMINUM	75 PCNT RECYCLE ALUMINUM	100 PCNT RECYCLE ALUMINUM
INPUTS TO SYSTEMS							
MATERIAL WOOD FIBER	POUNDS	2699.	2699.	2699.	2699.	2699.	2699.
MATERIAL LIMESTONE	POUND	10752.	9139.	8064.	5376.	2688.	0.
MATERIAL IRON ORE	POUND	0.	0.	0.	0.	0.	0.
MATERIAL SALT	POUND	10892.	9260.	8169.	5446.	2723.	0.
MATERIAL GLASS SAND	POUND	0.	0.	0.	0.	0.	0.
MATERIAL NAT SODA ASH	POUND	0.	0.	0.	0.	0.	0.
MATERIAL FELDSPAR	POUND	0.	0.	0.	0.	0.	0.
MATERIAL BAUXITE ORE	POUND	180055.	153047.	135041.	90027.	45014.	0.
MATERIAL PROCESS ADD	POUNDS	13278.	12019.	11182.	9086.	6989.	4893.
ENERGY PROCESS	MIL BTU	7054.	6223.	5675.	4296.	2917.	1536.
ENERGY TRANSPORT	MIL BTU	217.	222.	181.	145.	109.	73.
ENERGY OF MATL RESOURCE	MIL BTU	685.	589.	553.	421.	290.	158.
WATER VOLUME	THOU GAL	1585.	1416.	1308.	1030.	753.	475.
OUTPUTS FROM SYSTEMS							
SOLID WASTES PROCESS	POUND	15306.	14486.	13941.	12576.	11212.	9847.
SOLID WASTES FUEL COMB	POUND	12999.	11341.	10229.	7459.	4689.	1919.
SOLID WASTES MINING	POUND	263876.	225040.	199156.	134436.	69715.	4995.
SOLID WASTE POST-CONSUM	CUBIC FT	298.	258.	232.	166.	100.	34.
ATMOS PARTICULATES	POUND	5975.	5202.	4681.	3386.	2092.	796.
ATMOS NITROGEN OXIDES	POUND	6503.	5781.	5217.	3931.	2645.	1359.
ATMOS HYDROCARBONS	POUND	5267.	4800.	4469.	3670.	2871.	2073.
ATMOS SULFUR OXIDES	POUND	13324.	11631.	10470.	7617.	4763.	1909.
ATMOS CARBON MONOXIDE	POUND	3085.	2716.	2405.	1725.	1045.	365.
ATMOS ALDEHYDES	POUND	25.	23.	21.	16.	11.	7.
ATMOS OTHER ORGANICS	POUND	37.	34.	31.	25.	18.	12.
ATMOS ODOROUS SULFUR	POUND	22.	22.	22.	22.	22.	22.
ATMOS AMMONIA	POUND	3.	3.	3.	2.	1.	1.
ATMOS HYDROGEN FLOURIDE	POUND	62.	53.	46.	31.	15.	0.
ATMOS LEAD	POUND	1.	1.	0.	0.	0.	0.
ATMOS MERCURY	POUND	0.	0.	0.	0.	0.	0.
ATMOSPHERIC CHLORINE	POUND	43.	37.	32.	22.	11.	0.
WATERBORNE FLUORIDES	POUND	266.	226.	199.	133.	66.	0.
WATERBORNE DISS SOLIDS	POUND	1228.	1094.	1002.	775.	549.	322.
WATERBORNE BOD	POUND	234.	209.	193.	152.	111.	69.
WATERBORNE PHENOL	POUND	3.	2.	2.	1.	1.	0.
WATERBORNE SULFIDES	POUND	1.	1.	1.	1.	0.	0.
WATERBORNE OIL	POUND	386.	381.	378.	369.	361.	352.
WATERBORNE COD	POUND	2232.	1899.	1677.	1123.	568.	14.
WATERBORNE SUSP SOLIDS	POUND	392.	369.	354.	317.	279.	242.
WATERBORNE ACID	POUND	673.	586.	527.	382.	237.	92.
WATERBORNE METAL ION	POUND	185.	161.	144.	104.	63.	23.
WATERBORNE CHEMICALS	POUND	704.	610.	548.	391.	235.	79.
WATERBORNE CYANIDE	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE ALKALINITY	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE CHROMIUM	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE IRON	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE ALUMINUM	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE NICKEL	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE MERCURY	POUND	0.	0.	0.	0.	0.	0.
WATERBORNE LEAD	POUND	0.	0.	0.	0.	0.	0.
SUMMARY OF ENVIRONMENTAL IMPACTS							
RAW MATERIALS	POUNDS	217676.	186164.	165155.	112634.	60113.	7592.
ENERGY	MIL BTU	7956.	7034.	6409.	4862.	3316.	1769.
WATER	THOU GAL	1585.	1416.	1308.	1030.	753.	475.
INDUSTRIAL SOLID WASTES	CUBIC FT	3944.	3387.	3015.	2085.	1156.	226.
ATM EMMISSIONS	POUNDS	34347.	30303.	27397.	20446.	13496.	6546.
WATERBORNE WASTES	POUNDS	6303.	5539.	5026.	3749.	2471.	1194.
POST-CONSUMER SOL WASTE	CUBIC FT	298.	258.	232.	166.	100.	34.

