Life Cycle Design of Milk and Juice Packaging

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E. Timothy Oppelt, Director
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III. ABSTRACT

A life cycle design demonstration project was initiated between the U.S. Environmental Protection Agency National Risk Management Research Laboratory, Dow Chemical Company, and the University of Michigan to investigate the design of milk and juice packaging. The primary objective of this project was to develop design metrics and guidelines for environmental improvement of milk and juice packaging systems. Both refillable and single use systems including polycarbonate, HDPE and glass bottles; gable top and aseptic cartons; steel and composite cans; as well as flexible pouches were studied using previously published life cycle inventory data. Material production energy accounted for a large portion of the total life cycle energy for these systems. Conversely, postconsumer waste was responsible for a majority of their life cycle solid waste generation. Packaging systems were also evaluated with respect key performance criteria, life cycle costs, and regulatory trends at the local, state and national levels. Environmentally preferable containers were identified, and tradeoffs and correlations between design criteria were highlighted.

This report was submitted in partial fulfillment of Cooperative Agreement number CR822998-01-0 by the National Pollution Prevention Center at the University of Michigan under the sponsorship of the U.S. Environmental Protection Agency. This work covers a period from November 1, 1994 to August 30, 1996 and was completed as of September, 1996.

IV. CONTENTS

V. ACKNOWLEDGMENTS

We wish to thank Scott Noesen, Environmental Performance Manager and John Difazio, Environmental Business Development Director for Dow Plastics for initiating this life cycle design project with the National Pollution Prevention Center. Mr. Noesen was responsible for leading the Dow Project Team and contributed valuable input for advancing life cycle design principles and tools. We also wish to thank other members of the Dow Project Team for their participation. Joe Ceraso was very helpful in providing life cycle inventory data. Tony Kingsbury kindly provided us with information on packaging regulatory issues. Greg Jozwiak helped us identify sources for market data and performance data which were used in this study.

1. Project Description

1.1 Introduction

Integration of environmental considerations into the design process represents a complex challenge to designers, managers and environmental professionals. A logical framework including definitions, objectives, principles and tools is essential to guide the development of more ecologically and economically sustainable product systems. In 1991, the US. Environmental Protection Agency collaborated with the University of Michigan to develop the life cycle design framework [1-3]. This framework is documented in two publications: Life Cycle Design Guidance Manual [1] and the Life Cycle Design Framework and Demonstration Projects [3].

Two demonstration projects evaluating the practical application of this framework have been conducted with AlliedSignal and AT&T. AT&T applied the life cycle design framework to a business phone [4] and AlliedSignal investigated heavy duty truck oil filters [5]. In these projects environmental, performance, cost and legal criteria were specified and used to investigate design alternatives. A series of new demonstration projects with Dow Chemical Company, Ford Motor Company, General Motors Corporation, United Solar and 3M Corporation have been initiated with Cleaner Products through Life Cycle Design Research Cooperative Agreement CR822998-01-0. Life cycle assessment and life cycle costing tools are applied in these demonstration projects in addition to establishing key design requirements and metrics. This report provides a description of the Dow Chemical Packaging project that investigated the life cycle design of milk and juice containers. An overview of the life cycle design framework is provided in Appendix C of this document.

1.2 Project Origin/Team

The life cycle design (LCD) research group at the National Pollution Prevention Center (NPPC) established a collaborative relationship with Dow Chemical over a 2-year period before proposing this project. During this time, several meetings were held to discuss the life cycle design framework. In the spring of 1994, Greg Keoleian, Manager of the NPPC, proposed to Scott Noesen, Environmental Performance Manager of Dow Chemical Plastics Division, that the NPPC and Dow collaborate on the Cleaner Products Through Life Cycle Design project. Dow Chemical was interested in testing the applicability of the life cycle design framework and thus agreed to participate in the study.

The project team for Dow consisted of representatives from market development, environmental management and business development. Scott Noesen served as project coordinator for the Dow team. Dow assisted the NPPC by narrowing the project scope and providing life cycle data sources and contacts. Researchers at the NPPC conducted the study. Members of the Dow team helped monitor project progress and review research results in a series of meetings. Core participants from both Dow and the NPPC were:

National Pollution Prevention Center
- Greg Keoleian, Center Manager
- David Spitzley, Research Assistant

Jeff McDaniel, Research Assistant
Dow Chemical Company Plastics Division
Scott Noesen, Environmental Performance Manager
Tony Kingsbury, Environmental Programs Manager
Joe Ceraso, Project Manager
Greg Jozwiak, Market Development Manager
John Difazio, Environmental Business Development

This work was sponsored by the National Risk Management Research Laboratory (NRMRL) of the U.S. Environmental Protection Agency. Since 1990, NRMRL has been at the forefront of development of Life Cycle Assessment as a methodology for environmental assessment. In 1994, NRMRL established an LCA team to organize individual efforts into a comprehensive research program. In addition to project reports, the LCA team has published guidance manuals, including "Life Cycle Assessment: Inventory Guidelines and Principles (EPA/600/R-92/245)" and "Life Cycle Design Guidance Manual (EPA/600/R-92/226)".

1.3 Significance

Dow Chemical is a major supplier of plastic resins to the packaging industry. Dow identified packaging as an area of concern because 31.6% of all municipal solid waste is composed of packaging and related material [6]. Improved packaging thus offers opportunities for significant reductions in household solid waste. Life cycle analysis was recognized as an essential tool for this study because focusing solely on postconsumer waste reduction is limited in scope.

Container systems for the milk and juice market have changed from glass refillable bottles to coated paperboard, which dominated the market in the '50s and '60s, to HDPE jugs, which are the current market leader [7]. Thus, history suggests that significant changes in beverage delivery systems are possible; such future changes might offer the opportunity for improved environmental performance.

1.4 Objectives

General objectives for the Cleaner Products through Life Cycle Design project include:

- Developing environmental metrics for evaluating cleaner products
- Using multicriteria matrices to develop and prioritize model design requirements
- Selecting design strategies that reduce environmental burdens and meet critical performance, cost and legal requirements

The National Pollution Prevention Center and Dow Chemical collaborated on this project to enhance Dow's decision making and strategic planning capabilities in the production and marketing of plastic resins for milk and juice packaging. Specific objectives of this study include:

- Applying the life cycle design framework in a comparative assessment of packaging systems
- Identifying and evaluating key criteria and metrics that influence the economic and ecological sustainability of alternative packaging systems and performing tradeoff analyses

2. Systems Analysis

2.1 Scope and Boundaries

This study considered the life cycle aspects of both milk and juice packaging for sale to households. In studying delivery of fresh dairy milk, it was assumed that the composition (whole, skim, etc.) of milk would not affect analysis of the various container systems. Other milk types, such as dehydrated and soy, were not considered, although these types of milk can be shelf stable and therefore may have benefits in terms of energy use and long-term storage. The choice of fresh dairy milk was not meant to dismiss various alternatives but rather to focus on the type of milk most often used in households today.

Delivery of orange juice from concentrate was the only juice packaging system studied. This degree of specificity was necessary due to the wide variety of juice types and derivatives available. Reconstituted orange juice was selected based on its availability in several container types and its widespread distribution in grocery and convenience stores. Delivery systems for frozen orange juice concentrate were also considered.

Systems for delivering milk and juice to on-site users, such as school lunch programs, were not included in this study. Although on-site use is much more standardized than household delivery, the findings of this study should also generally apply. However, on-site use will probably result in much higher reuse/recycle rates for all materials because disposition can be more easily controlled.

This study does not address impacts associated with beverage production. We assumed that any differences in juice or milk production methods do not affect the container life cycle.

2.2 Product Selection

Products for this study were selected based on available information, Dow core team advice and NPPC experience. Noncarbonated beverage containers were selected because many of these packages are manufactured with resins produced by Dow. Milk and juice containers were selected for study because public information from many previous life cycle studies was readily available. In addition, consumer demand for these products is substantial: in 1993 over 150 billion gallons of milk were sold in the US [8]. As of 1990, high-density polyethylene (HDPE) dominated the milk container market with a 68% share while paperboard (gable top) commanded 32% of the market; all other milk containers had a less than 1% share [8]. Table 2-1 shows which beverage systems and container sizes are included in this study.

Table 2-1. Beverage Delivery Systems Examined

Container	Juice (size examined)	Milk (size examined)
Glass Bottle	1 L	0.5/1.0 gal
HDPE Bottle	0.5 gal	0.5/1.0 gal
Paperboard Gable Top	0.5 gal	0.5/1.0 gal
Flexible Pouch	N/I	0.5 gal
Polycarbonate Bottle	0.5 gal	0.5 gal
Steel Can	46 oz	N/I
Composite Can	48 oz	N/I
PET Bottle	2 L	N/I
Aseptic Carton	1 L	N/I

N/I - Not Investigated: Either the package is not used for the given beverage or life cycle information was unavailable.

2.3 Product Composition and Description

A total of nine different container types were included in this study. Containers and their volumes, weights and composition are summarized in Table 2-2.

Flow sheets for these container systems appear in Figures 2-1 to 2-9. Container volume was limited to multiple-serving containers commonly selected for household use. This was done in an attempt to compare relatively equivalent systems.

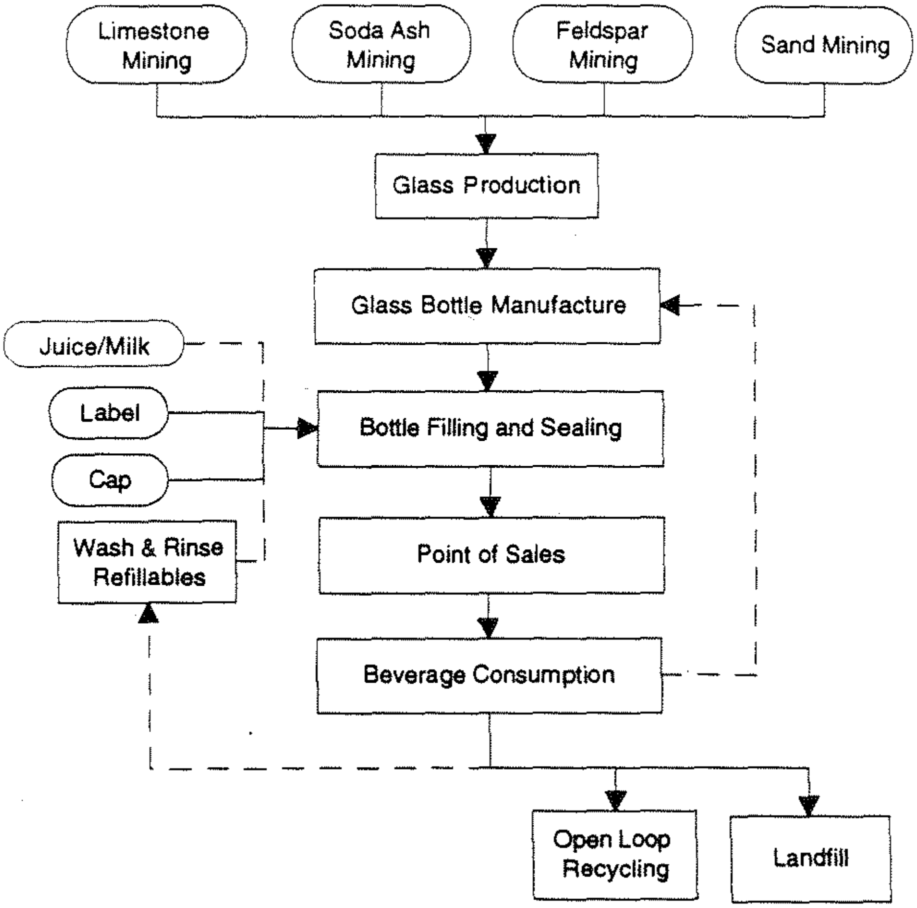
These diagrams only show the general flow of materials; they provide an overall view of which steps are included in the life cycles studied. Many of these containers also require other raw materials for their production, and some have alternative manufacturing scenarios.

Table 2-2. Container Systems Examined

Container		Volume	Weight	Composition	Data Source
Glass Bottle					
	refillable	0.5 gal	923.0 g	921 g glass, 2.3 g paper	[9]
		1.0 gal	1464.0 g	1452 g glass, 10 g handle, 2.3 g paper	[9]
		1.0 L	679.0 g	NA	[10]
	single use	0.5 gal	559.0 g	555 g glass, 3.9 g steel	NPPC
		1.0 L	408.2 g	NA	[10]
HDPE Bottle					
	refillable	0.5 gal	134.0 g	131.7 g HDPE, 2.3 g paper	[9]
		1.0 gal	168.0 g	165.7 g HDPE, 2.3 g paper	[9]
	single use	0.5 gal	45.2 g	44.6 g HDPE, 0.6 g label	[11]
		1.0 gal	64.2 g	63.6 g HDPE, 0.6 g label	[11]
Paperboard Gable					
	single use	0.5 gal	64.5 g	57.4 g paper, 7.1 g LDPE	[11]
		1.0 gal	113.0 g	101.7 g paper, 11.3 g LDPE	[11]
Flexible Pouch					
	single use	0.5 gal	10.4 g	8.3 g LLDPE, 2.1 g LDPE	NPPC
Polycarbonate Bottle					
	refillable	0.5 gal	121.9 g	119.1 g PC, 2.8 g cap	[7]
Steel Can					
	single use	46 oz.	162.3 g	156.8 g steel, 5.5 g label	[12]
Composite Can					
	single use	12 oz.	31.5 g	22.8 g paper, 8.7 g steel	[12]
PET Bottle					
	single use	2.0 L	60.6 g	57.5 g PET, 3.1 g cap	[12]
Aseptic Carton					
	single use	1.0 L	31.4 g	NA	[10]

Glass Bottle

The life cycle flow sheet for glass bottles as examined in this study is shown in Figure 2-1. The bottles examined had either paper or steel caps; in either case the impacts associated with the production of closures were included in the reported data. Both refillable and single-use glass bottles were examined. Refillable container systems require fewer containers for delivery of an equivalent volume. However, there are additional impacts associated with the washing process.



source:[9]

Figure 2-1. Life Cycle Flow Sheet for Glass Bottles

High-Density Polyethylene (HDPE) Bottle

HDPE jugs are the most popular milk delivery container by beverage volume on the market today and have almost complete control of the one-gallon market [7]. In figure 2-2, bottle formation and filling are shown as though they occur separately; in fact about 50% of HDPE bottles are blow molded in-house by dairies. The percentage of in-house blow molding used in the studies that served as data sources was unknown.

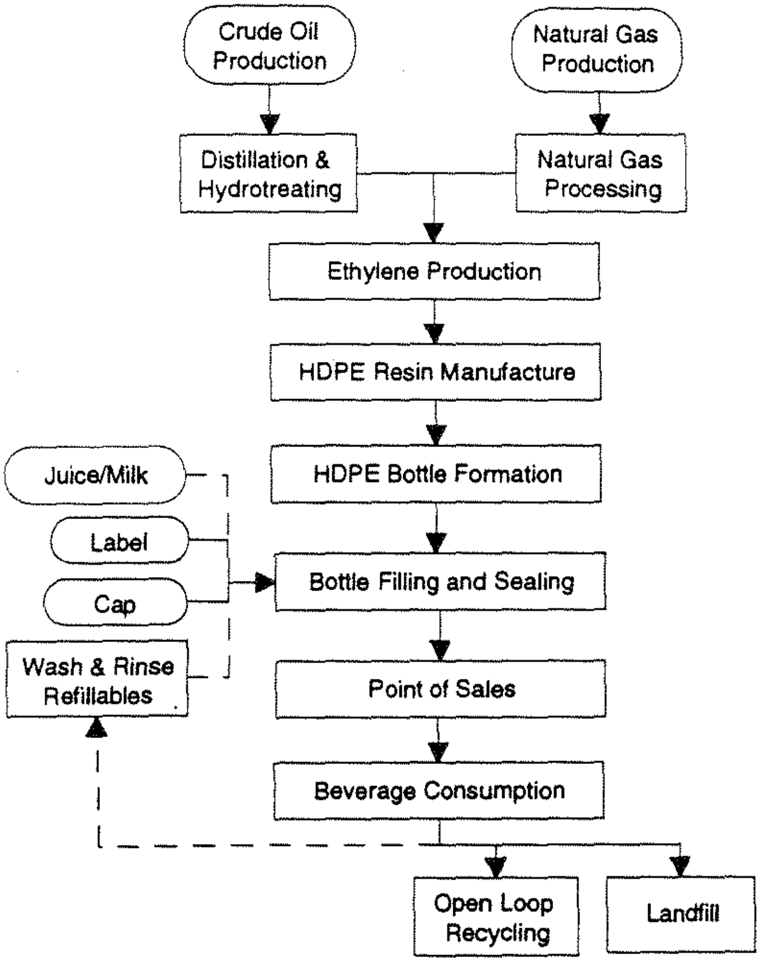


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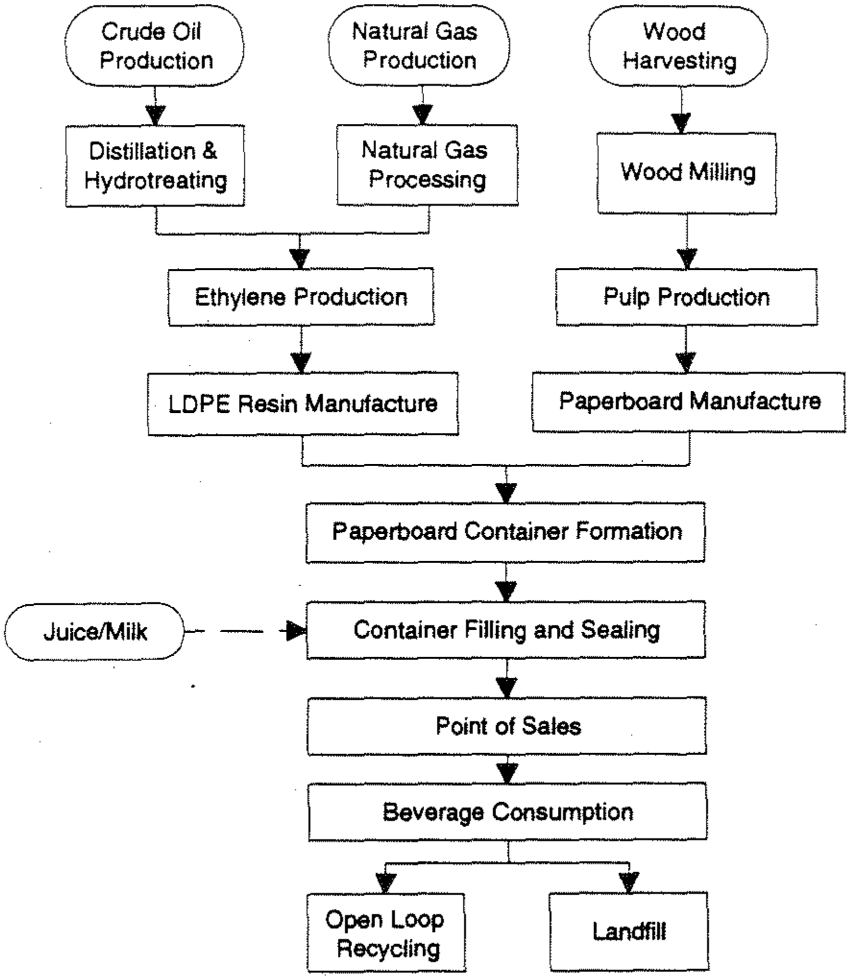
Figure 2-2. Life Cycle Flow Sheet for High Density Polyethylene Bottles

Paperboard Gable Top Carton

Paperboard gable top cartons are made from bleached paperboard which generally does not contain postconsumer recycled fiber. Our assumptions for this study match current practice - no postconsumer recycled content from beverage containers. Paperboard used to manufacture milk and juice containers is coated on both sides with low-density polyethylene (LDPE). Cartons are produced by fabricators and shipped flat to the fillers. Filling equipment for paperboard containers folds, seals and fills the cartons. Figure 2-3 shows this process.



source: [11]

Figure 2-3. Life Cycle Flow Sheet for Paperboard Gable Top Cartons

Flexible Pouch

The flexible pouch examined in this study is made from a mixture of LLDPE (linear, low-density polyethylene) and LDPE. The flow sheet shown in Figure 2-4 and the data given in Table 2-1 are the result of conversations with various industry representatives. Because the pouch system is a form, fill and seal operation, container conversion and filling always occur at one location. Impacts associated with the 195-gram HDPE pitchers used to facilitate pouring from the pouch are not included in this study. The current lifetime of one of these pitchers causes its impacts to be negligible compared to those of the pouch.

