LIFE CYCLE INVENTORY
OF REUSABLE PLASTIC CONTAINERS
AND DISPLAY-READY CORRUGATED CONTAINERS
USED FOR FRESH PRODUCE APPLICATIONS

FINAL REPORT

Prepared For

REUSABLE PALLET & CONTAINER COALITION

By

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A DIVISION OF EASTERN RESEARCH GROUP, INC.

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PREFACE

The report that follows is a Life Cycle Inventory (LCI) of two types of shipping containers used for shipping fresh produce: reusable plastic containers (RPCs) and display-ready common footprint corrugated containers (DRCs). The study was conducted for the Reusable Pallet and Container Coalition (RPCC) under the management of Jeanie Johnson, Executive Director of RPCC.

At Franklin Associates, the project was managed by Beverly J. Sauer, who served as primary life cycle analyst in developing the model, running the models and analyzing results, and preparing the report. James Littlefield assisted with data analysis and modeling. William E. Franklin provided overall project oversight as Principal in Charge.

Franklin Associates gratefully acknowledges significant contributions to this project by RPCC member companies, whose assistance in providing data on RPC processes and characterizing the operation of RPC pooling systems was invaluable.

In analyzing and presenting the results of this LCI study, the report makes no claims regarding the superiority or equivalence of the container systems studied. Comparative assertions are defined by ISO 14040 as “environmental claim(s) regarding the superiority or equivalence of one product versus a competing product which performs the same function.” The authors discourage the use of this study as the sole basis for comparative assertions of environmental superiority or preferability.

This study was conducted for RPCC by Franklin Associates as an independent contractor. The findings and conclusions presented in this report are strictly those of Franklin Associates. Franklin Associates makes no statements nor supports any conclusions other than those presented in this report.

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INTRODUCTION

Continuous environmental improvement has become a principle of most business and government organizations, with particular attention to reductions in energy use, reductions in greenhouse gases (GHG) and reductions in solid waste. The report that follows is a supply chain analysis of two types of packaging used for shipping fresh produce. The two types of containers evaluated are reusable plastic containers (RPCs) and display-ready common footprint corrugated containers (DRCs). The analysis includes different sizes and weights of containers used in ten produce applications.

This study of the two types of containers is a Life Cycle Inventory (LCI), which identifies and quantifies energy and material inputs and emissions to the air, water, and land over the life cycle of a product system. The life cycle steps analyzed in this study include extraction of raw materials from the earth, materials and container manufacture, outgoing transportation of containers, backhauling and washing of empty RPCs, recycling of DRCs and RPCs, and end-of-life disposition. Thus, the study is a full systems analysis for the entire supply chain for the two types of containers. The discussion of LCI results focuses on energy use, GHG releases, and solid waste.

PURPOSE OF THE STUDY

The purpose of this study is to identify and quantify the energy, solid wastes, and atmospheric and waterborne emissions associated with RPCs and DRCs used for shipping fresh produce. Ten different high-volume produce applications were analyzed.

KEY FINDINGS

For the average condition produce shipping scenarios analyzed within the defined scope of this study, findings indicate that, on average across all 10 produce applications, RPCs:

- Require 39% less total energy
- Produce 95% less total solid waste
- Generate 29% less total greenhouse gas emissions

than do DRCs for corresponding produce applications. These findings can be explained as follows:

One factor dominates the findings. Multiple trips ("turns") in an RPC closed operating system lead to materials efficiencies that create relatively low environmental burdens that are only partly offset by backhaul and cleaning steps. In the DRC system a container is manufactured for each trip to retail. Recovery and recycling rates for DRCs are high, but the production step (including recycling) introduces a higher level of burdens. In the case of RPCs and DRCs, multiple reuses of RPCs result in lower environmental burdens than single-trip DRC containers.

- **The more lifetime uses that can be achieved for an RPC, the lower the environmental burdens for container production that are allocated to each use of the container.** Thus, the success of a reusable container system depends on keeping RPCs in circulation for repeated reuse and recycling.