TABLE 53

IMPACTS FOR 1 TON ALUMINUM CONTAINERS (15 PERCENT RECYCLE)

NAME	UNITS	BAUXITE MINING 6834 LBS	CAUSTIC SODA SYSTEM 386 LB	LIME SYSTEM 204 LB	PETROL PRODUCTS SYS 1196 LBS	BAUXITE REFINING 4012 LB	ALUMINUM SMELTING 1302 LB	ALUMINUM ROLLING 2360 LB	AL CLOSE FABRICA 546 LB	AL CAN BODY FABRICA 1463 LB	CAN FILLING AND PLAS CARRIER	PAPER PACKAGING 121 LB	TRANSPOR	DISPOSAL	RECYCLE AL FROM SCRAP
INPUTS TO SYSTEMS															
MATERIAL WOOD FIBER	POUNDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	120.500	0.000	0.000	0.000
MATERIAL LIMESTONE	POUND	0.000	0.000	408.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL IRON ORE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL SALT	POUND	0.000	413.406	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL GLASS SAND	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL NAT SODA ASH	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL FELDSPAR	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL BAUXITE ORE	POUND	0.000	0.000	0.000	0.000	6832.436	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL PROCESS ADD	POUNDS	0.000	6.186	0.000	2.316	280.840	63.070	92.276	22.302	51.246	3.582	8.506	0.000	0.000	6.000
ENERGY PROCESS	MIL BTU	1.853	3.540	.482	4.647	41.070	167.430	14.065	.548	32.358	8.033	1.733	0.000	0.000	1.627
ENERGY TRANSPORT	MIL BTU	.096	.004	.010	.143	0.000	0.000	0.000	0.000	0.000	1.190	.210	8.067	.109	.063
ENERGY OF MATL RESOURCE	MIL BTU	0.000	0.000	0.000	22.174	0.000	0.000	0.000	0.000	0.000	2.008	0.000	0.000	0.000	0.000
WATER VOLUME	THOU GAL	.094	1.502	.052	5.911	1.758	33.979	15.685	.009	.928	.313	1.798	.446	.007	.160
OUTPUTS FROM SYSTEMS															
SOLID WASTES PROCESS	POUND	0.000	4.546	37.210	.739	0.000	174.794	253.700	3.510	29.200	135.436	5.591	0.000	0.000	1.800
SOLID WASTES FUEL COMB	POUND	.766	9.688	.676	2.095	61.883	354.117	14.019	.705	42.133	8.728	7.734	1.784	.027	1.732
SOLID WASTES MINING	POUND	2.008	80.485	3.771	5.652	8793.742	964.142	38.177	1.919	114.733	31.849	4.917	0.000	0.000	4.514
SOLID WASTE POST-CONSUM	CUBIC FT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	13.301	-1.770
ATMOS PARTICULATES	POUND	23.104	2.052	6.674	.947	72.138	103.332	3.843	.155	9.252	3.616	3.565	1.214	.011	2.215
ATMOS NITROGEN OXIDES	POUND	1.222	3.589	.342	3.203	31.404	152.301	9.890	.414	24.512	12.204	1.240	16.015	.116	1.344
ATMOS HYDROCARBONS	POUND	1.645	1.426	.221	9.546	20.021	91.627	10.517	24.138	36.686	9.961	.631	5.712	.118	1.107
ATMOS SULFUR OXIDES	POUND	.874	9.064	.923	6.202	74.043	348.783	13.206	.662	39.577	11.402	4.682	7.242	.028	1.961
ATMOS CARBON MONOXIDE	POUND	.903	.451	.121	.788	5.851	88.215	1.666	.066	3.877	5.275	.531	12.080	1.117	.243
ATMOS ALDEHYDES	POUND	.013	.006	.001	.074	.121	.294	.025	.001	.058	.068	.010	.354	.009	.008
ATMOS OTHER ORGANICS	POUND	.037	.008	.002	.084	.119	.469	.053	.002	.113	.136	.013	.385	.096	.009
ATMOS ODOROUS SULFUR	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.978	0.000	0.000	0.000