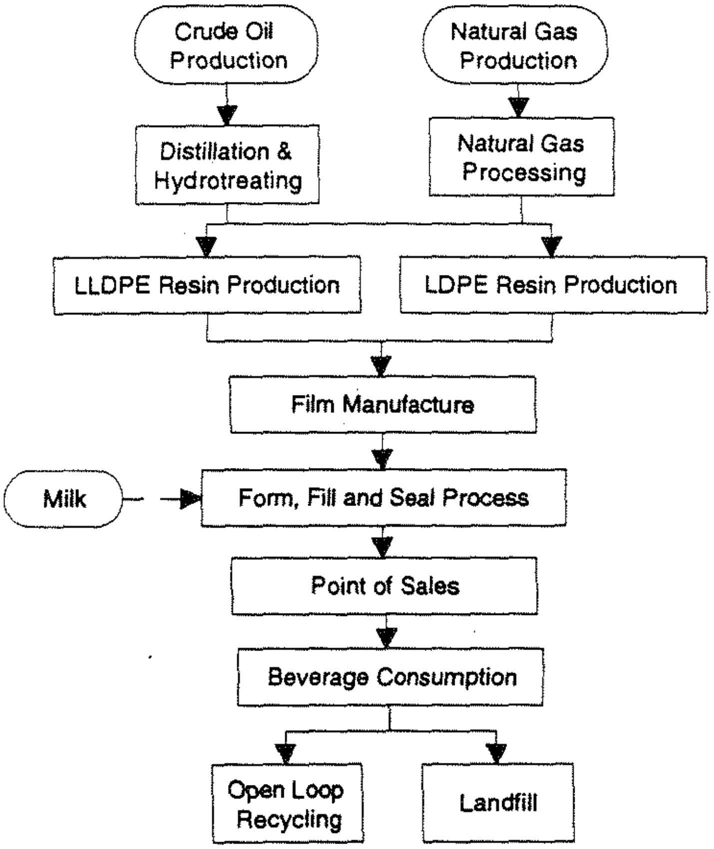
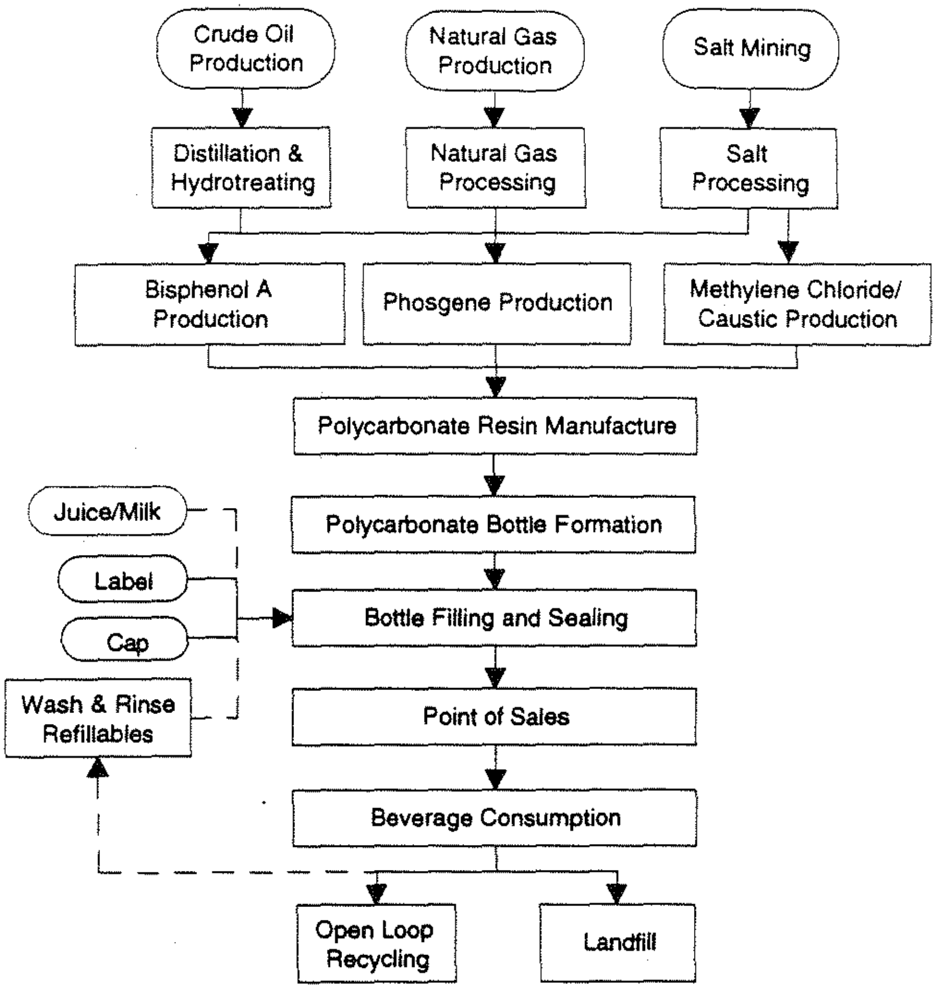


Figure 2-4. Life Cycle Flow Sheet for Flexible Pouches

Polycarbonate Bottle

All polycarbonate bottles studied are refillable; the high price of polycarbonate makes this resin impractical to use in one-way containers. In Figure 2-5, it is important to note that the production of polycarbonate resin requires phosgene, a toxic gas, and bis-phenol A, a potential endocrine disrupter.



source: [13]

Figure 2-5. Life Cycle Flow Sheet for Polycarbonate Bottles

Steel Can

Steel cans are only used for juice delivery. Because very little information could be found on steel beverage containers, the flow sheet presented in Figure 2-6 and data presented later in the report are based on limited available sources.

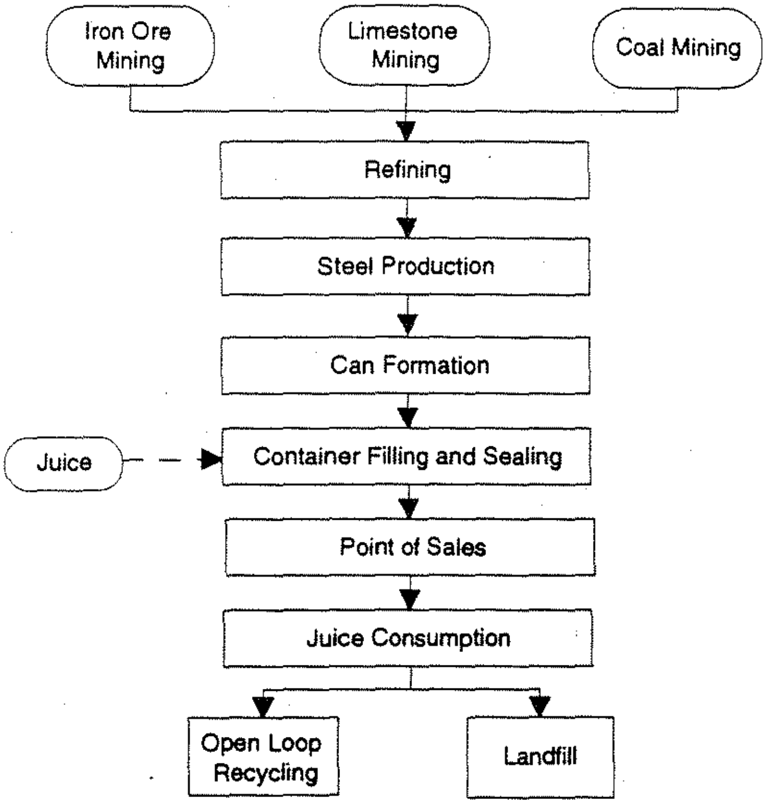
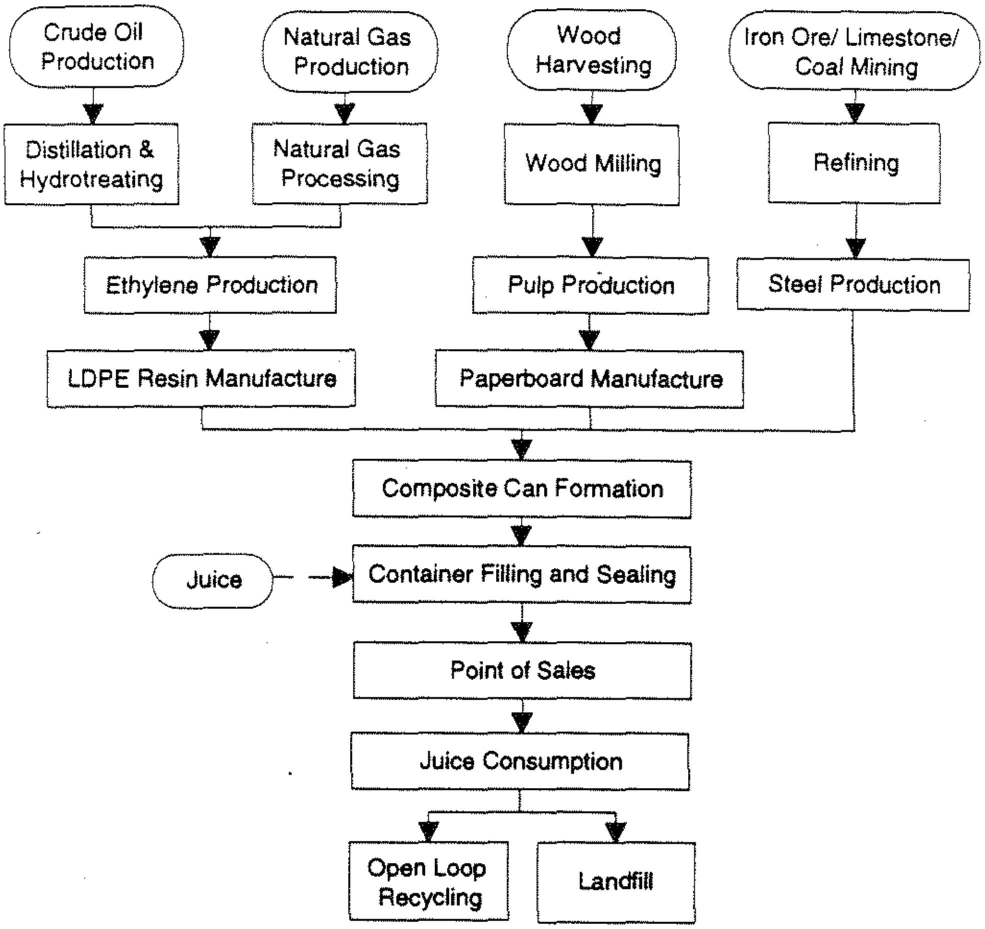


Figure 2-6. Life Cycle Flow Sheet for Steel Cans

Composite Can

Composite cans are used to deliver juice in frozen concentrate form. The concentrate in a 12 oz. can makes 48 oz. of reconstituted juice. Very little information was available on composite cans and their use. Data reported in this study were based on a combination of available information and NPPC calculations. Figure 2-7 shows how composite cans are made.

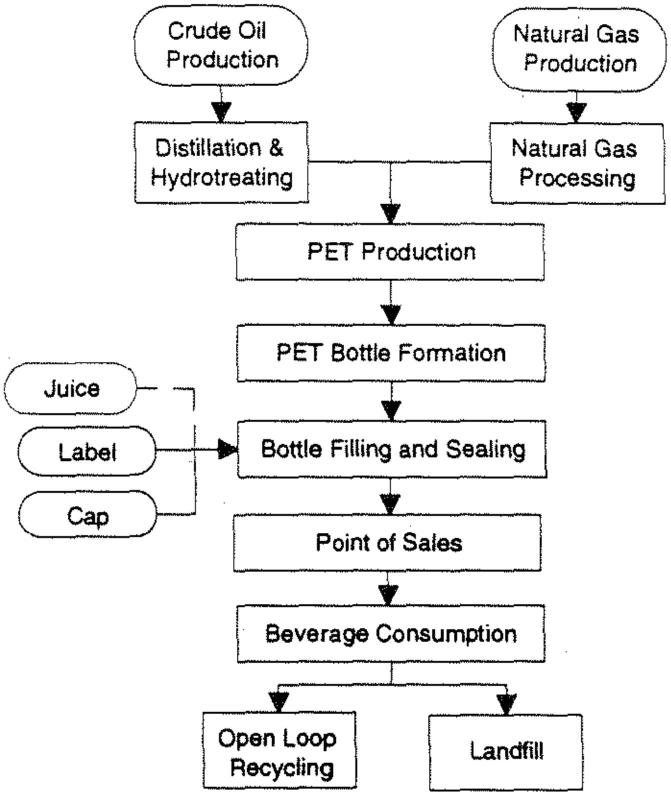


source: [14]

Figure 2-7. Life Cycle Flow Sheet for Composite Cans

Polyethylene Terephthalate (PET) Bottle

Because little information is available on PET bottle use for juice delivery, a system was approximated for figure 2-8 based on those used to deliver soft drinks.

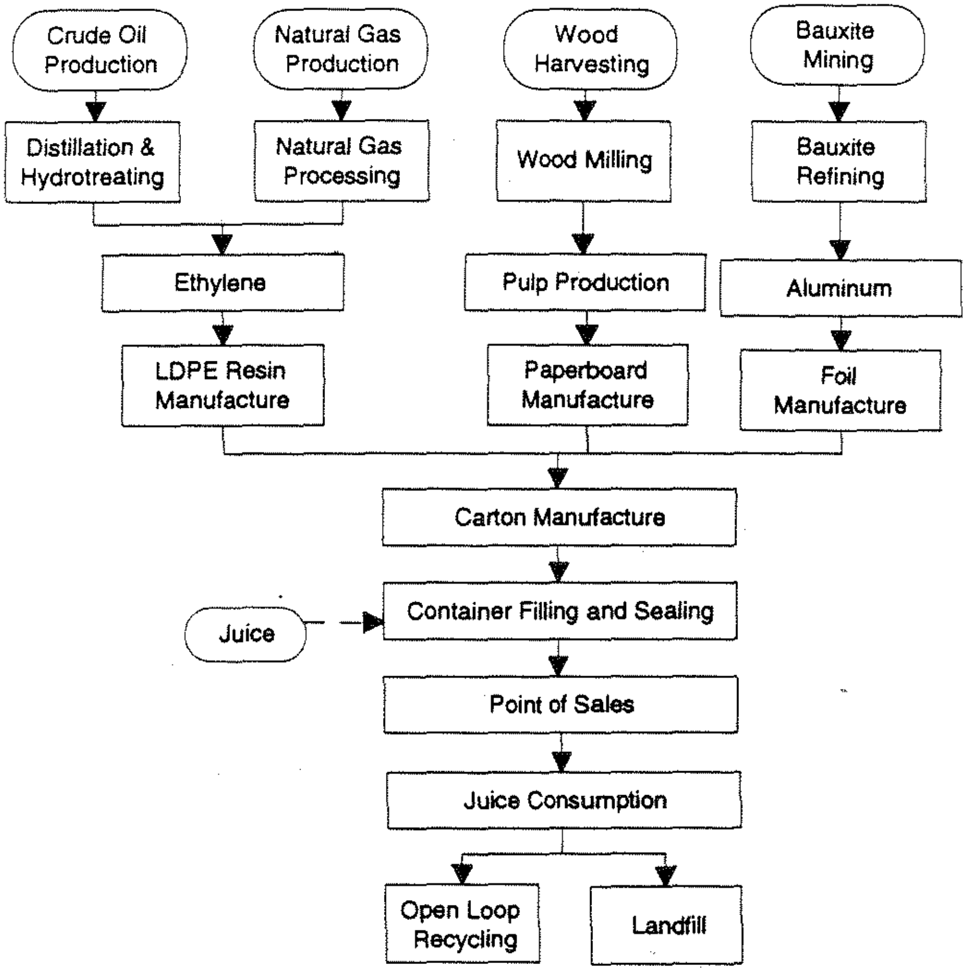


source: [15]

Figure 2-8. Life Cycle Flow Sheet for PET Bottles

Aseptic Carton

Aseptic cartons deliver juice in a shelf-stable form that requires no refrigeration. As shown in figure 2-9, aseptic cartons are multilayer containers made of an inner layer of LDPE, an aluminum layer, paperboard and an outer layer of LDPE. The paperboard in aseptic cartons often contains some recycled material, although as previously noted for paperboard gable top cartons, we assumed no postconsumer content. Generally, aseptic cartons deliver smaller volumes than the other container systems in this study. Some aseptic cartons are available with plastic "flip-top" pour spouts. These containers are not considered in detail here. However, we believe that such pour spouts would increase energy use in material production and carton manufacture while decreasing container recyclability.



source: [9]

Figure 2-9. Life Cycle Flow Sheet for Aseptic Cartons

3. Data Collection and Analysis

3.1 Methodology

Data from several publicly available life cycle studies of milk and juice packaging were used for environmental analysis in this study. One should be aware of the limitations of such resources. Summarized below are some of the major assumptions and limitations of the studies which supplied much of the data presented in this report.