  Maximum reductions in container production burdens and disposal burdens are achieved by multiple uses of a container without remanufacturing (i.e., RPC reuse compared to DRC recycling).

- Total System Energy Results

  In almost every product application studied, the benefits of the closed-loop RPC pooling operation more than offset the benefits of lighter container weight and a high recycling rate for corrugated containers. As a result, total energy requirements for RPCs are lower than corresponding DRCs in all average use scenarios. RPCs also have lower total energy requirements than corresponding DRCs in eight out of ten alternative scenarios evaluating the effects of lower reuse rates and higher loss rates for RPCs compared to lightweighted DRCs.

- Total System GHG Results

  GHG results generally track closely with fossil fuel consumption, since that is the source of the majority of GHG emissions. GHG comparisons for the RPC and DRC average scenarios are lower for RPCs for 18 of 20 average scenarios covering 10 produce applications.

- Total System Solid Waste Results

  RPCs produce less solid waste than corresponding DRCs in all produce applications and scenarios. This is due to several key factors:

  - The burdens for production of RPCs are allocated over a (large) number of useful lives,
  - RPCs that remain in the closed-loop pooling system are recycled when they are removed from service,
  - Losses of RPCs from the closed-loop system are small,

  - DRCs make only one trip before they are recycled (requiring repulping and remanufacture) or disposed.

- EPA has long used the waste management hierarchy of “Reduce, Reuse, Recycle.” This LCI considers all three techniques: reduction in weight of DRCs, reuse of RPCs, and recycling of both RPCs and DRCs. The results indicate that, for the produce applications studied, **reuse** with closed-loop recycling at end of life is the most efficient means of reducing not only solid waste but also energy use and GHG emissions. Reduction in container weight was observed to reduce not only the environmental burdens for container production and end-of-life management, but also the burdens for container transportation (less weight to haul = less fuel consumption). In this study, lightweighting was evaluated only for DRCs; however, the observations about the benefits of lightweighting hold true for any type of container.

The following sections describe in more detail the systems studied, data sources, key modeling assumptions, and LCI results.

SYSTEMS STUDIED

Two general types of container systems are analyzed in this study: RPCs and DRCs. Various sizes and weights of containers are analyzed in the study for use in ten fresh produce applications. The produce applications studied were selected from high-volume commodities representing a range of product sizes and weights and a range of container sizes used for packing. Table ES-1 shows the container weights and packing data for each fresh produce application.

Table ES-1

CONTAINER WEIGHTS AND PACKING

	Average Weight per Empty Container (lb)		Pounds of Produce per Container		Thousand Container Movements Required to Ship 1,000 Tons of Produce	
	RPC	**DRC**	**RPC**	**DRC**	**RPC**	**DRC**
Apples	5.4	1.8	41	40	48.5	50.0
Bell Peppers	4.8	2.0	25	26	79.4	76.9
Carrots	5.1	2.0	48	48	41.7	41.7
Grapes	3.3	1.7	19	21	105	95.2
Lettuce - head	5.3	2.5	35	40	56.8	50.0
Oranges	4.8	2.2	40	40	50.0	50.0
Peaches/Nectarines	3.5	1.9	34	35	58.4	57.1
Onions	3.9	1.8	40	40	50.0	50.0
Tomatoes	3.9	1.5	28	28	71.4	71.4
Strawberries	2.5	0.9	9	9	222	222

The corrugated containers analyzed in this study are “common footprint” containers that have the same base dimensions as RPCs; thus, the pallet and truck loading are very similar for RPCs and DRCs in corresponding produce applications. There are some minor loading differences due to variations in container heights. Also, in some applications trucks pack out by weight sooner with RPCs compared to corresponding DRCs due to the heavier container weight for RPCs.

The RPCs analyzed in this study operate in a closed pooling system. In this type of system, ownership of the containers is maintained by a company (the pooler) that operates depots at various locations across the country. The depots are the locations where containers are issued to users and returned from users. The user leases the containers from the pooler, and the pooler inspects containers after use, cleans them, and keeps them in good repair so they can be used over and over again. In addition to high reuse rates, another benefit of maintained ownership is that the pooler maintains control of the containers for end-of-life management. Damaged containers are removed from service by the pooler and sent to RPC manufacturers to be reground and made back into containers.