ATMOS AMMONIA	POUND	.001	.000	.000	.072	.015	.001	0.000	0.000	0.000	.006	.001	.028	.000	.001
ATMOS HYDROGEN FLOURIDE	POUND	0.000	0.000	0.000	0.000	0.000	2.352	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ATMOS LEAD	POUND	.002	.000	.000	.000	.000	.000	0.000	0.000	0.000	.006	.000	.013	.002	.000
ATMOS MERCURY	POUND	.000	.004	.000	.000	.001	.006	.000	.000	.001	.000	.000	0.000	0.000	.000
ATMOSPHERIC CHLORINE	POUND	0.000	1.640	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE FLUORIDES	POUND	0.000	0.000	0.000	0.000	.981	9.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE DISS SOLIDS	POUND	.376	.281	.046	14.325	5.836	14.107	1.856	.065	3.845	2.224	.301	3.834	.058	.324
WATERBORNE BOD	POUND	.000	.001	.000	.061	3.300	2.484	.001	.000	.002	.614	2.463	.010	.000	.000
WATERBORNE PHENOL	POUND	.000	.000	.000	.017	.075	.007	.000	.000	.001	.001	.000	.003	.000	.000
WATERBORNE SULFIDES	POUND	.000	.000	.000	.022	.004	.008	.000	.000	.001	.001	.000	.004	.000	.000
WATERBORNE OIL	POUND	.000	.000	.000	.046	.145	1.100	15.458	.000	.001	.263	.000	.005	.000	.000
WATERBORNE COD	POUND	.001	.002	.000	.192	79.878	4.094	.003	.000	.009	.536	.003	.039	.001	.002
WATERBORNE SUSP SOLIDS	POUND	.001	.001	.000	.108	.024	6.390	8.415	.000	.005	.183	1.166	.025	.000	.151
WATERBORNE ACID	POUND	.039	.505	.042	.108	3.378	16.467	.731	.037	2.198	.465	.066	.007	.000	.087
WATERBORNE METAL ION	POUND	.010	.126	.011	.027	.844	5.249	.183	.009	.549	.116	.017	.002	.000	.022
WATERBORNE CHEMICALS	POUND	0.000	0.000	0.000	0.000	23.270	.476	3.505	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE CYANIDE	POUND	0.000	0.000	0.000	0.000	0.000	.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE ALKALINITY	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE CHROMIUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE IRON	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE ALUMINUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE NICKEL	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE MERCURY	POUND	0.000	.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE LEAD	POUND	0.000	.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SUMMARY OF ENVIRONMENTAL IMPACTS															
RAW MATERIALS	POUNDS	0.000	419.592	408.000	2.316	7113.276	63.070	92.276	22.302	51.246	3.582	129.005	0.000	0.000	6.000
ENERGY	MIL BTU	1.949	3.544	.492	26.964	41.070	167.430	14.065	.548	32.358	11.231	1.943	8.067	.109	1.690
WATER	THOU GAL	.094	1.502	.052	5.911	1.758	33.979	15.685	.009	.928	.313	1.796	.446	.007	.160
INDUSTRIAL SOLID WASTES	CUBIC FT	.038	1.280	.563	.115	119.551	21.156	4.130	.083	2.512	2.276	.246	.024	.000	.109
ATM EMMISSIONS	POUNDS	27.800	18.241	8.284	20.916	203.715	787.380	39.200	25.437	114.075	42.674	11.651	43.039	1.499	6.887
WATERBORNE WASTES	POUNDS	.427	.919	.099	14.697	117.734	61.691	30.153	.112	6.611	4.405	4.016	3.930	.060	.507
POST-CONSUMER SOL WASTE	CUBIC FT	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	13.301	-1.770