Franklin Associates (1991) [11]	Franklin Associates, a leading LCA consulting firm, conducted a study comparing paperboard gable top milk cartons to HDPE milk containers for the Council for Solid Waste Solutions in February of 1991. Based on available recycling infrastructure and technology at the time of the study, it provides life cycle inventory data for HDPE containers at recycle rates ranging from zero to 100% (both closed and open loop). Life cycle inventory data for the gable top carton assumes zero percent recycling. Because both container types are equivalently refrigerated, no impacts associated with refrigeration are included. However, this study does consider the energy credits and solid waste associated with incinerating 15% of postconsumer solid waste.
Deloitte and Touche (1991) [10]	Deloitte and Touche conducted a life cycle inventory of the Canadian fruit juice market for Tetra Pak, Inc. in 1991 that investigated the current Canadian market with regard to both aseptic cartons and glass bottles. It was not possible to review specific assumptions of this study because we only had access to a summary, not the full report.
Midwest Research Institute (1976) [9]	Prepared for the Office of Solid Waste Management, US Environmental Protection Agency, this report characterizes several aspects of milk delivery systems including health and economic considerations. Four relevant container systems were examined in this study: refillable glass, refillable HDPE, single-use HDPE and single-use paperboard. This study includes incineration only as a reduction in solid waste, not as a waste-to-energy credit. It is possible that data taken from this study will overestimate some burdens due to the age of the data.

Evaluation of Criteria

As stated in section 1.4, one of the objectives of this study was to identify and evaluate key criteria and metrics. This objective was accomplished through a two-stage process. First, criteria and metrics were determined based on NPPC research and experience. Then, in a series of meetings with the core team at Dow Chemical, these initial criteria and metrics were narrowed, leaving only those believed to be key for design. To facilitate analysis, design criteria were split into four categories: environmental, cost, performance and legal. Multicriteria matrices were then developed for each stage of the product life cycle.

Design criteria were evaluated using existing life cycle studies, where available. Some additional research was necessary to fill gaps in data. Several assumptions also had to be made in order to present the information collected. Clarifications of assumptions, terms and their usage follows. Section 2.2 describes additional boundaries and limitations.

Basis

In order to compare containers on an equivalent use basis, a functional unit of 1000 gallons was selected. All criteria were evaluated based on quantities necessary to deliver 1000 gallons to the consumer.

Reuse

Trippage rates for refillable bottle systems are those reported in the available studies. These reuse rates are not meant to reflect current conditions unless specifically stated by the author of the study from which the data was taken. In most cases, these values bound the range of plausable trippage rates and the actual trippage rate is between the given values. For this study, it was assumed that washing refillables takes place at the filling location. Therefore, transportation energy between bottle washing and filling was not considered. The reuse rates for refillable container systems and their sources are given in Table 3-1.

Table 3-1. Reuse Rates for Refillable Container Systems

Container	Size	Trippage	Source
Glass Bottle	1.0 gal	5, 20	[9]
Glass Bottle	0.5 gal	5, 20	[9]
Glass Bottle	1.0 L	10, 20	[10]
HDPE Bottle	1.0 gal	5, 20, 50	[9]
HDPE Bottle	0.5 gal	5, 20, 50	[9]
Polycarbonate Bottle	0.5 gal	5, 40	[7]

Recycling

The base case for container systems other than glass bottles assumes that no postconsumer recycling takes place. However, many of these containers can be recycled using currently available technology. For this reason, we performed calculations and reported life cycle data with specified recycle rates (% of containers recovered) where appropriate. These calculations were based on open-loop recycling, so none of the original container material is assumed to be reused in the manufacture of new beverage containers, with the exception of glass. The glass bottle case assumes that 25% of glass bottles are recycled in a closed-loop system (i.e. 25% of the glass bottles are recovered after use and processed into cullet which is used to manufacture new glass bottles).

Recycle rates used in these scenarios are intended to reflect statistics for postconsumer container recycling under recently published economic, regulatory and technological conditions. Table 3-2 gives current postconsumer material recycling rates for reference.

Table 3-2. Recycling Rates by Material Type

Material	Recycling Rate
Glass bottles	34%
HDPE bottles	17%
Steel cans	33%
PET bottles	35%
Cartons (gable top, aseptic)	2%
PE film	2%

source: [16]

Refrigeration

Several juice containers in this study are differentiated by their refrigeration requirements: aseptic cartons, steel cans, glass bottles and composite cans. Aseptic cartons, glass bottles and steel cans do not require refrigeration until use, while composite cans used to deliver frozen concentrate must be kept frozen until use. All other containers must be kept refrigerated until their contents have been consumed. Calculations were performed based on conversations with grocers and data from Detroit Edison in order to determine energy use for refrigerating juice during transport and storage. It was assumed that all containers are equally refrigerated during use.

Impacts associated with milk refrigeration were not included because milk containers were assumed to all be equally refrigerated.

4. Results

4.1 Environmental Criteria

The following environmental criteria were evaluated for the entire product life cycle: energy use, solid waste, airborne emissions and waterborne emissions. Criteria were evaluated based on published life cycle inventory studies, where available. The results appear on the following pages. Sample calculations used to obtain these results are contained in Appendix A.

Energy Use

Total life cycle energy use for milk and juice containers is the first environmental criteria examined. In order to evaluate the energy requirements for each container, the containers were divided between juice delivery systems, which include impacts associated with refrigeration, and milk delivery systems which do not.

Tables 4-1 and 4-2 show energy use data for milk and juice containers respectively. In both tables, total life cycle energy is given in the fourth column. Material production represents energy required to produce the raw materials for each container, or "cradle-to-gate" energy use; it is given in the sixth column. Cradle-to-gate energy data are shown to highlight their importance in the life cycle of the product.

Sources for each energy value are also included. When several published studies were used to arrive at a calculation, the source is identified as "various"; these sources appear in Table 4-3.

Of the milk containers examined, the one-gallon, 50-trip refillable HDPE bottle had the lowest reported life cycle energy use (1630 MJ/1000 gal), while the half-gallon, 5-trip refillable polycarbonate bottle had the highest life cycle energy use (10,900 MJ/1000 gal). The single-use, one-liter glass bottle had the lowest life cycle energy use of the juice containers. For both beverage types, overall energy use decreases as the number of uses increases. Energy use also decreases as unit container volume increases, although this trend can only be seen clearly in the milk container data.

Table 4-1. Energy Use for Milk Delivery Systems, MJ/1000 gal delivered

Container		Volume	Tripage/ Recycling*	Total LC Energy Use[a]	Data Source	Mat. Prod. Energy Use	Data Source
Glass Bottle							
	refillable	0.5 gal	20 trip	3900	[9]	1910	[9]
			5 trip	9940	[9]	8000	[9]
		1.0 gal	20 trip	3060	[9]	1500	[9]
			5 trip	7820	[9]	6360	[9]
	single use	0.5 gal		7000	various		
HDPE Bottle							
	refillable	0.5 gal	50 trip	2320	[9]	470	[9]
			20 trip	3290	[9]	1240	[9]
			5 trip	8140	[9]	4960	[9]
		1.0 gal	50 trip	1630	[9]	300	[9]
			20 trip	2240	[9]	780	[9]
			5 trip	5210	[9]	3110	[9]
	single use	0.5 gal		8250	[11]	7920	[17]
			25% [b]	7720	[11]	6930	[17]
		1.0 gal		6220	[11]	5620	[17]
			25% [b]	5690	[11]	4920	[17]
Gable Top Carton							
	single use	0.5 gal		8040	[11]		
			2% [b]	8000	various		
		1.0 gal		7040	[11]		
			2% [b]	7000	various		
Polycarbonate Bottle							
	refillable	0.5 gal	40 trip	2630	various	1020	[13]
			5 trip	10,900	various	8140	[13]
Flexible Pouch							
	single use	0.5 gal		1900	various	1750	[18]
			2% [b]	1700	various	1550	[18]

*Where trippage is given, this value represents the number of times an individual refillable container is used to deliver beverage. For single use containers, the values are recycling rates which give the amount of container material recycled after use.

a Some values converted from Btu to MJ

b Open loop recycling energy credit: credit is given for half of energy saved from recycled materials

For more information on data calculated from various sources, see accompanying text and Appendix A

Table 4-2. Energy Use for Juice Delivery Systems, MJ/1000 gal delivered

Container		Volume	Trips/ Recycling	Total LC Energy Use[a]	Data Source	Mat. Prod. Energy Use	Data Source
Aseptic Carton							
	single use	1.0 L		8910	[10]	5370	[10]
			2% [b]	8880	various	5320	[10]
Glass Bottle							
	refillable	1.0 L	20 trip	10,300	[10]	4100	[10]
			10 trip	11,600	[10]	5360	[10]
	single use	1.0 L		24,000	[10]	18,800	[10]
HDPE Bottle							
	refillable	0.5 gal	50 trip	2570	[9]	470	[9]
			20 trip	3540	[9]	1240	[9]
			5 trip	8390	[9]	4960	[9]
	single use	0.5 gal		8500	[11]	7920	[17]
			25% [b]	7970	[11]	6930	[17]
Gable Top Carton							
	single use	0.5 gal		8290	[11]		
			2% [b]	8250	various		
Polycarbonate Bottle							
	refillable	0.5 gal	40 trip	2880	various	1020	[13]
			5 trip	11,200	various	8140	[13]
Composite Can							
	single use	48 oz.		5650	various	5250	[17]
Steel Can							
	single use	46 oz.		21,200	various	21,200	[17]
			33% [b]	16,200	various	15,600	[17]
PET Bottle							
	single use	2.0 L		9830	various	9120	[15]
			35% [b]	8860	various	6380	[15]

a Some values converted from Btu to MJ

b Open loop recycling energy credit: credit is given for half of energy saved from recycled materials

For more information on data calculated from various sources, see accompanying text and Appendix A

No conversion energy information could be obtained for steel and composite cans

Table 4-3. Sources of Data for Container Energy Use Estimates

Container Type	Data Sources
Glass Bottle: single use, 0.5 gal	[9]
Paperboard Gable Top, with recycling	[11,16]
Polycarbonate Bottle	[13,7,19]
Flexible Pouch	[18,20,19,16]
Composite Can	[17,12,19,21,16]
Steel Can	[17,12,19,21,16]
PET Bottle	[15,12,19,21,16]
Aseptic Carton, with recycling	[10,16]

Solid Waste

Total life cycle solid waste resulting from each container system is shown in Table 4-4. Postconsumer solid waste data included in Table 4-4 were calculated by NPPC based on container mass reported in Table 2-1, assuming 16% incineration of combustible waste [16] (glass and steel are not considered combustible). Total life cycle solid waste values reported include waste from industrial processing in addition to postconsumer waste. We assumed that the product (milk/juice) inside the container has no effect on filling losses, spoilage rates and the corresponding amount of solid waste produced during the container life cycle.

The one-gallon, 50-trip refillable HDPE bottle generated the least solid waste over its life cycle (4 kg/1000 gal). In contrast, the single-use, one-liter glass bottle generated the greatest mass of life cycle solid waste (1220 kg/1000 gal). Life cycle solid waste, like energy, seems to decrease as unit container volume increases. Increased trippage rates for refillable containers also decreases solid waste generation.

Table 4-4. Solid Waste for Container Systems, kg/1000 gal delivered

Container		Volume	Trips/ Recycle	Postconsumer Solid Waste	Total LC Solid Waste	Data Source
Aseptic Carton						
	single use	1.0 L		100	190	[10]
			2% rec.	97		
Glass Bottle						
	refillable	1.0 L	20 trip	96	140	[10]
			10 trip	190	230	[10]
		0.5 gal	20 trip	92	120	[9]
			5 trip	370		
		1.0 gal	20 trip	73	93	[9]
			5 trip	290	360	[9]
	single use	1.0 L		1160	1220	[10]
		0.5 gal		840		
HDPE Bottle						
	refillable	0.5 gal	50 trip	5	6	[9]
			20 trip	11	12	[9]
			5 trip	45		
		1.0 gal	50 trip	3	4	[9]
			20 trip	7		[9]
			5 trip	28		
	single use	0.5 gal		76	84	[11]
			25% rec.	53	67	[11]
		1.0 gal		54	62	[11]
			25% rec.	38	49	[11]
Gable Top Carton						
	single use	0.5 gal		100	140	[11]
			2% rec.	100		
		1.0 gal		95	120	[11]
			2% rec.	93		
Polycarbonate Bottle						
	refillable	0.5 gal	40 trip	5		
			5 trip	41		
Composite Can						
	single use	48 oz.		71		
Steel Can						
	single use	46 oz.		450		
			33% rec.	300		
PET Bottle						
	single use	2.0 L		120		
			35% rec.	67		
Flexible Pouch						
	single use	0.5 gal		17		
			2% rec.	17		

Airborne Emissions

Airborne emissions were available for only a limited number of containers. The following four emissions were included in this study based on Clean Air Act regulations and recommendation of the Dow core team: particulates, nitrogen oxides, hydrocarbons and sulfur oxides. Amounts of these emissions reported for each containers system are shown in Table 4-5.

Life cycle emission data were unavailable for the flexible pouch, refillable HDPE bottle and PET bottle systems. Only emissions data reported for manufacture of the resins used in these containers are shown. In addition, no reliable life cycle data on airborne emissions could be found for glass bottles (0.5 gal size), polycarbonate bottles, composite cans or steel cans. Therefore, these systems do not appear in Table 4-5.

In general, airborne emissions data show significant variability. Because we do not know the methodology used for these measurements, we cannot account for the wide variance in reported data.

The following discussion considers only those containers for which complete life cycle data was available; it excludes containers whose emissions were estimated from various sources.

Among the containers for which complete data from one source was available, single-use, half-gallon gable top cartons had the highest emissions of particulates (2.0 kg/1000 gal). One-gallon, single-use HDPE bottles had the lowest mass of particulate emissions (0.27 kg/1000 gal). In the category of nitrous oxide emissions, the one-gallon, single-use HDPE bottle again had the lowest reported emissions (0.82 kg/1000 gal). Single-use, one-liter glass bottles had the highest emissions in this category (7.1 kg/1000 gal). Aseptic cartons produced the least emissions of hydrocarbons (0.81 kg/1000 gal). Single-use, half-gallon glass bottles had the highest hydrocarbon emissions (3.1 kg/1000 gal). Sulfur oxide emissions were the last category of emissions examined. Single-use, one-liter glass bottles had the highest emissions

Table 4-5. Life Cycle Air Emissions for Container Systems, kg/1000 gal delivered

Container		Volume	Trips	Particulates	NOx	HC	SOx	Source
Aseptic Carton								
	single use	1.0 L		1.1	2.9	0.81	3.8	[10]
Glass Bottle								
	refillable	1.0 L	10 trip	1.1	4.6	0.96	6.8	[10]
			20 trip	0.58	2.8	0.93	5.6	[10]
	single use	1.0 L		1.7	7.1	1.1	19	[10]
HDPE Bottle								
	refillable	0.5 gal	20 trip	0.027	0.13	0.28	0.080	various[a]
		1.0 gal	20 trip	0.017	0.084	0.18	0.050	various[a]
	single use	0.5 gal		0.36	1.2	3.1	1.5	[11]
		1.0 gal		0.27	0.82	2.2	1.0	[11]
Gable Top								
	single use	0.5 gal		2.0	2.1	1.3	3.8	[11]
		1.0 gal		1.8	1.9	1.0	3.3	[11]
PET Bottle								
	single use	2.0 L		0.41	2.2	4.4	2.7	various[a]
Flexible Pouch								
	single use	0.5 gal		0.031	0.18	0.41	0.082	various[a]

a These estimates based on material production emissions in this category (19 kg/1000 gal), while single-use, one-gallon HDPE bottles had the lowest (1.0 kg/1000 gal). Once again, increasing trippage rate and container size seems to decrease air emissions.

Waterborne Emissions

Data for waterborne emissions were limited in a similar manner as airborne emissions. Where available, four waterborne emissions were selected based on recommendation of the Dow Chemical core team: dissolved solids, biological oxygen demand, suspended solids and chemical oxygen demand. Although heavy-metal emissions were selected for inclusion in the analysis, none of the container systems studied had any reported emissions of heavy metals. Waterborne emissions appear in Table 4-6.
The following discussion of waterborne emissions, like the discussion of airborne emissions, considers only those containers for which complete life cycle data were available. Of these containers, the aseptic carton had the lowest emissions of dissolved solids (0.042 kg/1000 gal) and the highest emissions of COD (6.6 kg/1000 gal). The glass bottle had the highest emissions in two categories: dissolved solids (36 kg/1000 gal) and suspended solids (21 kg/1000 gal). In general, glass containers had higher reported emissions of solid materials than did the other containers. The single-use, one-gallon HDPE bottle reported the lowest emissions in two categories: BOD (0.005 kg/1000 gal) and suspended solids (0.091 kg/1000 gal). The single-use, one-gallon gable top carton had the highest emissions of BOD (2.7 kg/1000 gal) and the lowest emissions of suspended solids (0.007 kg/1000 gal).

Table 4-6. Waterborne Emissions for Container Systems, kg/1000 gal delivered

Container	Volume	Trips	Dissolved Solids	BOD	Suspended Solids	COD	Data Source
Aseptic Carton							
single use	1.0 L		0.042	1.2	0.66	6.6	[10]
Glass Bottle							
refillable	1.0 L	10 trip	6.1	0.33	4.4	0.38	[10]
		20 trip	3.1	0.33	2.6	0.38	[10]
single use	1.0 L		36	0.41	21	0.38	[10]
HDPE Bottle							
refillable	0.5 gal	20 trip	0.007	0.001	0.003	0.003	various[a]
	1.0 gal	20 trip	0.004	0.001	0.002	0.002	various[a]
single use	0.5 gal		0.36	0.008	0.010	0.014	[11]
	1.0 gal		0.27	0.005	0.091	0.091	[11]
Gable Top							
single use	0.5 gal		0.27	2.7	2.2	0.009	[11]
	1.0 gal		0.23	2.7	2.2	0.007	[11]
PET Bottle							
single use	2.0 L		0.063	0.11	0.065	0.36	various[a]
Flexible Pouch							
single use	0.5 gal		0.015	0.001	0.004	0.011	various[a]

a These estimates based on material production emissions

4.2 Cost

Costs representative of the life cycle of each container product were determined from published information and conversations with industry. Actual retail product (beverage and container) costs were not included because factors other than container type contribute to these highly variable costs. Preliminary research indicated that the retail price of milk was independent of container type, although it has been reported that milk in pouches may cost consumers 10 - 15 cents less [22]. Cost data were collected for a representative sample of container systems only. Tables 4-7 through 4-9 present costs for three stages of the container life cycle: raw materials, filling and end-of-life management. Costs for milk and juice containers were evaluated equivalently.