RPCs are modeled at the average weight, lifetime use rate, and loss rate reported by four poolers. DRCs are modeled at the reported container weight for one-piece folded boxes. Additional scenarios are evaluated for sensitivity analysis, to examine the effects of reduced backhaul distance for RPCs, a lower reuse rate and higher loss rate for RPCs, and container lightweighting for DRCs.

FUNCTIONAL UNIT

In order to ensure a valid basis for comparison for the container systems studied, a common functional unit is essential. For this study, the functional unit for each system is shipment of 1,000 short tons (two million pounds) of each type of produce using RPCs and DRCs.

SCOPE AND BOUNDARIES

The produce container system models include the following steps:

- Production of virgin polypropylene resin (beginning with raw material extraction) and RPC manufacture
- Production of corrugated containers with industry average recycled content (including collection and processing of postconsumer corrugated boxes and industrial scrap as well as virgin inputs to box manufacture)
- Transportation of containers to growers
- Transportation of packed containers from growers to retail
- Backhauling, washing, and reissue of RPCs
- Recycling and disposal of DRCs at end of life
- Recycling of RPCs retired from service

- Disposal of RPCs lost during use

The analysis does not include environmental burdens for growing the produce, nor is any additional packaging of produce (e.g., plastic film bags, individual strawberry containers, etc.) included in the analysis. Printing of corrugated boxes and labeling of RPCs is not included. The analysis does not attempt to evaluate differences in produce damage and spoilage associated with use of the different types of containers. The analysis does not include any analysis of differences in labor associated with the different containers.

DATA SOURCES

Data on RPC systems, including RPC weights, reuse and loss rates, loading, transportation modes and distances, and washing, were provided by RPCC member companies. Weights and loading for DRCs were provided by a DRC producer. DRC weights were validated using Corrugated Packaging Alliance (CPA) case studies on three produce applications that correspond to applications analyzed in this study.

Production of RPCs was modeled using industry average data for the production of polypropylene resin and RPC fabrication data provided by RPC producers. Production of DRCs was modeled using industry average data for the production of the various virgin and recycled paperboard inputs to linerboard and medium, production of linerboard and medium, and box fabrication, recovery, and recycling. Paperboard industry statistics were used to model the composition and recycled content of linerboard and medium and the iterative cycles associated with recovery and recycling of boxes at end of life.

MODELING APPROACH

Key data and issues in modeling the container systems include RPC lifetime trip rates, pooling system operation, RPC backhauling, DRC box weights, and end-of-life management of containers. A more detailed discussion of individual issues can be found in the corresponding sections of Chapter 2.

RPC Lifetime Trip Rates

Data on average RPC lifetime trip rates were provided for this study by RPCC member companies involved in produce shipping using pooled RPCs. The total number of lifetime trips for an RPC is equal to the number of trips (“turns”) per year times the number of years the container remains in service. The number of turns per year depends on the transportation distances and handling logistics, not on the properties of the RPC itself.

This study uses the standard LCI basis of product functionality, which in this case is the average number of trips an RPC is expected to make before it is removed from service for wear or damage, regardless of the number of years it takes to make that number of trips. The lifetime trip rate affects the modeling of the number of RPCs (and associated resin) that must be produced to replace the RPCs “used up” for shipping 1,000 tons of produce, as described in the following section.

RPC Pooling Operation

An important assumption in the modeling of RPC systems in this analysis is the assumption that the pooling system is a shared-use pool operating at steady state. That is, it is assumed that a pool of RPCs is already in existence and available for any and all applications (produce or other) that use each size of RPCs. Thus, each produce system is charged with replacing the number of RPCs “used up” by shipping that commodity, based on the number of shipments in RPCs required to move the produce divided by the useful lives per RPC, plus replacement of losses of RPCs during use, e.g., due to theft.