TABLE 64

IMPACTS FOR 1 TON OF EACH PROCESS FOR ALUMINUM SYSTEM

NAME	UNITS	BAUXITE MINING	CAUSTIC SODA SYSTEM	BAUXITE REFINING	ALUMINUM SMELTING	ALUMINUM ROLLING	ALUMINUM CAN BODY FAB	ALUMINUM CLOSURE FAB	ALUM RECYCLE
INPUTS TO SYSTEMS									
MATERIAL WOOD FIBER	POUNDS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL LIMESTONE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	471.056	0.000
MATERIAL IRON ORE	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL SALT	POUND	0.000	2142.000	0.000	0.000	0.000	0.000	477.709	0.000
MATERIAL GLASS SAND	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL NAT SODA ASH	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL FELDSPAR	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MATERIAL BAUXITE ORE	POUND	0.000	0.000	3406.000	0.000	0.000	0.000	8196.923	0.000
MATERIAL PROCESS ADD	POUNDS	0.000	32.050	140.000	70.000	78.200	70.200	595.681	40.000
ENERGY PROCESS	MIL BTU	.542	18.343	20.474	185.827	11.919	44.326	273.739	10.8[illegible]
ENERGY TRANSPORT	MIL BTU	.028	.022	0.000	0.000	0.000	0.000	4.637	.417
ENERGY OF MATL RESOURCE	MIL BTU	0.000	0.000	0.000	0.000	0.000	0.000	29.228	0.000
WATER VOLUME	THOU GAL	.028	7.780	.876	37.713	13.292	1.271	67.439	1.058
OUTPUTS FROM SYSTEMS									
SOLID WASTES PROCESS	POUND	0.000	24.070	0.000	194.000	215.000	40.000	519.994	32.000
SOLID WASTES FUEL COMB	POUND	.230	50.198	30.849	393.026	11.881	57.716	525.840	11.545
SOLID WASTES MINING	POUND	.588	417.022	4383.720	1070.080	32.353	157.168	11830.042	30.094
SOLID WASTE POST-CONSUM	CUBIC FT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-11.800
ATMOS PARTICULATES	POUND	6.761	19.634	35.961	114.666	3.257	12.674	250.948	14.744
ATMOS NITROGEN OXIDES	POUND	.358	18.596	15.655	169.036	8.382	33.578	243.241	8.960
ATMOS HYDROCARBONS	POUND	.481	7.387	9.981	101.695	8.912	50.255	251.456	7.380
ATMOS SULFUR OXIDES	POUND	.256	46.965	36.911	387.107	11.191	54.215	533.504	13.971
ATMOS CARBON MONOXIDE	POUND	.264	2.339	2.917	97.908	1.412	5.310	139.582	1.620
ATMOS ALDEHYDES	POUND	.004	.033	.061	.326	.021	.079	.940	.053
ATMOS OTHER ORGANICS	POUND	.011	.042	.059	.521	.045	.155	1.939	.0[illegible]
ATMOS ODOROUS SULFUR	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ATMOS AMMONIA	POUND	.000	.000	.008	.001	0.000	0.000	.122	.005
ATMOS HYDROGEN FLOURIDE	POUND	0.000	0.000	0.000	2.610	0.000	0.000	2.744	0.000
ATMOS LEAD	POUND	.001	.000	.000	.000	0.000	0.000	.070	.000
ATMOS MERCURY	POUND	.000	.019	.001	.006	.000	.001	.013	.000
ATMOSPHERIC CHLORINE	POUND	0.000	6.500	0.000	0.000	0.000	0.000	1.894	[illegible]
WATERBORNE FLUORIDES	POUND	0.000	0.000	.489	10.100	0.000	0.000	11.796	[illegible]
WATERBORNE DISS SOLIDS	POUND	.110	1.455	2.909	15.657	1.573	5.257	47.526	2.160
WATERBORNE BOD	POUND	.000	.003	1.645	3.201	.001	.003	7.413	.003
WATERBORNE PHENOL	POUND	.000	.001	.037	.007	.000	.001	.122	[illegible]
WATERBORNE SULFIDES	POUND	.000	.001	.002	.009	.000	.001	.047	[illegible]
WATERBORNE OIL	POUND	.000	.001	.072	1.220	13.100	.002	16.466	.032
WATERBORNE COD	POUND	.000	.011	33.819	4.543	.002	.012	100.914	.013
WATERBORNE SUSP SOLIDS	POUND	.000	.007	.012	7.092	7.132	.008	15.061	1.005
WATERBORNE ACID	POUND	.011	2.618	1.684	20.496	.620	3.010	27.245	.579
WATERBORNE METAL ION	POUND	.003	.654	.421	5.826	.155	.753	7.562	.145
WATERBORNE CHEMICALS	POUND	0.000	0.000	11.600	.528	2.970	0.000	31.983	0.000
WATERBORNE CYANIDE	POUND	0.000	0.000	0.000	.011	0.000	0.000	.011	[illegible]
WATERBORNE ALKALINITY	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	[illegible]
WATERBORNE CHROMIUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE IRON	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE ALUMINUM	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE NICKEL	POUND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WATERBORNE MERCURY	POUND	0.000	.000	0.000	0.000	0.000	0.000	.000	0.000
WATERBORNE LEAD	POUND	0.000	.012	0.000	0.000	0.000	0.000	.003	0.000
SUMMARY OF ENVIRONMENTAL IMPACTS									
RAW MATERIALS	POUNDS	0.000	2174.050	3546.000	70.000	78.200	70.200	9743.369	40.000
ENERGY	MIL BTU	.570	18.365	20.474	185.827	11.919	44.326	307.604	11.267
WATER	THOU GAL	.028	7.780	.876	37.713	13.292	1.271	67.439	1.058
INDUSTRIAL SOLID WASTES	CUBIC FT	.011	6.632	59.597	22.371	3.500	3.441	173.757	.72-
ATM EMMISSIONS	POUNDS	8.136	94.515	101.553	873.896	33.221	156.267	1426.460	45.913
WATERBORNE WASTES	POUNDS	.125	4.763	58.691	68.691	25.553	9.056	267.701	3.912
POST-CONSUMER SOL WASTE	CUBIC FT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-11.800