Raw Material Cost

Raw material cost is the price paid by container manufacturers (converters) for the materials necessary to produce containers. In the case of glass bottles, manufacturers buy mined minerals, whereas they buy pelletized HDPE resin for making HDPE bottles. Material cost for the pouch consists of the price for resin pellets before extrusion into film.

Table 4-7 shows the price per pound of raw materials and the weight of materials required to manufacture containers for delivering 1000 gallons of beverage. Resin prices are those listed in the June 1995 issue of Plastics Technology (these prices fluctuate regularly); paperboard prices come from Official Board Markets, June 1995 and material prices for mined materials (feldspar, soda ash, limestone, and sand) were obtained from the US Bureau of Mines World Wide Web site (http://www.usbm.gov) in June 1995. In some cases, data from these sources were combined to arrive at reported costs.

Table 4-7. Raw Material Cost for Selected Milk and Juice Containers, $/1000 gal delivered

Container		Volume	Trips	Price ($/lb.)	Weight (kg/1000 gal)	Total
HDPE Bottle						
	refillable	0.5 gal	20 trip	0.62	13.4	$18.00
	single use	0.5 gal		0.62	90.4	$121.16
Gable Top Carton						
	single use	0.5 gal		0.28	129.0	$78.34
Polycarbonate Bottle						
	refillable	0.5 gal	40 trip	2.23	6.1	$29.21
Glass Bottle						
	refillable	0.5 gal	20 trip	*		$4.93
		1.0 L	20 trip	*		$7.32
	single use	0.5 gal		*		$71.61
		1.0 L		*		$88.69
Flexible Pouch						
	single use	0.5 gal		0.64	20.8	$29.00
Aseptic Carton						
	single use	1.0 L		0.40	103.3	$92.05
Composite Can						
	single use	48 oz.		0.31	84.0	$56.09
PET Bottle						
	single use	2.0 L		0.69	114.7	$174.00

* Calculations performed to determine glass material prices are shown in Appendix A

Filling Costs

All the following filling costs exclude in plant operating costs such as labor and utilities because this information was regarded as proprietary and not released by the beverage packaging companies.

Empty Container

The price paid by fillers for containers to deliver 1000 gallons of consumer product is the empty container cost. For the pouch, film roll stock is considered to be the empty container; for cartons, creased board, sealed along one edge, is the empty container.

Transportation

The cost of transportation fuel for each container was evaluated at two stages of the container life cycle. First, the cost of transporting empty containers, or materials in the case of the pouch, to filling locations was calculated. The second category comprises the cost of transporting full containers to retail locations. Back hauls of empty containers for refillables were also included in the cost of transportation to retail. Samples of transportation cost calculations appear in Appendix A. Cost data reported in Table 4-8 assume that all containers travel the same distances. Calculations were performed based on transport distances given in [7], transport fuel efficiency obtained from [19], and the average national price of gasoline reported by the APA for March, 1995.

Filling Equipment Cost

The costs of amortizing filling equipment were included in the cost analysis shown in Table 4-8. Equipment was analyzed for filling the following four containers with milk: refillable bottle, single-use bottle, paperboard container and pouch systems. For each filling system, the various components were identified and cost estimates for each component were obtained. These cost were then totaled and divided by the anticipated lifetime production volume of the equipment. The specific assumptions and limitations of this approach are detailed in Appendix A.5.

Consumer Total Cost

Total cost to consumers is the sum of empty container cost, filling equipment cost and cost of transportation to retail. The cost of transportation to fillers is not added to this sum because it is generally included in the price of empty containers. Preliminary NPPC research indicated that total consumer cost for packaging is not always accurately reflected in the retail price of milk and juice because these products are generally price sensitive items with a very low profit margin.

Table 4-8. Cost of Filling Selected Milk and Juice Containers, $/1000 gal delivered

Container		Volume	Trips	Empty Container	Transport to Filler	Filling Equipment	Transport to Retail	Consumer Total Cost
HDPE Bottle								
	refillable	0.5 gal	20 trip	$45.00	$0.06	$4.13	$19.60	$68.73
	single use	0.5 gal		$300.00	$0.39	$2.29	$17.68	$319.97
Gable Top Carton								
	single use	0.5 gal		$132.00	$0.56	$3.58	$17.85	$153.43
Polycarbonate Bottle								
	refillable	0.5 gal	40 trip	$70.00	$0.03	$4.13	$19.39	$93.52
Glass Bottle								
	refillable	0.5 gal	20 trip	$64.00	$0.40	$4.13	$33.24	$101.37
		1.0 L	20 trip	$65.00	$0.55	$4.13	$39.78	$108.91
	single use	0.5 gal		$773.00	$4.81	$2.29	$22.11	$797.40
		1.0 L		$776.00	$6.64	$2.29	$24.34	$802.63
Flexible Pouch								
	single use	0.5 gal		$80.00	$0.09	$2.45	$17.38	$99.83
Aseptic Carton								
	single use	1.0 L		$584.00	$0.51	-	$18.21	$602.21
Composite Can								
	single use	48 oz.		$147.00	$0.36	-	$18.06	$165.06
PET Bottle								
	single use	2.0 L		$208.00	$0.49	$2.29	$18.19	$228.48

End-of-Life Costs

End-of-life costs include collection, recycling, incineration, and landfilling. Samples of calculations used to derive end-of-life costs in Table 4-9 appear in Appendix A.

The cost for collecting containers as part of household waste was calculated with the assumption that recyclable waste is separated in the home and collected at curbside. The cost for collecting this type of waste was taken from [16].

Two columns in Table 4-9 pertain to material recycling costs. The first column shows the cost for processing materials at a recycling facility as given in [16]. Then, the market value of the recovered materials, as reported in the May, 1995 issue of Waste Age's Recycling Times, is given. This value assumes that all recycled material can be completely recovered. Overall recycling costs are based on the percentage of container material recycled given in Table 3-2. Containers that are not currently recycled according to [16] are denoted by dashes.

Costs of incinerating combustible container materials at a facility equipped for energy recovery are listed in two columns of Table 4-9. The first cost shown is the fee paid to dispose of waste at an incinerator; this calculation is based on data reported in [16]. The "WTE" (waste-to-energy) column lists the amount of generated energy attributed on a mass basis to each container type. These data are based on information given in [16] and conversations with a representative of Detroit Edison.

The cost of disposing the remaining postconsumer wastes not recycled or incinerated is the final end-of-life cost. We used a typical tipping fee for sanitary landfill disposition of MSW as reported by the National Solid Waste Management Association in June 1995 ($30.25/ton).

Table 4-9. End-of-Life Management Cost for Container Systems, $/1000 gal delivered

Containers	Volume	Trips	Collect	Recycle Process	Recycle Value	Inciner. Tip Fee	WTE Value	Landfill Tip Fee	Total
HDPE Bottle									
refillable	0.5 gal	20 trip	$1.65	$0.47	($1.38)	$0.17	neglig.	$0.30	$1.21
single use	0.5 gal		$11.16	$3.20	($9.32)	$1.13	($0.02)	$2.10	$8.25
Gable Top Carton									
single use	0.5 gal		$15.93	-	-	$1.61	($0.02)	$3.61	$21.13
Polycarbonate Bottle									
refillable	0.5 gal	40 trip	$0.75	-	-	$0.08	neglig.	$0.17	$1.00
Glass Bottle									
refillable	0.5 gal	20 trip	$11.39	$2.47	($1.75)	-	-	$2.03	$14.14
	1.0 L	20 trip	$15.86	$3.44	($2.13)	-	-	$2.83	$20.00
single use	0.5 gal		$138.02	$29.91	($21.14)	-	-	$24.60	$171.39
	1.0 L		$190.72	$41.34	($25.46)	-	-	$34.00	$240.59
Flexible Pouch									
single use	0.5 gal		$2.57	-	-	$0.26	($0.01)	$0.58	$3.41
Aseptic Carton									
single use	1.0 L		$14.67	-	-	$1.49	($0.03)	$3.33	$19.46
Composite Can									
single use	48 oz.		$10.37	-	-	$0.76	($0.01)	$2.35	$13.47
PET Bottle									
single use	2.0 L		$14.16	$7.96	($12.21)	$1.43	($0.03)	$2.73	$14.04

Estimated Life Cycle Cost

Total cost to consumers shown in Table 4-8, and total end-of-life management costs shown in Table 4-9 were added together to arrive at an estimated life cycle cost for each container. Table 4-10 shows the results. No filling equipment costs were available for two container systems: aseptic cartons and composite cans. Life cycle cost estimates for these containers do not include this information.

Table 4-10. Estimated Life Cycle Cost of Container Systems, $/1000 gal delivered

Container	Size	Trips	Consumer Cost	End-of-Life Cost	Life Cycle Cost
HDPE Bottle					
refillable	0.5 gal	20 trip	$68.73	$1.21	$69.94
single use	0.5 gal		$319.97	$8.25	$328.22
Gable Top Carton					
single use	0.5 gal		$153.43	$21.13	$174.56
Polycarbonate Bottle					
refillable	0.5 gal	40 trip	$93.52	$1.00	$94.52
Glass Bottle					
refillable	0.5 gal	20 trip	$101.37	$14.14	$115.51
	1.0 L	20 trip	$108.91	$20.00	$128.91
single use	0.5 gal		$797.40	$171.39	$968.79
	1.0 L		$802.63	$240.59	$1,043.22
Flexible Pouch					
single use	0.5 gal		$99.83	$3.41	$103.24
Aseptic Carton					
single use	1.0 L		$602.21	$19.46	N/A
Composite Can					
single use	48 oz.		$165.06	$13.47	N/A
PET Bottle					
single use	2.0 L		$228.48	$14.04	$242.52

N/A - The cost of filling equipment for the aseptic carton and composite can was not known so no value is shown for these containers here. The corresponding values not including this cost are, respectively, $621.67 and $178.53.

As Table 4-10 shows, there is a wide disparity in estimated life cycle costs for delivering an equivalent volume of beverage. The lowest-cost container (50-trip refillable HDPE bottle, $69.94) delivers 1000 gallons of beverage for $973.28 less than the highest-cost container (single-use, one-liter glass bottle, $1,043.22). Although eight single-use containers were evaluated, only one of them was among the five least-expensive containers in this study: the flexible pouch, ranked third at $103.24. For the containers studied, it therefore appears that refillables generally have lower life cycle costs than single-use containers.

4.3 Performance

Performance requirements define the functions of a product system. While milk and juice packages share many of the same attributes, at least one important difference exists: light can quickly decrease the nutritional value of milk [23]. However, surveys indicate that consumers prefer to purchase beverages that are packaged in clear containers [24]. Thus, package clarity is desirable for juice containers but undesirable for milk packages. For this reason, two slightly different sets of performance requirements were developed for milk and juice containers.

Market Segmentation

Segmentation of product systems is necessary to determine the most effective set of performance requirements. Although the scope of this project was limited to juice beverages made from concentrate, if we had included fresh juice, additional performance requirements would have been selected. For example, excellent barrier properties are a critical performance requirement for fresh juice because fresh juice loses its flavor quickly when exposed to oxygen, but they are less important for concentrate juice [25].

Evaluation Process

Performance requirements for milk and juice packaging were determined with a multiple-step process. First, a literature search was conducted to determine which physical characteristics and other properties influence beverage retailers and consumers [26,27,7]. Next, the following set of six performance measures were chosen based on their apparent importance:

- Clarity
- Burst/Shatter Resistance
- Ease of Opening
- Weight
- Resealability
- Necessity of Storing Empties

Each container was then subjectively evaluated for the five performance measures and ranked as follows: good (+) , neutral (0) or poor (-). To demonstrate, flexible pouches were rated as good for Light Blocking because they are opaque; as neutral for Burst Resistance because their overall resistance to breakage, puncture and leaks is moderate; as poor for Ease of Opening because some consumers perceive them as difficult to open; as good for Weight because the pouches and other nonglass containers weigh much less than glass bottles; as poor for Resealable because they cannot be closed once opened; and as good for Empties Storage because retailers and consumers do not have to store empty pouches after consumption.

All of these measures were weighted equally to determine overall performance as shown in the Tables 4-11 and 4-12.

Table 4-11. Performance Requirements for Milk

Container	Light Blocking	Burst Resistance	Ease of Opening	Weight	Resealable	Empties Storage	Overall Performance
Flexible Pouch	+	0	-	+	-	+	0
Gable Top Carton	+	0	-	+	0	+	0
Glass Bottle							
refillable	-	-	+	-	+	-	-
single Use	-	-	+	-	+	+	-
HDPE Bottle							
refillable	0	+	+	+	+	-	+
single Use	0	+	+	+	+	+	+
Polycarbonate bottle							
refillable	-	+	+	+	+	-	0

Table 4-12. Performance Requirements for Juice

Container	Clarity	Burst Resistance	Ease of Opening	Weight	Resealable	Empties Storage	Overall Performance
Aseptic Carton	-	+	-	+	0	+	0
Composite Can	-	+	0	+	+	+	0
Gable Top Carton	-	0	-	+	0	+	-
Glass Bottle							
refillable	+	-	+	-	+	-	-
single Use	+	-	+	-	+	+	0
HDPE Bottle							
refillable	0	+	+	+	+	-	0
single Use	0	+	+	+	+	+	+
PET Bottle	+	+	+	+	+	+	+
Polycarbonate bottle							
refillable	-	+	+	+	+	-	0
Steel Can	-	+	0	0	-	+	-

Limitations

The requirements we selected provide a straightforward framework for evaluating the performance of packages but some limitations should be considered. For example, the selection of performance measures was not based on a statistically valid marketing study and several potentially important measures were not evaluated, such as barrier properties, taste characteristics and aesthetics. Additionally, each of the five measures included was considered to be equally important. Focused market research might reveal some variables are much more important than others. For instance, most retailers strongly oppose refillable packages because of the necessity of storing empties. This one criteria may well influence the commercial success of a package much more strongly than another characteristic such as clarity.

4.4 Legal Requirements for Milk and Juice Packaging

A variety of legal requirements exist for milk and juice packaging in the US and other countries. These requirements vary substantially and have impacts throughout the life cycle. In order to better understand this complex and ever-changing set of requirements, regulations are grouped into five categories for discussion:

- Fees and Taxes
- Municipal/State/Federal Goals
- Bans and Mandates
- Recycling/Waste Minimization Requirements
- Manufacturer Requirements

Fees and Taxes

Several legal requirements are in the form of fees or taxes that increase the costs of a targeted packaging type or material in one or more life cycle stages. For example, garbage disposal fees require consumers to pay for the amount of garbage they dispose and thereby increase the total cost of juice and milk packaging. Thus, heavier, bulkier packages would have higher disposal costs than lighter, more compactable packages in municipalities that have enacted garbage disposal fees. Other examples are included in the following list.

Bottle Bills	Consumers must pay a deposit when they purchase a container; the deposit is refunded when the container is returned for recycling [28]
Eco-taxes and Advance Disposal Fees	Manufacturers must pay a tax on each package - in some cases, the tax amount varies with container size and material
Garbage Disposal Fees	More traditional flat-fee structures are replaced with graduated scales so that consumers pay more when they dispose of more garbage; this legal requirement obviously impacts many products in addition to packaging [29]

Municipal/State/Federal Goals

Many municipalities and state governments have developed a set of specific environmental goals. For example, some state governments require local municipalities to develop waste reduction plans. This type of requirement does not directly impact the packaging life cycle because it does not mandate any specific action. However, these goals can lead to the formation of laws and regulations that do directly impact the packaging life cycle. The following list shows some examples of such goals.

Recycling and/or Waste Reduction Plans	Many local and state governments have adopted a set of environmental goals - for example, a city government might strive to achieve a 50% recycling rate by the year 2000
Packaging Advisory Board	At least one federal bill proposed the development of a packaging advisory board that would be chartered to reduce the environmental impact of packaging wastes
Procurement Guidelines	Some governmental agencies are evaluating or adopting procurement guidelines that give preference to “environmentally friendly” products [30]

Bans and Mandates

In some cases, specific actions have been mandated by governments. For example, the state of Maine banned the use of aseptic packaging for several years. Additionally, one bill in the Minnesota legislature would require public entities that sell milk (schools) to purchase milk only in bulk containers [30]. In other words, single use packaging for milk would be banned in public entities. Several bans and mandates are listed below.

Packaging Bans	Some states and European countries have imposed or proposed bans of specific packaging types, such as aseptic containers and nonrefillable soft drink bottles [31]
Material Bans	In some cases, specific materials might be banned; for example, several European countries are evaluating a ban on chlorinated packaging materials [32]
Disposal Bans	To minimize the burden on their landfills and support their recycling programs, some municipalities have banned the disposal of recyclable packages [32]
Mandates	Various laws have been proposed that would require the use of a particular packaging type

Recycling/Waste Minimization Requirements

Laws requiring that specific numerical objectives be achieved also affect packaging. In contrast to the Municipal/State/Federal Goals, these laws prescribe specific penalties or other actions if the objectives are not reached. For example, eco-taxes on packages could be imposed if a targeted recycling rate was not achieved within three years. The current trend in the US is to consider several aspects of packaging (recyclability, recycled content, reusability and weight reduction) instead of targeting only one objective [33]. The following list presents several such laws.

Minimum Recycling Rates	These laws require that a certain percentage of one or more packaging types or materials be recycled; sometimes a series of increasingly higher targets are established for different dates
Minimum Recycled Material Content	Some European countries require that a specific percentage of recycled material (on average) be used in packaging applications; California and other states are considered similar laws
Packaging Weight or Volume Reductions	Sometimes eco-taxes will be imposed unless quantifiable reductions in a package's mass or volume is achieved during a particular time frame
Reusable Packaging Rates	These regulations mandate that a specified percentage of packages be reusable

Manufacturer's Requirements

This category includes regulations that impose specific requirements directly on packaging manufacturers. One relatively mild regulation requires companies to identify the type of packaging material with a standardized symbol. Thirty-nine states currently mandate the use of SPI (Society of Plastics Industries) symbols on beverage containers and other packages. The most stringent law is the take-back legislation in Germany that requires companies to take full responsibility for all packaging waste and imposes constraints on disposal such as requiring that a minimum percentage of all German packaging waste must be recycled [32]. Several manufacturers' requirements are listed below.