Although an excess supply of RPCs (“float”) must be in place throughout the system in order to ensure that a sufficient number of RPCs are circulating to and from growers and retailers within the time frame to meet their needs, these RPCs are available for any and all uses of each size RPC rather than designated specifically for a certain type of produce.

For a shared-use pool of RPCs, any use of the RPCs for any application is withdrawing RPC **uses** from the pool rather than individual containers. To calculate the number of RPCs “used up” for shipping 1,000 tons of produce, the number of RPC trips required to ship 1,000 tons is divided by the number of lifetime trips per RPC and adjusted for the loss rate to determine the number of RPCs that must be produced to replace the RPC uses withdrawn from the pool.

RPC Backhauling

The pooling system operates nationwide, enabling growers to obtain RPCs from the nearest pooling location, regardless of where the RPCs were used prior to arrival at that pooling location. For this study, poolers reported the full backhaul distance from produce retailer to pooler back to grower (including routing through a washing facility) *specific to each produce application*.

In reality, taking into account movements of RPCs from all uses to all pooling locations, the average distance from an end user to a pooling location to a grower is likely considerably shorter, since empty RPCs returned to a pooler may be reissued to any user needing that size RPC; they are not required to be returned to the original grower location. However, because it is not possible to estimate with certainty where the empty RPCs came from to the pooling location, this analysis modeled RPC backhauling for each commodity as if the RPCs used for each type of produce were returned to the growers of that type of produce. This would be the maximum backhaul distance. For sensitivity analysis, each commodity is also evaluated at 20% reduced backhaul distance to illustrate the probable effect of shared-use pool operation.

DRC Box Weights

The weights of DRCs used in the average scenario are the weights reported by a producer of DRC containers and represent the weight of a one-piece folded box, which is the more prevalent DRC used in produce applications according to a contact at the CPA. Bliss boxes are another type of DRC container that can be used. Bliss boxes provide more strength per unit weight, but are more expensive and require that the user purchase equipment to convert the blank into a box by folding and gluing.

The DRC box weights provided by the DRC producer were compared to box weights in three case studies on costs of produce shipping in RPCs and corrugated published by the CPA. For the three produce applications (apples, oranges, and grapes), the corrugated box weights used in the CPA studies were 10 to 20 percent higher than the box weights modeled in the LCI study for the same produce applications. Thus, the weights used in the LCI study for the "average" DRC scenario already appear to be somewhat conservative for corrugated. In addition, to account for potential lightweighting of corrugated containers (e.g., achieved through redesign or perhaps use of a bliss box), the conservative scenario in the LCI evaluated DRCs at 10 percent lightweighting, i.e., 90 percent of the weight reported by the DRC producer.

End-of-life Management

RPCs. Poolers report that RPCs that are removed from service are returned to RPC producers, where they are reground and used to produce new RPCs, which will in turn be recycled when they are retired from service. This is considered closed-loop recycling. No burdens for disposal are assigned to the RPCs that remain in the system and are repeatedly recycled back into RPCs when they are removed from service after each multi-trip, multi-year life cycle. Retired RPCs that are not recycled back into RPCs would most likely be recycled into durable products such as plastic lumber, indefinitely diverting the material from disposal.

Although the material in the RPCs may ultimately be recycled many times, this analysis uses a conservative approach in allocating the burdens for production of the virgin material between the initial use and the first recycled use, rather than allocating over a larger number of lifetime cycles of RPC use and recycling.

All RPCs that are lost from the system during use are modeled as entering the municipal solid waste stream, where they are managed by a combination of landfilling and waste-to-energy incineration, as described below.

DRCs. The recovery rate for corrugated containers is about 70 percent overall in the U.S.[1]; however, recovery of corrugated containers from grocery stores is much higher and is modeled in this study at a rate of 95 percent. Thus, only 5 percent of corrugated

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[1] U.S. Environmental Protection Agency. **Municipal Solid Waste in the United States: 2001 Facts and Figures.** EPA/530-R-03-011. October 2003. Table 22.

containers are modeled as being directly disposed after use. For the 95 percent of boxes that are recovered, burdens for production and disposal of the box are allocated between the produce box and secondary uses of the recovered fiber based on the percentages of open- and closed-loop recycled content in the box. Further explanation of this allocation can be found in the Recycling Allocation section of Chapter 1.