Table 63 summarizes all operations for 1 ton of cans. All the operations and systems listed refer to the production of the can cylinder, closure and associated packaging. It is clear that the steps of bauxite refining and aluminum smelting dominate the environmental impact profile of the aluminum can system.

Table 64 is a printout for 1 ton of product from each operation. Its purpose is to convert raw data into environmental profiles for each step. Data for 1 ton of each operation are presented in the following sections of this chapter.

Table 62 compares the impacts for the conventional aluminum can system with five hypothetical recycle levels. These are discussed in Section H.

B. Bauxite Mining

Aluminum is the most widely distributed metal in the earth's crust, with only the nonmetallic elements oxygen and silicon surpassing it in abundance. However, bauxite ore is at the present time the only commercially exploited source of aluminum. Although other types of earth, including ordinary clay, contain aluminum, industry economics favor bauxite as the preferred ore.

Bauxite is formed by the action of rain and erosion on materials containing aluminum oxide (alumina). The heavy rainfall and warm temperatures of the tropics provide the most nearly ideal conditions for this process, and most of the world's bauxite is mined in these regions. Although the United States is the world's largest consumer of bauxite, nearly 90 percent of the bauxite used here is imported.

Most bauxite is mined by open-pit methods. In Jamaica, the leading producer of bauxite, the ore lies close to the surface, and only the vegetation and topsoil need to be stripped. In Arkansas, the top domestic producing region, open-pit mining is also used, with stripping ratios of 10 feet of overburden to 1 foot of ore considered minable. Underground mining is employed at one location in Arkansas, and this method is the most common in Europe.[95]

Table 65 presents the data relating to the mining of 1 ton of bauxite ore, based on domestic data.

TABLE 65

DATA FOR THE MINING OF 1 TON BAUXITE ORE

		Source
Energy		89
Distillate	0.122 gal.	
Residual	0.0737 gal.	
Gasoline	0.194 gal.	
Natural gas	398 cu ft	
Electric	7.03 kwhr	
Water Volume	15.7 gal.	90
Atmospheric Emissions		
Particulates	6.7 lb	52
Transportation		67,86
Truck	10 ton-miles	
Barge[a]	950 ton-miles	

a/ Domestic transportation of imported ore.