Labeling Laws	A variety of laws require beverage companies to label their products with environmental information, such as material type or recycled material content
Take-Back Legislation	In Germany, the packaged goods industry (material suppliers, beverage companies and retailers) must take full responsibility for packaging waste; used containers are returned to designated drop-off locations after which industry bears full responsibility for disposing the waste
Disposal Cost Requirements	A modification of take-back laws requires industry to bear the disposal costs of packaging; in France, eco-taxes on packages fund the government's disposal of beverage containers and other packages

Life Cycle Legal Matrix

Legal requirements are diverse and dynamic. Several of the described requirements are currently only proposals, but new regulations are continually being proposed and occasionally adopted by local, state and federal governments. Table 4-13 organizes legal requirements according to life cycle stage and product or process components.

Table 4-13. Legal Requirements Matrix

Life Cycle Stage	System Component	Legal Requirement
Conversion	product	Eco-taxes & Advance Disposal Fees
	product	Packaging Bans
	product	Material Bans
	product	Labeling Laws
	product	Packaging Weight/Volume Reductions
	product	Reusable Packaging Rates
	process	Minimum Recycled Material Content
Retail	product	Bottle Bills
	process	Mandates (use of bulk milk)
Recovery & Disposal	product	Garbage Disposal Fees
	product	Disposal Bans
	process	Take-Back Legislation
	process	Disposal Cost Requirements
	process	Minimum Recycling Rates
	process	Reusable Packaging Rates

Key Legislative Trends

Our analysis of current regulatory requirements for juice and milk packaging did not reveal any containers that were clear winners or losers. Different packages and materials might be favored under some of the regulations, but none of them optimally meet every requirement. However, four significant trends emerged that can guide package designers:

- Regulations have been and will continue to be developed at local, state and national levels. This complex situation changes rapidly and its future course cannot be forecasted exactly.
- During the past several years; a trend towards broader, more flexible laws has emerged. For example, Maine's ban on aseptic cartons was reversed and proposed regulations in California provide an option of meeting recyclability, reusability or weight reduction goals.
- Currently, the primary objective of most regulations concerning packaging is to minimize postconsumer waste and associated costs. Few laws have addressed air emissions, water emissions and energy consumption specifically caused by packaging.
- Finally, legal requirements are not directly targeting an overall reduction in environmental burden created by milk and juice packaging.

The influence of these legislative trends on container design and selection are discussed later in the Management Decision Making section.

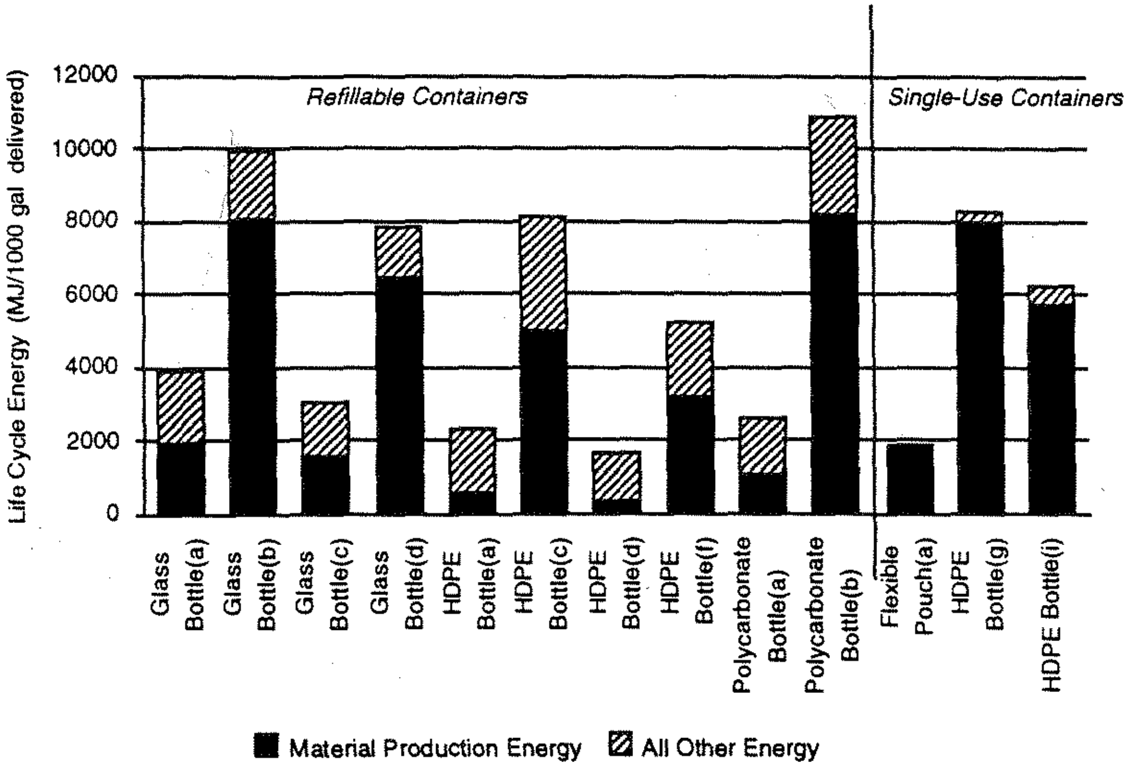
5. Design and Management Decision Making

5.1 Key Trends

Life cycle data presented in chapter 4 were further analyzed to develop key metrics for guiding packaging design. Subsets of the data that appeared to be significant (such as material manufacturing energy use) were compared with totals in that category (i.e. life cycle energy data) to determine their relative importance. In some cases, significant correlations could be identified, and these are discussed in more detail below. However, no significant correlations could be established for air and water emissions due to uncertainty in the data.

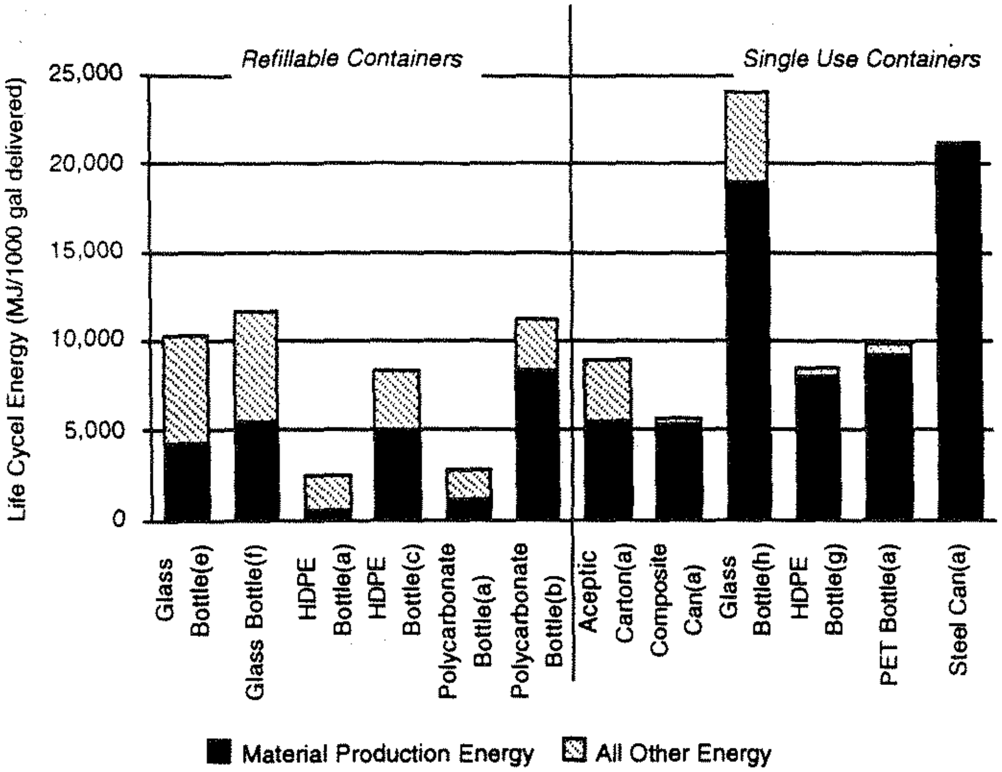
Energy Consumption

As is apparent from Tables 4-2 and 4-3, material production energy constitutes the majority of many container systems' life cycle energy inputs. This relationship is examined in Figures 5-1 and 5-2. On average, material production consumes 91% of total life cycle energy for milk containers and 85% of total energy used by juice containers. In both cases, this percentage is much lower (~60%) for high-trippage refillable containers, and slightly higher (~95%) for single-use containers. For this reason, material production energy is clearly a key design criteria for beverage packages.



Glass Bottle(a)	Refillable	0.5 gal	20 trips
Glass Bottle (b)	Refillable	0.5 gal	5 trips
Glass Bottle(c)	Refillable	1.0 gal	20 trips
Glass Bottle(d)	Refillable	1.0 gal	5 trips
HDPE Bottle(a)	Refillable	0.5 gal	50 trips
HDPE Bottle(c)	Refillable	0.5 gal	5 trips
HDPE Bottle(d)	Refillable	1.0 gal	50 trips
HDPE Bottle(f)	Refillable	1.0 gal	5 trips
Polycarbonate Bottle(a)	Refillable	0.5 gal	40 trips
Polycarbonate Bottle(b)	Refillable	0.5 gal	5 trips
Flexible Pouch(a)	Single Use	0.5 gal	
HDPE Bottle(g)	Single Use	0.5 gal	
HDPE Bottle(i)	Single Use	1.0 gal	

Figure 5-1. Material Production Energy vs Total Life Cycle Energy for Milk Containers

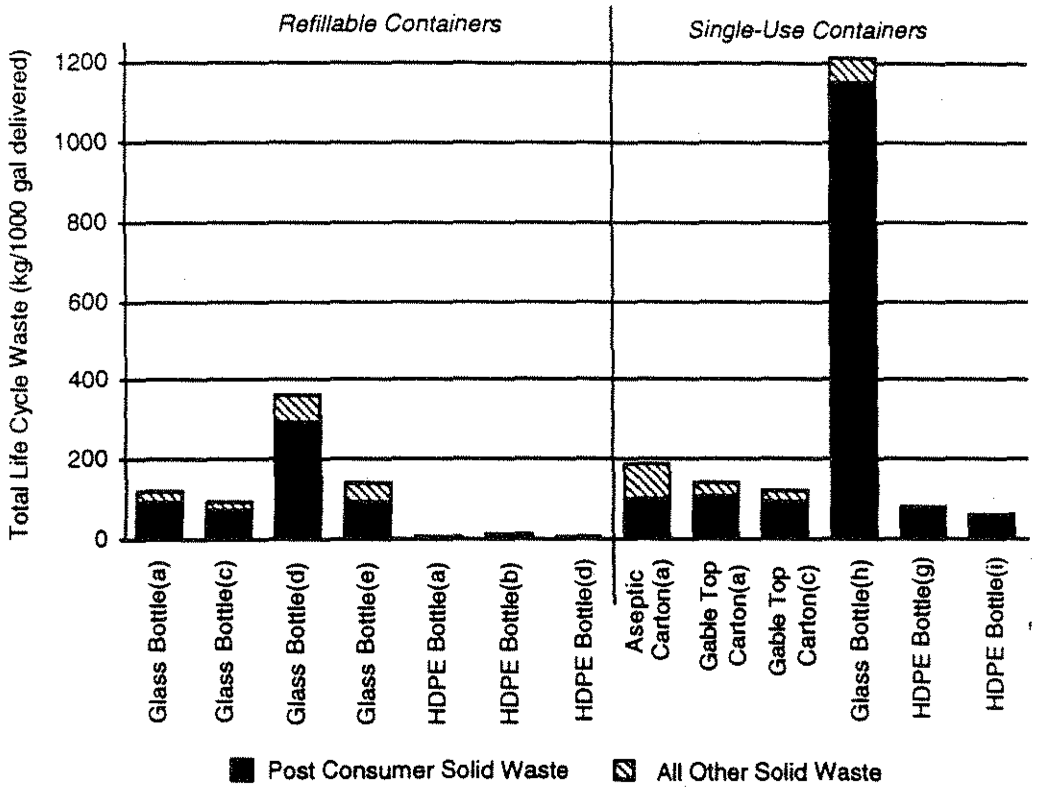


Glass Bottle(e)	Refillable	1.0 L	20 trips
Glass Bottle(f)	Refillable	1.0 L	10 trips
HDPE Bottle(a)	Refillable	0.5 gal	50 trips
HDPE Bottle(c)	Refillable	0.5 gal	5 trips
Polycarbonate Bottle(a)	Refillable	0.5 gal	40 trips
Polycarbonate Bottle(b)	Refillable	0.5 gal	5 trips
Aseptic Carton(a)	Single Use	1.0 L	
Composite Can(a)	Single Use	48 oz.	
Glass Bottle(h)	Single Use	1.0 L	
HDPE Bottle(g)	Single Use	0.5 gal	
PET Bottle(a)	Single Use	2.0 L	
Steel Can(a)	Single Use	46 oz.	

Figure 5-2. Material Production Energy vs Total Life Cycle Energy for Juice Containers

Solid Waste Generation

For both milk and juice packaging, postconsumer solid waste accounts for approximately 80% of total life cycle solid waste, on average. Figure 5-3 shows the relationship between postconsumer solid waste and total life cycle solid waste. Details of these values for all container systems appear in Table 4-4.

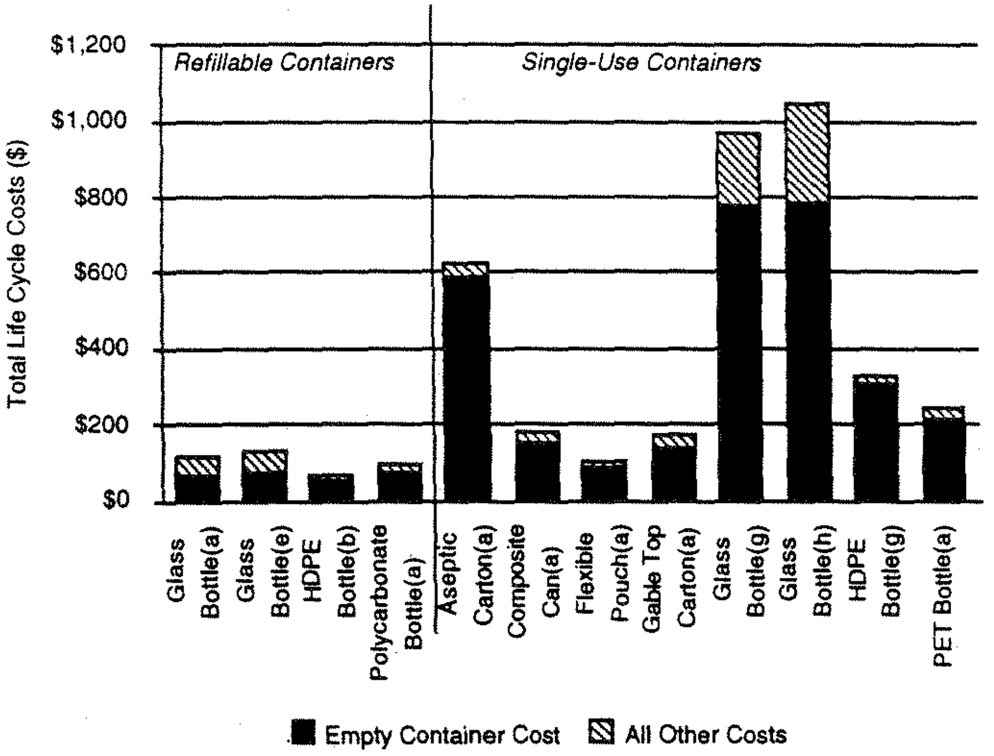


Glass Bottle(a)	Refillable	0.5 gal	20 trips
Glass Bottle(c)	Refillable	1.0 gal	20 trips
Glass Bottle(d)	Refillable	1.0 gal	5 trips
Glass Bottle(e)	Refillable	1.0 L	20 trips
HDPE Bottle(a)	Refillable	0.5 gal	50 trips
HDPE Bottle(b)	Refillable	0.5 gal	20 trips
HDPE Bottle(d)	Refillable	1.0 gal	50 trips
Aseptic Carton(a)	Single Use	1.0 L	
Gable Top Carton(a)	Single Use	0.5 gal	
Gable Top Carton(c)	Single Use	1.0 gal	
Glass Bottle(h)	Single Use	1.0 L	
HDPE Bottle(g)	Single Use	0.5 gal	
HDPE Bottle(i)	Single Use	1.0 gal	

Figure 5-3. Postconsumer vs Life Cycle Solid Waste for Container Systems

Costs

The price of empty containers accounts for the majority of total life cycle costs as calculated by the NPPC. For the container systems examined in section 4-3, empty container cost represented 75% of the total on average. Costs for refillable container systems are less dependent on empty container costs than single-use systems. The relationship between empty container cost and total cost is shown in Figure 5-4.



Glass Bottle(a)	Refillable	0.5 gal	20 trips
Glass Bottle(e)	Refillable	1.0 L	20 trips
HDPE Bottle(b)	Refillable	0.5 gal	20 trips
Polycarbonate Bottle(a)	Refillable	0.5 gal	40 trips
Aseptic Carton(a)	Single Use	1.0 L	
Composite Can(a)	Single Use	48 oz.	
Flexible Pouch(a)	Single Use	0.5 gal	
Gable Top Carton(a)	Single Use	0.5 gal	
Glass Bottle(g)	Single Use	0.5 gal	
Glass Bottle(h)	Single Use	1.0 L	
HDPE Bottle(g)	Single Use	0.5 gal	
PET Bottle(a)	Single Use	2.0 L	

Figure 5-4. Empty Container vs Total Costs for Container Systems

5.2 Recommended Design Guidelines

Our analysis of life cycle data resulted in several environmental and economic guidelines for milk and juice package design. A brief discussion of both categories of guidelines follows.

Environmental Design Guidelines

Based on life cycle solid waste and energy data for a variety of container systems, we propose the following two environmental guidelines for container design:

- Minimize material production energy by using less energy intensive materials, producing lighter containers and achieving high refill rates with refillable systems.
- Minimize postconsumer solid waste through reductions in container weight per volume delivered.

A special caveat must be stated here regarding these guidelines: they do not address environmental impacts related to air emissions and water effluents and do not distinguish between types of solid waste. As more accurate and refined data on air emissions, waterborne effluents, and solid waste type become available, appropriate metrics and guidelines can be developed to account for related impacts. Therefore, these guidelines are limited in their ability to facilitate the design or selection of container systems with the least overall environmental impact. Special caution should be exercised when applying these guidelines to other beverage container systems, although functionally similar systems are expected to follow similar patterns for the distribution of solid waste and energy across the life cycle.

Economic Design Guideline

We offer one design guideline based on the life cycle economics of container manufacture:

- Minimize empty container cost on a per volume basis. This can be achieved by either high-trippage-rate refillables or light-weight, single-use containers.

Life cycle cost represents the total societal cost of a container system as reflected by the marketplace. Externalities such as possible global warming caused by greenhouse gas emissions are not included in total life cycle cost.