It is clear that the environmental impacts of bauxite mining are relatively small. This is evident upon examination of Table 63 which indicates that mining of bauxite accounts for quite low levels of impacts of the aluminum can system.

Mining solid wastes which are often associated with ore mining are not included here, but are instead counted in the refining operation, where they show up either as suspended solids in wastewater effluents or as solid wastes.

C. Caustic Soda Manufacture

The refining of bauxite ore to alumina employs strong caustic soda solutions. The major raw material for caustic soda is salt, and it is assumed here that this is obtained by the mining of rock salt. Rock salt mines are widely distributed throughout the United States, with 17 states reporting production in 1969.[97]

Data pertaining to the mining of 1 ton of rock salt are presented in Table 66.

TABLE 66

DATA FOR THE MINING OF 1 TON ROCK SALT

		Source
Energy		84
Residual	0.11 gal.	
Gasoline	0.01 gal.	
Natural gas	168 cu ft	
Electric	85 kwhr	
Water Volume	521 gal.	84
Mining Wastes	262 lb	68
Transportation		68
Rail	300 ton-miles	
Truck	50 ton-miles	

Caustic soda (sodium hydroxide) is manufactured from salt by an electrolytic process. The aqueous sodium hydroxide solution is electrolyzed to produce caustic soda, chlorine, and hydrogen gas. The chlorine and caustic soda each account for about half the output of the process, with hydrogen amounting to only 1 percent by weight. Therefore, half the impacts of the process are allocated to chlorine production and half to caustic soda production. The chlorine is a useful product in other manufacturing processes, so its impacts are not included in the aluminum can system. The impacts allocated to caustic soda manufacture are presented in Table 67.

TABLE 67

DATA FOR THE MANUFACTURE OF 1,000 POUNDS CAUSTIC SODA

		Source
Virgin Raw Materials		12,68
Salt	1,071 lb	
Process additives	16 lb	
Energy - Electric	722 kwhr	12,68
Water Volume	3,475 gal.	11
Process Solid Wastes	12 lb	68
Process atmospheric emissions		
Chlorine	4.25 lb	68
Mercury	0.009 lb	68
Waterborne Wastes		68
Lead	0.006 lb	
Mercury	0.00013 lb	
Dissolved solids	0.2 lb	

D. Refining of Alumina

Before it can be used in the manufacture of metallic aluminum, bauxite ore must be refined to nearly pure aluminum oxide, Al_2O_3, usually called alumina. The method used to accomplish this is called the Bayer process, which is used almost exclusively. The bauxite is crushed and dissolved in digesters, using strong caustic soda and lime solutions. The undissolved residue, known as red mud, is filtered out and constitutes a major disposal problem for alumina refiners. Sodium aluminate remains in solution, where it is hydrolyzed and precipitated as aluminum hydroxide, which is then calcined to alumina, generally in a rotary kiln.

The data for bauxite refining (Table 63) indicate that solid wastes constitute the largest part of the environmental profile. This category consists largely of mining wastes, the roughly 45 percent of bauxite that is discarded after the sodium aluminate is removed in solution. The manner in which wastes are handled determines whether they show up as waterborne wastes or as solid wastes. If these red muds are simply discharged into a river, they are of course a major water pollutant. However, we have assumed that in the near future, all of these wastes will be impounded in settling ponds, where they end up as solid wastes on land. The figures used in the present study are based on data reflecting this assumed future practice. Current industry projections call for reductions of as much as 97 percent in the waterborne wastes of alumina plants by mid-1975.[81/]

Impact data for alumina refining are presented in Table 68.

TABLE 68

DATA FOR THE PRODUCTION OF 1 TON OF REFINED ALUMINA

		Source
Virgin Raw Materials		35,97
Bauxite	3,046 lb	
Other	140 lb	
Energy		83
Coal	0.140 ton	
Distillate	6.56 gal.	
Residual	12.2 gal.	
Natural gas	5,400 cu ft	
Electric	700 kwhr	
Water Volume	479 gal.	68
Mining Solid Wastes	3,722 lb	68
Atmospheric Emissions		
Particulates	24.4 lb	52
Waterborne Wastes		70,71,74,76
BOD	1.64 lb	
COD	39.8 lb	
Chemicals	11.6 lb	
Fluorides	0.489 lb	
Oil and grease	0.0698 lb	
Phenols	0.0356 lb	
Transportation		68
Rail	600 ton-miles	
Barge	600 ton-miles	
Truck	68 ton-miles	

E. Aluminum Smelting

The reduction of refined alumina to metallic aluminum results in the largest environmental impact of any process in the production of aluminum cans. When both the can body and the top are considered, smelting operations lead all other subsystems in three of the seven categories.

The principal cause of the high environmental impacts associated with aluminum smelting is the high consumption of electrical energy required to effect the separation of aluminum from its oxide. The process is carried out in a long series of electrolytic cells, carrying direct current. The alumina is dissolved in a molten bath of cryolite and aluminum fluoride. Carbon anodes carry the current to the solution, and a carbon cathode lining carries the current out of the solution and on to the next cell. The anodes are consumed during the reaction at a rate of approximately 0.75 ton of material per ton of aluminum produced. The principal products of the reaction are carbon dioxide, which is evolved as a gas, and elemental aluminum which settles to the bottom of the cell and is periodically drained off.

Although there are significant pollution problems at the smelter site, most of the impacts in the categories of atmospheric emissions, waterborne wastes, and solid wastes result from the generation of electricity and the mining of coal for fuel in electrical generation. It is clear, therefore, that the extremely high electrical requirement is the overriding environmental concern in aluminum smelting operations.

The emission factors for electrical generation--which are used for every system in this study--are based on a national average mix of fuels for electrical generation, including hydroelectric power. It is true that the aluminum industry uses a relatively high proportion of hydroelectric power. It is our judgment, however, that a study such as this should not distinguish between different "kinds" of kilowatt hours, since if the hydroelectric power were not used by the aluminum industry, it would be available as an alternative to power generated with fossil fuels. In cases where electricity is generated by the aluminum companies for captive use in their plants, the power is not included in the electrical energy category. Rather, the fuels used to generate that power are included separately; and, in this latter case of self-generated power, full credit is given for hydroelectric generation to the extent it occurs.

The primary pollution problem at the smelter site is fluoride emissions from the cryolite baths. These occur as both particulate and gaseous atmospheric emissions, and as waterborne wastes. Carbon monoxide, while constituting a greater weight percent of the emissions, is of a lower order of toxicity and of secondary concern to smelter operators.

A newly developed process is said to be able to produce aluminum with about 30 percent less power, while eliminating fluoride emissions altogether. It would still use an electrolytic process, but the alumina would first be converted to aluminum chloride. The products of the electrolysis would be molten aluminum and chlorine, which would then be reused in the chlorination step. Although the new process appears to hold promise for the long run, there is not indication that it will have a significant effect on the industry's practices in the foreseeable future.[17/]

The data used in calculating the environmental impacts of aluminum smelting are presented in Table 69.

TABLE 69

DATA FOR THE SMELTING OF 1 TON OF ALUMINUM

		Source
Virgin Raw Materials[a/]		
Process additives	70 lb	35
Energy		83
Distillate	0.465 gal.	
Residual	1.37 gal.	
Natural gas	40,000 cu ft	
Electric	12,800 kwhr	
Water Volume	34,800 gal.	76
Solid Wastes	194 lb	58,68
Atmospheric Emissions		76
Particulates	30.6 lb	
HF gas	2.61 lb	
SO_x	18.8 lb	
Hydrocarbons	4.19 lb	
CO	75.0 lb	
NO_x	1.36 lb	
Waterborne Wastes		76
Suspended Solids	7.04 lb	
Fluorides	10.1 lb	
BOD	3.18 lb	
COD	4.46 lb	
Cyanide	0.0107 lb	
Ammonia	0.528 lb	
Metal ions	0.702 lb	
Oil and grease	1.21 lb	

a/ Coke and pitch production, for anode manufacture, is counted as a separate system. See data for refinery products in Chapter III.