5.3 Management Decision Making

A firm is more likely to promote life cycle design as a management tool if it believes that products identified as preferable by this tool will succeed in the marketplace. Successful implementation of life cycle design is promoted by a corporate environmental vision that addresses the product life cycle. As outlined in Appendix B, the environmental management system (EMS) at Dow chemical is compatible with LCD practices. This section examines how decisions based on the findings presented earlier can be made within the existing EMS at Dow. This process has two steps: determining which containers are preferable and deciding how this information can best be applied.

The following section describes two simple methods for weighting disparate or incommensurable criteria. Integration of multiple criteria and metrics is essential for an overall evaluation of alternative container systems. More elaborate techniques are available for weighting various criteria to arrive at a final evaluation [34,35], but the results from all such methods are limited by the participants' value judgments.

Criteria Weighting and Scoring

This section describes two simple approaches for evaluating products based on a partial life cycle inventory analysis, a life cycle cost analysis and a performance analysis. Simple methods were used here because details of Dow's decision analysis process and their weighting factors were kept confidential. Dow also uses additional criteria, discussed in the next section, for their internal strategic planning process.

The first method for scoring criteria relies on semi-quantitative valuations as shown in Tables 5-1 and 5-2. Containers were subjectively scored based on findings in three key classifications of requirements: environmental, cost and performance. Each container was rated as either positive (+), neutral (0) or negative (-) in each area based on the information presented in chapter 4. Life cycle energy and solid waste data presented in chapter 4 were translated into +, 0 or - scores, then averaged to produce the total environmental score shown in Tables 5-1 and 5-2.

Environmental, cost and performance criteria were also weighted equally to determine the average overall score for each container. It is important to note that we chose equal weighting for this exercise even though cost and performance are generally more important to customers. Milk containers were scored separately from juice containers because of differences in the evaluation of energy and performance requirements for these containers.

With respect to the two environmental criteria that were evaluated here, HDPE and polycarbonate refillable bottles along with the flexible pouch have the least environmental burden. The single-use glass bottle and the steel can generated the most solid waste and consumed the greatest amount of life cycle energy. These findings must be qualified by the fact that air emissions and water effluents were not analyzed. For example, HDPE refillable bottles are expected to have lower toxic releases relative to polycarbonate refillable bottles.

Using equal weighting factors for environmental, cost and performance, HDPE and polycarbonate refillable bottles and the flexible pouch were the most preferable overall. The HDPE refillable bottle had the best overall score for milk packaging. Tables 5-1 and 5-2 show some clear tradeoffs among the criteria for many containers.

Table 5-1. Milk Container Evaluation

Container Type	Environmental			Cost	Performance	Overall[a]
	Solid Waste	Energy	Total			
Flexible Pouch						
single use	+	+	+	+	0	+
Gable Top Carton						
single use	0	0	0	0	0	0
Glass Bottle						
refillable	0	+	0	+	-	0
single use	-	-	-	-	-	-
HDPE Bottle						
refillable	+	+	+	+	+	+
single use	0	0	0	0	+	0
Polycarbonate Bottle						
Refillable	+	+	+	+	0	+

a Overall is an average of total environmental, cost and performance

Table 5-2. Juice Container Evaluation

Container Type	Environmental			Cost	Performance	Overall[a]
	Solid Waste	Energy	Total			
Aseptic Carton						
single use	0	0	0	-	0	0
Composite Can						
single use	0	0	0	0	0	0
Gable Top Carton						
single use	0	0	0	0	-	0
Glass Bottle						
refillable	0	+	0	+	-	0
single use	-	-	-	-	0	-
HDPE Bottle						
refillable	+	+	+	+	0	+
single use	0	0	0	0	+	0
PET Bottle						
single use	0	0	0	0	+	0
Polycarbonate Bottle						
refillable	+	+	+	+	0	+
Steel Can						
single use	-	-	-	0	-	-

a Overall is an average of total environmental, cost and performance

A second method was also used to evaluate alternative milk containers. Results of this more quantitative approach for multicriteria scoring are shown in Table 5-3. Data for 0.5-gallon containers under best-case-scenario conditions were analyzed. Data sets involving the highest recycling and trippage rates were used, although these rates do not necessarily represent accurate best-case scenarios. In Table 5-3, trippage rates for glass, polycarbonate and HDPE refillable bottles were assumed to be 20, 40 and 50 respectively. However, polycarbonate refillable bottles may have the longest useful life.

Life cycle energy data, which ranged from 1700 MJ/1000 gallons delivered in flexible pouches with 2% recycling to 8000 MJ/1000 gallons delivered in gable top cartons with 2% recycling, were normalized to arrive at life cycle energy scores ranging from 0 to 10. These scores represent total life cycle energy relative to gable top cartons and are computed by dividing the life cycle energy data reported in Table 4-2 by 800 MJ/1000 gallons. Thus, containers that consume the least life cycle energy have scores that are closest to zero, and gable top cartons receive the worst score of 10. Similarly, life cycle solid waste data were normalized on a 0 to 10 scale using the highest solid waste data point of 1220 kg/1000 gallons for 1-liter, single-use glass bottles. Life cycle solid waste data for flexible pouches and polycarbonate bottles were not available, so postconsumer solid waste data were used as surrogates.

Table 5-3. Milk Container Evaluation (for 0.5 gal containers)

Container Type	Environmental			Cost	Performance	Overall[a]
	Solid Waste	Energy	Total			
Flexible Pouch						
single use	.14	2.1	1.1	1.1	6.2	2.8
Gable Top Carton						
single use (2% rec.)	1.1	10.0	5.6	1.8	5.0	4.1
Glass Bottle						
refillable	1.1	4.9	3.0	1.2	10.0	4.7
single use	10.0	8.8	9.4	10.0	7.5	9.0
HDPE Bottle						
refillable	.05	2.9	1.5	0.7	3.8	2.0
single use(25% rec.)	.55	9.7	5.1	3.4	1.2	3.2
Polycarbonate Bottle						
refillable	.04	3.3	1.7	1.0	5.0	2.6

Each environmental and cost rating based on data from Tables 4-2, 4-4 and 4-8, using a scale from best to worst of 0 - 10, where the highest energy, waste and cost data for the selected containers receives a 10 and all other data normalized to this point; performance ratings convert the subjective evaluations in Table 4-11 to numerical values using + = 0.0 (the best case), 0 = 5 and - = 10 then averaging to arrive at a final rating.

[a] Overall score is an average of total environmental, cost and performance

Life cycle cost data were also adjusted to a 10 point scale by dividing total life cycle cost for each container by $969. This converts single-use glass, which is the most costly alternative selected for analysis, to a score of 10.

A quantitative score was computed for the performance criteria shown in Tables 4-11 by translating the +, 0 or - system into numerical scores of 0, 5 and 10 respectively. In this case, the lowest score represents the highest performance rating. Again, each of these criteria were weighted equally, although weighting factors that reflected the relative significance of each criterion could easily be applied.

Overall scores for milk containers were obtained by averaging their environmental, cost and performance scores. Again, equal weighting was assumed. Results of this analysis are consistent with results from the qualitative scoring method. Although this method highlights more subtle differences among the containers, finer distinctions based on numerical values should be considered in the context of their uncertainty. Unfortunately, no uncertainty limits on the published data were available.

Influence of Legal Requirements on Container Design and Selection

The various legal requirements can significantly effect the selection of the optimal packaging design. For example, Garbage Disposal Fees have become established in many communities in the United States and these fees encourage homeowners to minimize their postconsumer waste. Therefore, milk and juice suppliers in areas with Garbage Disposal Fees might benefit by switching to less bulky, recyclable, or reusable packages.

These legal requirements for milk and juice packaging are complex and dynamic. Additionally, some laws favor only one or two container types, while other rules favor different set of containers. Since these regulations are developed at the local, state and federal levels, the first step for packaging manufacturers and other stakeholders is to continuously and closely monitor regulatory developments. Once companies become aware of pending legislation, they can assess its potential effect and determine what changes, if any, are appropriate.

These legal requirements should be considered throughout the product development process, expecially during the initial stages when cost, performance and environmental issues are addressed.

One proactive step that stakeholders can pursue is to decrease the amount and costs of postconsumer waste created by their packages. Thus far, nearly all of the regulations in the United States have focused on this environmental concern instead of other burdens, such as life cycle energy consumption. Companies might be able to minimize the negative effect of, or even benefit from, future regulations by using containers that create less postconsumer solid waste.

Finally, while regulations have not explicitly focused on the total life cycle burden created by milk and juice packaging, the NPPC team assesses that the legislative trend is towards more holistic guidelines. The life cycle methodology could enable lawmakers and other stakeholders to develop regulations that most effectively decrease the environmental burdens associated with milk and juice packaging.

Decision Making from a Resin Supplier's Perspective

Dow's overall objective in this project was to use the life cycle design framework as a method of enhancing their strategic planning capabilities for producing and marketing milk and juice packaging resins. Results of the multiobjective analysis of alternative containers were presented to the Dow core team. The Dow core team and the NPPC project team recognized that the success of milk and juice packaging in today's marketplace is dictated more by cost and performance criteria than environmental considerations. Although cost and performance issues strongly dominate packaging market trends, Dow has demonstrated their commitment to promoting environmentally preferable packaging.

Dow indicated that their strategic planning would incorporate the results of this study along with an analysis of the economic profitability of the specific resins that Dow supplies to packaging fabricators. Investment decision making regarding Dow's resin production is one of the potential activities in the strategic planning process. Profitability to Dow was identified early on in this project as a financial criteria, but it was not analyzed in this study because of confidentiality issues. Because Dow is upstream in the milk and juice packaging supply chain, they have less direct involvement in packaging decisions. However, the metrics developed in this study can be used by all stakeholders in the milk and juice packaging life cycle chain. These metrics will assist Dow and other stakeholders as they pursue the environmental improvement of milk and juice packaging in a more comprehensive and objective manner.

6. Conclusions

This project used the life cycle design framework and tools to develop environmental and cost metrics for guiding milk and juice packaging design. Simplified guidelines for evaluating the environmental performance of milk and juice packaging were developed based on analysis of previous life cycle inventory studies. The packaging community does not have easy access to life cycle inventory data or the resources to perform rigorous life cycle inventory studies on a routine basis. The metrics and guidelines developed in this study are intended to respond to these limitations.

Metrics and guidelines were proposed to address life cycle energy and life cycle solid waste issues in packaging design and management. Life cycle energy can be approximated by computing the material production energy of the package. For this reason, less energy-intensive materials should be encouraged along with less material-intensive containers. For refillable containers, high refill rates should be achieved to best exploit the initial energy investment in the production of the container. Life cycle solid waste is largely determined by postconsumer packaging waste; consequently less material-intensive containers in general should be emphasized.

Caution should be taken in extending the metrics introduced here to other beverage and nonbeverage consumer packaging systems. Special issues to consider include refrigeration, pressurized containers and packages for fragile products. Unique packaging/product features that significantly alter processes along the package life cycle relative to the systems studied here may affect the applicability of the guidelines for energy and solid waste. Furthermore, life cycle data presented here do not account for processes such as pasteurization of milk, which is associated with the beverage system.

The environmental metrics developed in this project address two important issues: energy and solid waste. As published life cycle data become more widely available and techniques for impact assessment are further developed, additional metrics addressing ecological and human health consequences caused by air pollutants and water effluents should established for milk and juice packaging. These metrics will compliment the metrics proposed here and will provide a more comprehensive measure of packaging systems' environmental performance.

In addition to the environmental analysis, cost, performance and regulatory criteria were evaluated. Life cycle cost analysis considered empty container, transportation, filling and end-of-life costs such as collection and disposal. This analysis showed that the empty container was the major determinant of total life cycle cost.

A set of performance criteria including light blocking, burst resistance, ease of opening, weight, resealability and special storage requirement for empty refillable bottles were identified and subjectively scored. These criteria were weighted equally in our analysis. A survey of key stakeholders including dairies/distributors and juice producers/distributors, retailers, and customers would provide a means for weighting key criteria more accurately.

A review of regulations on international, national, state and local levels that impact containers was conducted and regulations were grouped into five categories. These categories are: fees and taxes, municipal/state/federal goals, bans and mandates, recycling/waste minimization requirements and manufacturer requirements. Based on the findings of this study and other life cycle assessments, regulations should be reviewed to encourage more environmentally preferable packaging. Regulations that support postconsumer solid waste minimization should be encouraged, but they should not prohibit systems such as the flexible pouch which are among the most environmentally preferable container systems.

Analysis of milk and juice container systems highlighted both tradeoffs and some consistent patterns among environmental, cost and performance criteria.

Refillable HDPE and polycarbonate bottles and the flexible pouch were shown to be the most environmentally preferable containers with respect to life cycle energy and solid waste criteria. These containers were also found to have the least life cycle costs. The strong correlation between least life cycle cost and least life cycle environmental burden indicates that the market system is encouraging environmentally preferable containers in these cases. In other cases, significant externalities (environmental burdens) not reflected in the market system may create a barrier for market penetration of an environmentally preferable container.

Several performance criteria present potential barriers to otherwise preferable containers. For example, containers that require significant changes in merchandising and/or consumer practices may encounter market resistance. In the case of refillable containers, merchants must accommodate returns of refillable containers while consumers must be responsible for rinsing and returning them to the grocery store. A return infrastructure has been established in bottle bill states although the trend is shifting almost exclusively toward recycling nonrefillable containers. Even though returns may be considered inconvenient, nonreturnable packaging also requires some type of consumer action, either through trash disposal or recycling. In the case of the pouch, performance issues must be addressed in order to achieve successful market penetration. A pitcher, which must be cleaned periodically, is required to hold the pouch and facilitate pouring and storage. Thus, although this system is currently popular in Canada, both the pouch and refillable bottles exhibit clear performance tradeoffs.

Public education about the environmental merits of these systems is required to influence their acceptance. In general, consumers lack information about the environmental profiles of packages and consequently give little attention to this factor in milk and juice purchases. The metrics established in this study can help educate the public, milk and juice distributors, retailers, packaging designers and material suppliers about the environmental consequences of milk and juice packaging.

Dow's participation in this project demonstrates how a material supplier can take a proactive role in life cycle management of its products. Each stakeholder in the product life cycle has a responsibility for improving the environmental performance of systems that meet societal needs. Dow's efforts in life cycle design enable the company to partner with their customers (package fabricators) in a more effective way to both enhance environmental performance and economic success. Partnerships are particularly valuable in addressing the complex parameters that affect multiple stages of a product life cycle.

Appendix A. Sample Calculations

A.1 Emission Calculations

- **Airborne and Waterborne Emissions calculated based on Boustead resin manufacturing data**

$E = efWc$

example - Particulate emissions for flexible pouch (80% LLDPE, 20% LDPE):

$ef = .00148$ kg particulate/kg [18]

$Wc = 20.8$ kg/1000 gal

$E = (.00148)(20.8) = .0308$ kg particulate/1000 gal

A.2 Cost Calculations

- **Raw material costs for glass bottles**

$CRM = \Sigma Cmi$

$Cmi = 1.31 yiWcPmi$

Glass raw material cost were calculated based on the following composition of raw materials and their respective prices as listed on the USBM (United States Bureau of Mines) world wide web page (http://www.usbm.gov) in June, 1995.

Component	yi	Pm (\$/kg)
Soda Ash	.133	.078
Feldspar	.046	.045
Lime	.161	.063
Glass Sand	.41	.019
Cullet	.25	.054

example - Cost of soda ash for 1/2 gal single use bottle:

$yi = .133$ [9]

$Wc = 1118$ kg/1000 gal

$Pmi = .078$ \$/kg (http://www.usbm.gov)

$Cmi = 1.31(.133)(1118)(.078) = 15.19$ \$/1000 gal

- **Fuel cost to transport empty containers to filling location**

$CTF = evCgDWE(.0011/n)$

example - HDPE 1/2 gal 20 trip bottles:

$ev = .0275$ gal gas/ton-mile [19]

$Cg = 1.17$ \$/gal gas {APA March 1995}

$D = 125$ miles

$WE = 268$ g/gal [9]

$n = 20$

$CTF = (.0275)(1.17)(125)(268)(.0011/20) = 0.06$ \$/1000 gal

- **Fuel cost to transport full containers to retail**

  CTR = .0011evCgD(WE + WB)
  example - HDPE 1/2 gal refillable:
  WB = 1.04 g milk/mL = 3927 g milk/gal
  other variables as above
  CTR = (.0011)(.0275)(1.17)(125)(3927 + 268) = 18.58 $/1000 gal

- **Fuel cost to back haul empty containers from retailer**

  CTB = .0011evCgDWE
  example - HDPE 1/2 gal refillable:
  variables as above
  CTB = .0011(.0275)(1.17)(125)(268) = 1.19 $/1000 gal

- **Cost of collection of separated household waste**

  CCW = CcWE(.0011/n)
  example - HDPE 20 trip 1/2 gal bottles:
  Cc = 112 $/ton [16]
  WE = 268 g/gal [9]
  n = 20
  CCW = (112)(268)(.0011/20) = 1.65 $/1000 gal

- **Cost to recycle container materials**

  CPR = riCpiWE(.0011/n)
  example - HDPE 20 trip 1/2 gal bottles:
  ri = .17 [16]
  Cpi = 188.9 $/ton [16]
  n = 20
  other variables as above
  CPR = .17(188.9)(268)(.0011/20) = 0.47 $/1000 gal

- **Cost to dispose of container waste at an incinerator**

  CID = .16WECI(.0011/n)
  example - HDPE 20 trip 1/2 gal bottles:
  CI = 71 $/ton [16]
  other variables as above
  CID = .16(268)(71)(.0011/20) = 0.17 $/1000 gal

- **Waste-to-energy value of incinerated materials**

$VE = .16WEPEeE(.0011/n)$
example - HDPE 20 trip 1/2 gal bottles:
$PE = .0015$ \$/kwh (detroit edison August 1995)
$eE = 550$ kwh/ton [16]
other variables as above
$VE = .16(268)(.0015)(550)(.0011/20) = 0.00$ \$/1000 gal

- **Cost to dispose of container waste in a landfill**

$CLD = (1 - (.16 + ri))WEPL(.0011/n)$
example - HDPE 20 trip 1/2 gal bottles:
$ri = .17$ [16]
$PL = 30.25$ \$/ton {NSWMA March 1995}
other variables as above
$CLD = (1 - (.16 + .17))(268)(30.25)(.0011/20) = 0.30$ \$/1000 gal

A.3 Energy Use Calculations

- **Total life cycle energy use estimation**

$ELC = Em + Ec + Ewf + Et$

Each of the terms (Em etc.) are calculated from various sources (listed in Table 4-3) depending on the container. example - Polycarbonate 1/2 gal 40 trip bottles:
$Em = 1018$ MJ/1000 gal
$Ec = 41.83$ MJ/1000 gal
$Ewf = 358$ MJ/1000 gal
$Et = 2$ MJ/1000 gal
$ELC = 1018 + 41.83 + 358 + 2 = 1420$ MJ/1000 gal

A.4 Solid Waste Calculations

- **Estimation of postconsumer solid waste**

$Sw = (1 - (.16 + ri))WE(1/n)$
example - HDPE 1/2 gal. single use bottle with 25% recycling:
$ri = .25$
$WE = 90.4$ g/gal [11]
$n = 1$
$Sw = (1 - (.16 + .25))(90.4)(1/1) = 53.34$ kg/1000 gal

Notation Table

Symbol	Meaning	Units
Cc	Cost of collection of presorted household waste	$/ton
CCW	Cost of collection of presorted household container waste	$/1000 gal
Cg	Cost of gasoline	$/gal gas
CI	Waste-to-energy facility tipping fee	$/ton
CID	Cost to dispose of container materials at a waste-to-energy facility	$/ton
CLD	Cost to dispose of container materials in a landfill	$/1000 gal
Cmi	Component material cost	$/1000 gal
Cpi	Cost to process specific recycled materials	$/ton
CPR	Cost of processing for recycled container materials	$/1000 gal
CRM	Cost of raw materials for container manufacture	$/1000 gal
CTB	Cost of fuel for back haul of empty containers from retailer	$/1000 gal
CTF	Cost of fuel for transportation of empty containers to filling location	$/1000 gal
CTR	Cost of fuel for transportation of full containers to retail location	$/1000 gal
D	Distance traveled	miles
E	Mass of pollutant released to the air or water	kg/1000 gal
Ec	Estimated energy use for material conversion	MJ/1000 gal
eE	Efficiency of energy generation at a waste-to-energy facility	kwh/ton
ef	Manufacturing emission factor for material resin	kg/kg resin
ELC	Estimate of life cycle energy use	MJ/1000 gal
Em	Estimated energy use for container manufacture (incl. raw materials)	MJ/1000 gal
Et	Estimated energy use for transportation of containers	MJ/1000 gal
ev	Vehicle transportation efficiency	gal gas/ton-mile
Ewf	Estimated energy use for filling containers	MJ/1000 gal
n	Number of trips made by one bottle	---
PE	Price paid by utility for generated electricity	$/kwh
PL	Landfill facility tipping fee	$/ton
Pmi	Market price of component material	$/kg
rl	Mass fraction of container material which is recycled	---
Sw	Estimated post consumer container solid waste	kg/1000 gal
VE	Value of energy generated from container materials at a waste-to-energy facility	$/1000 gal
WB	Beverage density	ton/gal
Wc	Container mass required for delivery of one functional unit	kg/1000 gal
WE	Mass of a single empty container relative to the volume delivered	g/gal
yi	Mass fraction of raw material in total container material	---

A5. Equipment Costs

Introduction

The costs of amortizing filling equipment were included in the overall cost analysis. Different packages require the purchase of different types of equipment and thus equipment costs vary from one type of package to another.

Four basic systems are used for filling milk: refillable bottle systems, single use bottle systems, paperboard container systems and pouch systems.

Methodology

For each filling system, a standard methodology was used to determine the equipment costs. First, the various components of the system were identified. Next, cost estimates of each component were obtained. These costs were then totaled and divided by the anticipated lifetime production volume of the equipment. The final cost values were reported in the units of $/1000 gallons filled.

Assumptions

The cost calculations are based on the following assumptions.

- Production level of 2 shifts/day or 16 hours/day.
- Equipment usage of 250 days/year (5 days/week).
- Equipment life without significant maintenance costs of 10 years.
- A standard fill rate of 100 half gallon containers per minute.

Limitations

Since published cost data for the milk filling process was not available, some limitations must be considered. First, this analysis focuses strictly on equipment costs and does not address the total production costs of the filling operation. Next, all cost data are approximations since this information was obtained entirely by phone interviews. Finally, equipment costs can vary substantially from one company to another. For example, companies sometimes choose to perform production steps manually (thus increasing labor costs) instead of purchasing equipment. Also various equipment characteristics, such as the degree of automation and space requirements can strongly influence equipment costs.

Refillable Bottle System

The major components of a refillable bottle system are an unscrambler, scanner, conveyor, washer, filler, coder and caser/stacker and can be purchased for approximately $495,000. Roughly 60% of this investment will be for the two primary components: the filler and washer. Based on the initial investment and anticipated equipment life, the expected equipment cost for a refillable bottle system is $4.13/1000 gallons.

Single Use Bottle System

A single use bottle system is simpler and less expensive than a refillable bottle system because the bottle checking and washing process are not performed. The three components of a single use system are a filler, coder and caser/stacker. The initial investment of $275,000 results in an expected equipment cost of $2.29/1000 gallons.

Paperboard Container System

The two pieces of equipment needed in a paperboard container system are a filler and a caser/stacker. A paperboard container filler is more expensive than other fillers because of the additional steps to bend, form and seal paperboard containers. The total initial investment is $430,000 and the equipment cost is $3.58/1000 gallons.

Pouch System

The pieces of equipment needed in a pouch system are a form/fill/seal (F/F/S) machine and a caser/stacker. This system requires the lowest initial investment, $250,000, but the equipment cost is not the lowest since the average fill rate is slightly lower. The estimated equipment cost is $2.45/1000 gallons.

Summary

The equipment costs are summarized in Table 4-8. Cost of Filling Selected Milk and Juice Containers. In order of highest to lowest costs, the filling systems are the single-use bottle, pouch, paperboard container and refillable bottle. However, these costs are a relatively small portion of the total life cycle costs for the different packaging types.

Appendix B. Environmental Management System

B.1 Introduction

One factor that strongly influences whether or not environmental concerns are addressed during the development of a new product is a company's environmental management system (EMS). Formal policies about product stewardship, reward systems and other components of a thorough EMS support the integration of environmental performance into the design process. This overview of Dow's EMS provides examples of the company's commitment to minimizing environmental burdens. The NPPC team did not evaluate the effectiveness of Dow's environmental management system. However, several elements of Dow's environmental management system that support life cycle design activities are highlighted in this summary.

Additional information about Dow's environmental performance can be found in their 1996 Progress Report on Environment, Health and Safety [36].

This overview of Dow's environmental management system will be organized into the following categories:

- Vision
- Organization
- Continuous improvement

B.2 Vision

Mission Statement

Dow addresses environmental, health and safety concerns with a single policy that guides the actions of all employees.

> Environment, Health and Safety Policy
> The Dow Chemical Company
>
> At Dow, protecting people and the environment will be a part of everything we do and every decision we make. Each employee has a responsibility in ensuring that our products and operations meet applicable government or Dow standards, whichever is more stringent.
>
> Our goal is to eliminate all injuries, prevent adverse environmental and health impacts, reduce wastes and emissions and promote resource conservation at every stage of the life cycle of our products. We will report our progress and be responsive to the public.

One key phrase within this mission statement is "every stage of the life cycle of our products." This focus on all stages helps build a corporate culture that support life cycle design efforts, such as this packaging study. In contrast, most organizations do not explicitly commit to reduce environmental burdens that occur throughout the life cycle.

Environmental Policy

Dow Chemical was one of the founders of the Chemical Manufacturers Association (CMA) and has committed to implementing the CMA's Responsible Care Initiative at all its manufacturing facilities.

The CMA Code of Management Practices is provided below. In its 1993 Environmental Report, Dow stated that 50-100% of the codes had been implemented at its various production facilities [38].

Code of Management Practices for Responsible Care

Community Awareness and Emergency Response	Aimed at assuring emergency preparedness and fostering better communications with residents of plant communities
Pollution Prevention and Waste Reduction	Designed to achieve ongoing reductions in wastes and emissions as well as manage all waste products in an environmentally sound manner
Process Safety	Aimed at preventing fires, explosions and accidental chemical releases; it covers process design, plant operation, routine maintenance and employee training
Distribution and Transportation	Designed to reduce risk to the general public, carrier, distributor, contractor, chemical industry employees and the environment posed by the transportation and storage of chemicals
Health and Safety	Intended to protect and promote the health and safety of people working at or visiting company work sites
Product Stewardship	Considers possible health, safety and environmental effects of new and existing products and promotes the safe and environmentally sound development, manufacture, transport, use and disposal of products

Since Dow is a member of the CMA, they are obligated to annually self-audit and report their progress on each of these Management Practices. One of these practices, Product Stewardship, supports life cycle design and related activities.

In addition to these codes and principles, Dow has developed a thorough set of environmental protection guidelines that detail procedures for specific activities and responsibilities [39]. The topics covered include employee training, waste management hierarchy, and soil and groundwater protection.

Core Competence

Throughout its recent history, Dow has aggressively pursued environmental objectives, such as emissions reduction, and thus developed a valuable area of expertise. To capitalize on this intellectual asset, Dow established Dow Environmental Inc. (DEI) as a wholly owned subsidiary. DEI offers waste minimization and pollution prevention consulting services to companies in the auto, chemical, food, paper and oil industries. DEI was founded in late 1994 and annual sales are anticipated to grow from the 1994 level of $100 million to $1 billion by the end of the decade [40]. Recently, Dow Chemical and Hartford Steamboiler, a parent company of Radian, Inc., have created a joint venture that incorporates Dow Environmental into a new venture called Radian International LLC.

B.3 Organization

Planning

Dow's long-term planning objectives include such programs as the EPA's 33/50 initiative. Dow and other participating companies volunteered to reduce their US emissions of 17 priority compounds 33% from 1988 baseline levels by 1993 and 50% by 1995. Dow includes all facilities worldwide in this voluntary program. By the end of 1993, Dow had reduced global emissions of the 17 priority compounds by 47% or 44,200 tons annually [37]. However, Dow acknowledges that the 50% target would likely not be reached in some locations until 1997 [41].

In a related initiative, Dow plans to reduce their US emissions of all chemicals included in the SARA Title III list. Dow set the same goals and timelines as the 33/50 program. By the end of 1992, a 35% reduction had been achieved [38]. Dow is currently revising its corporate goals on the environment and intends to implement the new goals by 2005.

Organizational Structure

To effectively incorporate life cycle concerns into the design process, a company needs sufficient organizational resources at multiple levels of the business. The NPPC team assesses that Dow's organizational structure supports their environmental goals. For example, Dow formally places responsibility for environmental activities with the individual businesses instead of the Environmental, Health and Safety (EH&S) organization. Each business has a Chief Product Steward who is responsible for all environmental issues related to the unit's product line. This responsibility covers the entire life cycle. In some businesses, an additional level of Product Stewards under the Chief Product Steward have responsibility for a smaller group of products.

Strong environmental management systems allow the top EH&S manager direct access to the CEO and other top officials. At Dow, David Buzzelli, V.P. and Corporate Director of Environmental, Health and Safety and Public Affairs, reports directly to the CEO. This provides a strong link between Dow's environmental group and the company's leadership, helping ensure that environmental concerns are addressed.

Additionally, Mr. Buzzelli leads both the Board of Directors' EH&S Board Committee and the Corporate Environmental Advisory Council. Several members of the board participate in the EH&S committee which oversees all of Dow's environmental activities. Dow's Corporate Environmental Advisory Council is a respected group of environmental leaders from outside the company who meet quarterly with the company's CEO and other top managers. The panel offers their insights and advises the company on environmental issues.

Product Development Process

An established process guides development of new products at Dow. Specific criteria must be met at each stage or the product development process will be halted. Environmental criteria that concern the product's entire life cycle are included in the initial stages of design. Thus, Dow can assess potential environmental concerns early in the design process and halt development of products that will not meet Dow's standards. The Chief Product Steward oversees the development process relative to environmental issues and confirms that new products meet all applicable criteria.

Information Systems

Quickly and efficiently obtaining data from many facilities throughout the world is a challenge for most global companies. Dow is currently developing an integrated information system that will track cost and other crucial performance data to meet this challenge. When completed, this system will provide information such as direct and indirect costs, Material Safety Data Sheets and life cycle information to the company's managers.

B.4 Continuous Improvement

Facilities and Operations

Dow expends considerable resources to protect the environment. From 1990 through 1994, Dow invested nearly $1 billion in projects to decrease emissions or otherwise improve the company's environmental performance. Additionally, continuing investments of $100 million per year are forecast for the next several years [37].

One major concern about chemical production facilities is waste disposal. Dow practices the following waste management hierarchy: source reduction, reuse, recycle, incinerate, landfill. By adhering to these prioritized steps and by processing most waste on-site, the company minimizes potential liabilities.

Since the 1950s Dow has relied on their own incinerators to reduce the volume and toxicity of their hazardous wastes [42]. As a result, Dow has been required to contribute only $26 million to Superfund cleanups while other major chemical companies with less advanced past disposal practices have made much larger contributions. Dow's 115 incinerators enable the company to handle the vast majority of their waste on-site but they also present significant environmental liabilities. In early 1995, Dow initiated a $250 million plan to reduce worldwide dioxin emissions by 90% over a ten year period. Most of the expenditures will be for modifying and consolidating their incinerators [43].

Dow's successful focus on waste reduction was acknowledged in a recent study by the Council on Economic Priorities (CEP). The CEP study compared the relative volume of hazardous waste produced by 11 chemical companies. Dow produces substantially less hazardous waste than other major chemical companies, as shown in the following list [44].

Company	Lbs Hazardous Waste Generated / $1,000 revenue
Dow Chemical	1.0
DuPont	4.8
Monsanto	13.7
Union Carbide	2.3
Industry Average	3.4

Energy efficiency is another important aspect of Dow's environmental management because most chemical production processes are energy intensive. Dow produces energy and steam via cogeneration and thus achieves efficiency levels of nearly 80%. Dow employed energy recycling, equipment modifications and waste-to-energy methods to improve its total energy efficiency by 24% during the past 10 years [38].

Performance Measures

A common business maxim is "what gets measured, gets managed." One tool that Dow is beginning to use to measure its environmental performance is environmental full-cost accounting. In many companies, costs such as waste disposal and permit fees are charged to a general fund instead of being directly charged to the business or product line that is responsible for the cost. With full-cost accounting, Dow allocates environmental costs, such as disposal fees and future site remediation charges, to the appropriate business groups and thus ensures that the financial performance of all groups includes their environmental impact [45]. Dow is currently considering inclusion of other indirect costs, such as liability insurance premiums, in its accounting procedures and is exploring mechanisms to allocate such traditionally corporate costs back to individual businesses.

Rewards and Recognition

In 1986, Dow began its Waste Reduction Always Pays Program (WRAP). The goal of this program was to motivate employees to focus on and achieve significant waste reductions. WRAP has regularly been cited as an industry best practice; one WRAP improvement reduced a latex plant's landfill waste stream by 80%. Through 1994, WRAP activities had decreased total emissions by approximately 120 million pounds per year [38].

The Environmental Care Award which recognizes "employees who have demonstrated environmental excellence" is a newer program. During 1993, over 300 projects were nominated and fifteen global awards were given. A total of 109 employees received recognition.

In addition to these formal incentive programs, employees are assessed on their ability to achieve environmental goals. Since 1993, most employees' job evaluation forms include an environmental category [36].

Auditing, Compliance Monitoring & Reporting, and Emergency Preparedness

Dow has a comprehensive schedule for conducting various audits at all facilities. These audits range from daily checks of production performance to 3-year reviews of the environmental management system [39].

Dow seeks to achieve high levels of credibility by using third party audits to periodically check its performance. For instance, the 1993 Environmental Report was supported by an audit statement from Arthur D. Little, an independent management consultant firm. Similarly, Dow was the first chemical company in the Netherlands to provide an environmental report that was certified by two independent firms [46]. These audits greatly increase the validity of the company's environmental reports as evidenced by Dow's European and Canadian subsidiaries each receiving the highest ranking of any chemical company in the Company Environmental Reporting study sponsored by the United Nations [47]. Dow received a score of four (maximum of five), whereas all other chemical companies received a three or lower.

Research and Development

To continually improve the company's performance, Dow spends 15-20% of its total research budget on environmental projects [48]. From 1992 through 1994, Dow spent approximately $1.3 billion for research and development programs [37].

Training and Education

Dow Chemical has training programs for both employees and customers. The company's ChemAware program helps educate over 15,000 solvent and chloralkali customers by providing information on proper handling, storage, recycling, disposal and safety procedures [49].

Employee education also receives attention at Dow. For example, over 300 employees at an Aratu, Brazil plant participated in day-long seminars on general environmental issues [38].

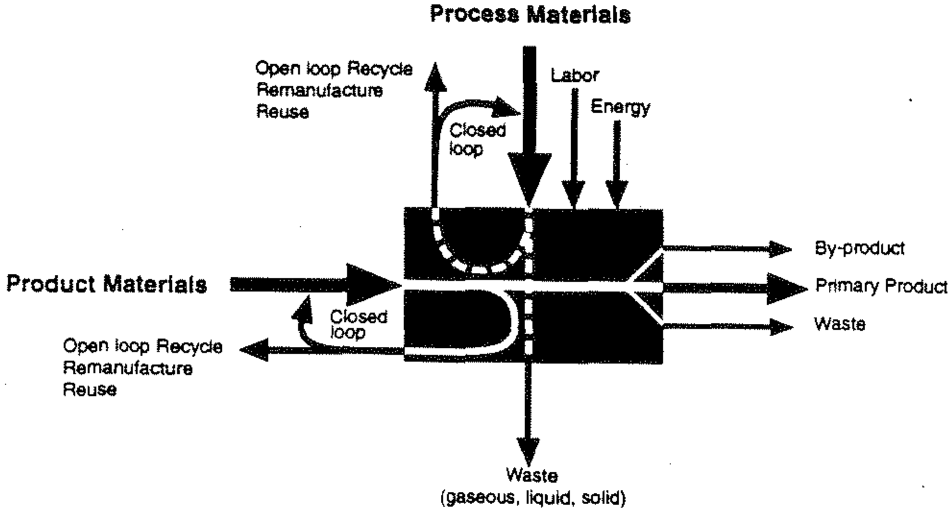


Figure C-2. Flow Diagram Template for Life Cycle Subsystem

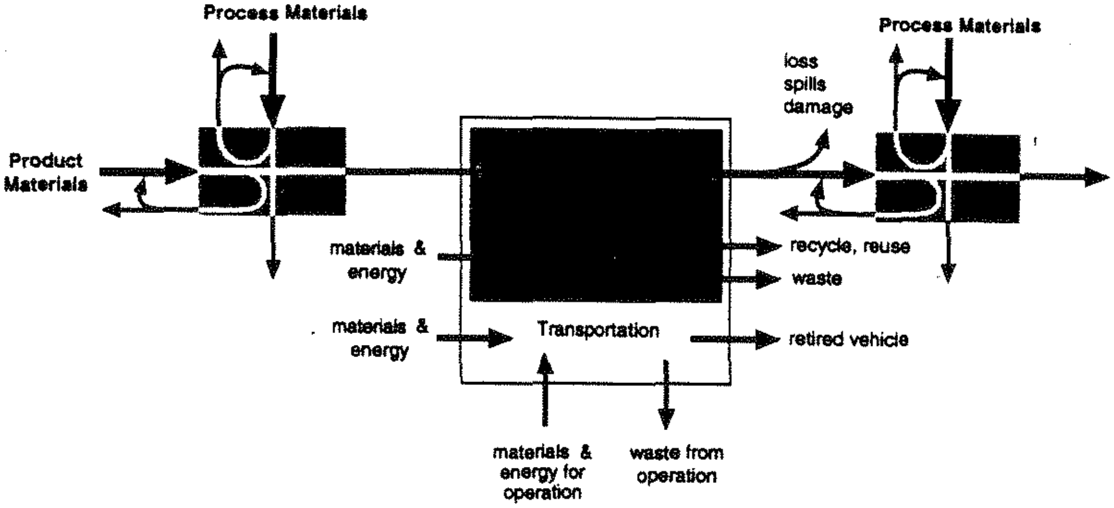


Figure C-3. Distribution Component Flow Diagram

Goals

The broad goal of life cycle design is to design and management products that are ecologically and economically sustainable. Necessary conditions for sustainability include: sustainable resource use (conserve resources, minimize depletion of non-renewable resources, use sustainable practices for managing renewable resources), pollution prevention, maintenance of ecosystem structure and function, and environmental equity (intergenerational, intersocietal, intrasocietal). All of these conditions are interrelated and highly complementary. Economic sustainability requires that the product system meet basic cost, performance, legal and cultural criteria.