F. Aluminum Rolling

Aluminum ingots from the smelter, along with some new scrap aluminum, are processed by rolling mills into aluminum alloy sheet. The alloying materials, mainly magnesium, are assumed to be added at the rate of less than 2 percent of the material input. The scrap used here is not postconsumer scrap, but is industrial scrap, usually from can fabricating plants. The post-consumer scrap considered in the recycle options in Section I is in addition to the new scrap normally used in conventional aluminum cans. Table 70 contains the data for rolling 1 ton of sheet for use in aluminum can bodies and tops.

TABLE 70

DATA FOR THE ROLLING OF 1 TON ALUMINUM SHEET

		Source
Virgin Raw Materials		68
Process Additives (alloying materials and lubricating oils)	78.2 lb	
Energy		68
Natural Gas	7,020 cu ft	
Electricity	387 kwhr	
Water Volume	13,100 gal.	68
Atmospheric Emissions		52
Particulates	0.594 lb	
Solid Wastes	215 lb	68
Waterborne Wastes		
Suspended Solids	7.13 lb	68
Phosphates	2.97 lb	
Oils and Grease	13.1 lb	
Transportation		68
Rail	1,420 ton-miles	
Truck	12.5 ton-miles	

G. Can Fabrication

The aluminum can body, which forms the sides and bottom of the container, is drawn from a single piece of aluminum sheet. The can top, also made from aluminum sheet, does not have to be drawn, and its fabrication therefore requires substantially less energy than does the can body. The can top and can body are not joined at the fabricating plant, but rather at the filling plant, after the beverage is in the can.

Tables 71 and 72 contain the basic data for the fabrication of the aluminum can body and top, respectively.

TABLE 71

DATA FOR THE FABRICATION OF 1 TON ALUMINUM CAN BODIES

Virgin Raw Materials	
Process additives	70.2 lb
Packaging	121 lb
Energy	
Natural gas	21,600 cu ft
Electricity	1,880 kwhr
Water Volume	563 gal.
Atmospheric Emissions	
Hydrocarbons	19.8 lb
Solid Wastes	40 lb
Transportation	
Truck	110 ton-miles
Rail	97 ton-miles
Barge	11 ton-miles

Source: 68

TABLE 72

DATA FOR THE FABRICATION OF 1 TON ALUMINUM CLOSURES

Virgin Raw Materials	
Process Additives	82.6 lb
Packaging	11.6 lb
Energy	
Natural Gas	1,000 cu ft
Electricity	85 kwhr
Atmospheric Emissions	
Hydrocarbons	88 lb
Solid Wastes	13 lb

Source: 68

H. Recycle Options

Considerable environmental gains can be made by using recycled aluminum as opposed to virgin aluminum used in a product. Table 73 summarizes the environmental data for a secondary smelter recycling aluminum cans. Included are operations for shredding and transporting the cans to a smelter as well as smelter data. A credit is given for the removal of the cans from the solid waste stream.

Two important assumptions have been made which make this recycling profile more favorable to aluminum recycling than for other situations. One assumption is that the cans are carried back to a grocery store and further carried on to processors by backhaul trucks. Thus, the cans are assumed to ride "piggy back" on transportation already occurring for another purpose. For voluntary collection centers where cars may be driven long distances for the sole purpose of delivering cans, this is not true. Some details concerning this possibility can be found in Volume I.

The second assumption is that the scrap recycled is "clean" cans. If significant impurities and alloying materials are present in aluminum scrap, then the impacts of smelting are greater. Highly corrosive and environmentally damaging materials such as chlorine may be required, as well as higher energy requirements. Much more serious air pollution can result, as well as considerably more solid waste. Thus, the recycling options considered here probably represent a "most favorable" situation for aluminum recycling.

TABLE 73

DATA FOR RECYCLING ONE TON ALUMINUM FROM CLEAN SCRAP

Materials	
Fluxes	40 lb
Energy	
Distillate	5.7 gal.
Residual	5.3 gal.
Natural gas	4,651 cu ft
Electricity[a/]	360 kwhr
Water	800 gal.
Industrial Solid Wastes	12 lb
Post-Consumer Solid Waste[b/]	-2,000 lb
Atmospheric Emissions	
Particulates	12 lb
Waterborne Wastes	
Suspended Solids	1 lb
Transportation	
Rail	500 ton-miles

a/ Includes 250 kwhr for shredding cans.
b/ This represents 2,000 lbs of cans removed from the solid waste stream.
Source: 68,83

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