The specific environmental goal of life cycle design is to minimize the aggregate life cycle environmental burdens and impacts associated with a product system. Environmental burdens include resource inputs and waste outputs which can be classified into impact categories according to life cycle impact assessment methods. [50-52] General impact categories include resource depletion and ecological and human health effects. No universally accepted method for aggregating impacts is available. Valuation is necessary to weigh and prioritize between energy use, non-energy resource use, and environmental consequences associated with waste generation and pollutant releases to the environment.

Principles

There are three main themes for guiding environmental improvement of product systems in life cycle design: systems analysis of the product life cycle; multicriteria analysis of environmental, performance, cost, and legal requirements and issues (see specification of requirements and design evaluation sections); and multistakeholder participation and cross-functional teamwork throughout the design process. The following principles relating to each of these themes have been derived from our empirical research. Many of these principles of life cycle design are already considered best design practice.

Systems Analysis

Systems analysis focuses on understanding the behavior of individual components of a system and the relationships between the collection of components that constitute the entire system. In addition the relationships between the system under study and higher order/larger scale systems should be analyzed. Both time and space dimensions must be addressed.

1. The product life cycle is a logical system for product management and design because it encompasses the total physical flow of product materials through the economy.
2. Design initiatives should establish clear system boundaries for analysis. The scope of a design activity can be restricted to smaller system boundaries such as individual life cycle stages or process steps, but this will inherently limit the opportunities for improvement.
3. Studying the relationship between product materials and related process/distribution components - systems that transform/transport the product material along the life cycle - is critical towards improving the product system design.
4. The breadth of system boundaries depends on the vision of the organization; less responsible firms do not address environmental issues much beyond the manufacturing domain whereas more ecologically responsible corporations will address the full product life cycle. The broader perspective may not yield immediate economic benefits but should lead to long term success.

Multiobjective Analysis

A successful design will satisfy multiple objectives including performance, cost, legal and environmental requirements. Many design requirements will overlap and reinforce each other while others conflict and limit design possibilities.

1. Specifying design requirements for both guiding improvement and evaluating alternatives is a critical to efficient product design and management. Clearly defined requirements that are both internal and external to an organization reduce uncertainty in decision making.
2. Understanding the interactions and conflicts between performance, cost, legal, and environmental requirements serves to highlight opportunities as well as vulnerabilities. In some cases, environmentally preferable designs may not be adopted because they do not

Collaboration

Dow participates with a wide variety of organizations to achieve environmental objectives. As mentioned previously, Dow is an active participant and leader in the Chemical Manufacturers Association. This organization requires all members to comply with its Responsible Care Initiative to improve environmental performance. Many of CMA's principles were modeled after Dow's policies.

Dow is also working with companies to increase the number of corporate environmental reports and improve their quality. Dow joined nine other industry leaders to develop the Public Environmental Reporting Initiative (PERI). This group proposed a format that addresses all areas of environmental activity and is available to any interested company. Dow's 1993 Global Environmental Report incorporated about 80% of the PERI guidelines.

Dow's collaborative efforts extend to the neighborhoods surrounding many of its facilities. The company's internal guidelines require each site to have an "active program to address the environmental concerns and needs of employees and the community" [39]. By the end of 1993, Dow had developed Community Advisory Panels throughout the world [38]. Each panel includes a diverse group of concerned citizens who meet regularly to discuss that facility's operations, emergency plans and other environmental issues.

Appendix C. Life Cycle Design Framework

Primary elements of the life cycle design framework are [3]:

- Product life cycle system
- Goals
- Principles
- Life cycle management
- Development process

Product Life Cycle System

Life cycle design and management requires an accurate definition of the product system, including both spatial and temporal boundaries. The product system can be organized by life cycle stages and product system components. Life cycle stages include materials production, manufacturing and assembly, use and service, and end-of-life management as shown in Figure C-1.

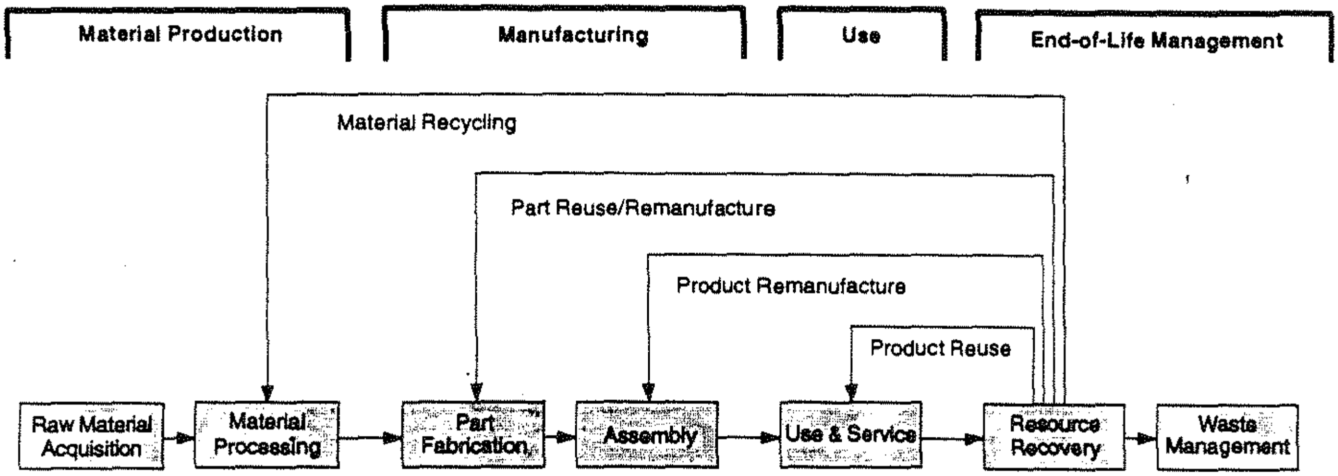


Figure C-1. Product Life Cycle System

Product, process and distribution components further characterize the product system for each life cycle stage as shown in Figures C-2 and C-3. This organization in contrast to LCA convention can better accommodate product and process design functions. The time frame for a design project ranges between a short term horizon that may emphasize incremental improvements in the product system or a long range view that explores next generation designs. Temporal boundaries also include the product development cycle, useful life of the product, and the time scale for pollutant fate, transport, and effect.

show a direct cost advantage to the manufacturer, are not supported by regulations, or do not demonstrate performance advantages.

3. Tools such as LCA can provide more comprehensive environmental assessment of alternative design and management options. More comprehensive environmental information can enhance decision analysis but data availability as well as time and cost constraints can limit the applicability of such tools.
4. Unless more specific guidance can be offered through well-established corporate environmental policies and goals or national environmental policies or goals design teams must rely on. their personal knowledge and experience to make complex tradeoffs. Tradeoffs often exist among environmental criteria, such as minimizing waste, energy and emissions as well as between environmental, cost, performance and legal criteria. Judgment is ultimately required to weight and rank criteria.

Multistakeholder Participation

The stakeholders that control the life cycle of a product can be considered part of a virtual organization. Some stakeholders share a common goal for enhancing the overall economic success of the product, while maximizing their own individual profit. Minimizing life cycle burdens, however, may not be a priority. Identifying the actors that control the life cycle of a product and their interests is a first step in achieving better life cycle management of a product.

1. Harmonizing the often diverse interests of stakeholders (suppliers, manufacturers, customers, waste managers, regulators, investors) into a product design that is technically, economically, socially and ecologically feasible/optimal is a fundamental challenge of design.
2. Partnerships are helpful in implementing changes that affect more than one stage or activity in the life cycle.
3. Initiatives to reduce life cycle environmental burdens will be limited in their effectiveness by the degree to which stakeholders recognize this a common goal for product design and management.

Life Cycle Management

Life cycle management includes all decisions and actions taken by multiple stakeholders which ultimately determine the environmental profile and sustainability of the product system. Key stakeholders are users and the public, policymakers/regulators, material and waste processors, suppliers, manufacturers, investors/shareholders, the service industry, and insurers. The design and management decisions made by the manufacturer of the end-use product may have the greatest influence over the life cycle environmental profile of a product system. It is useful to distinguish between environmental management by internal and external stakeholders. A major challenge for product manufacturers is responding to the diverse interests of external stakeholder groups.

The environmental management system (EMS) within a corporation is the organizations structure of responsibilities, policies, practices, and resources for addressing environmental issues. Several voluntary EMS standards and guidelines have been developed (BS7750, ISO 14,001, GEMI). Although EMS activities have emphasized proactive measures in addition to regulatory compliance, traditionally these systems have only addressed the manufacturing domain of the corporation [53] and did not cover end-of-life management or material acquisition processing stages.

Life Cycle Development Process

The product development process varies widely depending on the type of product and company and the design management organization within a company. In general, however, most development processes incorporate the key activities shown in Figure C-4. For life cycle design this process takes place within the context of sustainable development and life cycle management.

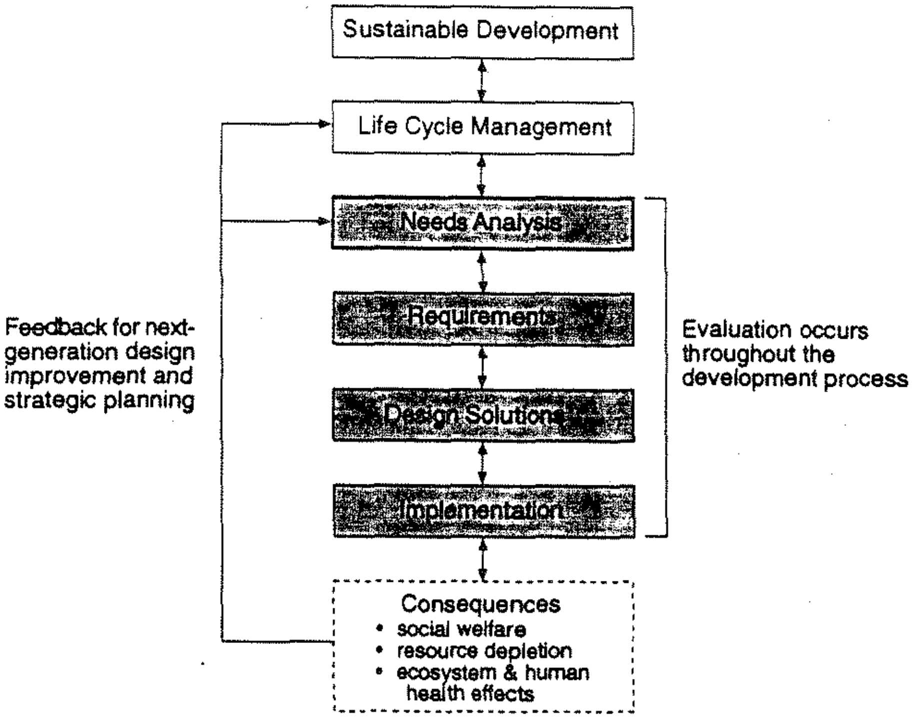


Figure C-4. Life Cycle Development Process (shaded boxes)

The life cycle design framework emphasizes three important design activities: specifying requirements to guide design improvements, selecting strategies for reducing environmental burden, and evaluating design alternatives.

The specification of requirements to guide design and management decisions is a fundamental activity for any design initiative [54]. Techniques for assisting development teams in establishing environmental design criteria have not been widely implemented. A multilayer requirements matrix has been developed as a tool to identify, organize, and evaluate environmental, cost, performance, legal and cultural design criteria [1-3]. DFX or Design for X strategies [55] such as design for recyclability, disassembly, and remanufacturability have been more widely promoted. Life cycle assessment tools for evaluating product systems [56-60] have probably received the most attention in the last two decades. The practical application of LCA tools by product development engineers, however, is limited [61,62]. It is the refinement and application of these three types of design and analysis tools that will lead to the most effective implementation of life cycle design and DFE.

Specification of Requirements

Specification of requirements is one of the most critical design functions. Requirements guide designers in translating needs and environmental objectives into successful designs. Environmental requirements should focus on minimizing natural resource consumption, energy consumption, waste generation, and human health risks as well as promoting the sustainability of ecosystems. A primary tool of life cycle design is the multicriteria matrices for specifying requirements shown in Figure C-5. Other tools for guiding designers include design checklists and guidelines.

The matrices shown in Figure C-5 allow product development teams to study the interactions and tradeoffs between environmental, cost, performance and legal requirements. Each matrix is organized by life cycle stages and product system components. Elements can then be described and tracked in as much detail as necessary. Requirements can include qualitative criteria as well as quantitative metrics.

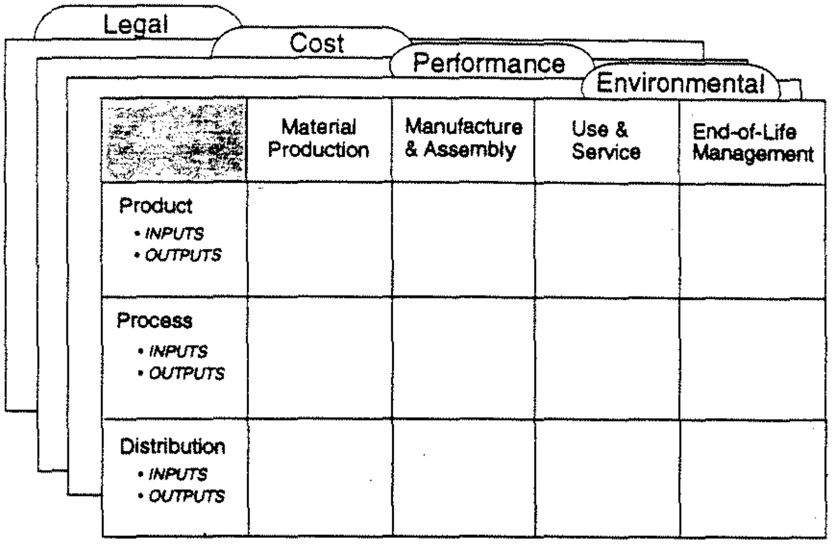


Figure C-5. Multicriteria Requirements Matrix

Design Strategies

Selecting and synthesizing design strategies for meeting the full spectrum of requirements is a major challenge of life cycle design and management. General strategies for fulfilling environmental requirements are product oriented (product life extension, remanufacturability, adaptability, serviceability, and reusability); material oriented (recycling, substitution, dematerialization); process oriented; and distribution oriented (optimize transportation and packaging). An explanation of each strategy is provided in the Life Cycle Design Guidance Manual [1].

Design Evaluation

Analysis and evaluation are required throughout the product development process as well as during strategic planning by management. Approaches for design evaluation range from comprehensive analysis tools such as life cycle assessment (LCA) to the use of single environmental metrics. LCA tools can be broadly classified as SETAC related methodologies [56-59], semi-quantitative matrix evaluation tools [63,64], and other techniques such as the Environmental Priority Strategies (EPS) system [65]. If environmental requirements for the product system are well specified, design alternatives can be checked directly against these requirements. Several tools for environmental accounting and cost analysis are also emerging [66-69]. Cost analysis for product development is often the most influential tool guiding decision making. Key issues of environmental accounting are: measuring environmental costs, allocating environmental costs to specific cost centers, and internalizing environmental costs.

In principle, LCA represents the most accurate tool for design evaluation in life cycle design and DFE. Many methodological problems, however, currently limit LCA's applicability to design [61]. Costs to conduct a LCA can be prohibitive, especially to small firms, and time requirements may not be compatible with short development cycles [70,62]. Although significant progress has been made towards standardizing life cycle inventory analysis, [59,57,56,60] results can still vary significantly [71,72]. Such discrepancies can be attributed to differences in system boundaries, rules for allocation of inputs and outputs between product systems, and data availability and quality issues.

Incommensurable data presents another major challenge to LCA and other environmental analysis tools. A large complex set of inventory data can be overwhelming to designers and managers who often lack environmental training and expertise. The problem of evaluating environmental data remains inherently complicated when impacts are expressed in different measuring units (e.g., kilojoules, cancer risks, or kilograms of solid waste). Furthermore, impact assessment models vary widely in complexity and uncertainty.

Even if much better assessment tools existed, LCA has inherent limitations in design and management, because the complete set of environmental effects associated with a product system can not be evaluated until a design has been specified in detail [61]. This limitation indicates the importance for requirements matrices, checklists and design guidelines which can be implemented during conceptual design phases.

Appendix D. Acronyms Table

CEP - Council on Economic Priorities
CMA - Chemical Manufacturers Association
DFE - Design For Environment
EH&S - Environmental, Health & Safety
EMS - Environmental Managment System
EPA - U.S. Environmental Protection Agency
HDPE - High Density Polyethylene
LCA - Life Cycle Assessment
LCD - Life Cycle Design
LDPE - Low Density Polyethylene
LLDPE - Linear Low Density Polyethylene
NPPC - National Pollution Prevention Center
NRMRL - National Risk Management Research Laboratory
PC - Polycarbonate
PERI - Public Environmental Reporting Initiative
PET - Polyethylene Terpthalate
WRAP - Dow Chemical Waste Reduction Always Pays Program

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