For RPCs and DRCs that are disposed, disposal is modeled as 80 percent landfill and 20 percent waste-to-energy incineration[2]. An energy credit is assigned to each system based on the weight of containers burned and the higher heating value of the material.

LCI RESULTS

Energy, solid waste, and greenhouse gas results for each application are summarized in Table ES-2.

For each produce application, Table ES-2 shows results for three RPC scenarios and two DRC scenarios, representing average container weights, reuse rates, and losses as well as scenarios with reduced RPC backhauling, reduced RPC reuse rate, increased RPC loss rate, and DRC lightweighting. Lower reuse rates and higher loss rates for RPCs mean that more containers must be manufactured to transport the same quantity of produce, more lost containers end up in solid waste, and there is more material to be recycled from retired containers.

DRCs results are shown for container weights reported by a DRC producer and for 10 percent lightweighting. For the DRCs, lightweighting reduces manufacturing requirements, transportation requirements, and disposal burdens.

Table ES-2 shows percent difference comparisons between RPCs and DRCs for the following scenarios:

- Average RPC (average reuse and loss rate) at maximum backhaul distance compared to average DRC (reported weight for folded box)
- Average RPC (average reuse and loss rate) at 20% reduced backhaul distance (“80% BH” in table) compared to average DRC
- Conservative scenario: RPC at 75% of average reuse rate, twice the average loss rate, maximum backhaul distance compared to DRC with 10% lightweighting.

Based on the experience and professional judgment of the analysts and supporting statistical arguments (see Chapter 3), a minimum percent difference of 10% is used as the threshold for considering a difference in energy results meaningful, while a minimum percent difference of 25% is used for GHG. Differences that are inconclusive (e.g., below these thresholds) are shaded in gray in the table.

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[2] Ibid. Table 29.

Table ES-2
Summary of LCI Results for All Produce Container Scenarios
(All results reported on basis of 1,000 tons of produce shipped)

	TOTAL ENERGY (million Btu)							
	RPCs			DRCs		Percent Difference*		
	avg	avg with 80% BH	conserv	avg	conserv	avg DRC, avg RPC	avg DRC, avg RPC w/80% BH	conserv
Apples	853	789	900	1,073	966	23%	31%	7%
Bell Peppers	1,121	1,040	1,188	1,818	1,637	47%	54%	32%
Carrots	531	504	567	981	883	60%	64%	44%
Grapes	1,080	1,010	1,141	1,920	1,729	56%	62%	41%
Lettuce - head	905	839	958	1,485	1,338	49%	56%	33%
Oranges	650	601	692	1,241	1,117	63%	70%	47%
Peaches/Nectarines	671	621	707	1,284	1,156	63%	70%	48%
Onions	533	501	566	1,075	968	67%	73%	52%
Tomatoes	797	736	846	1,241	1,117	44%	51%	28%
Strawberries	1,975	1,858	2,071	2,455	2,212	22%	28%	7%

	TOTAL SOLID WASTE (tons)							
	RPCs			DRCs		DRC/RPC		
	avg	avg with 80% BH	conserv	avg	conserv	avg DRC, avg RPC	avg DRC, avg RPC w/80% BH	conserv
Apples	1.35	1.32	1.60	25.3	22.8	18.8	19.2	14.2
Bell Peppers	1.99	1.96	2.37	43.2	38.9	21.7	22.1	16.4
Carrots	1.04	1.03	1.25	23.4	21.1	22.4	22.7	16.8
Grapes	2.15	2.12	2.50	45.5	41.0	21.2	21.4	16.4
Lettuce - head	1.53	1.50	1.82	35.1	31.6	23.0	23.5	17.3
Oranges	1.23	1.21	1.47	30.2	27.2	24.5	24.9	18.5
Peaches/Nectarines	1.25	1.23	1.45	30.5	27.5	24.4	24.8	18.9
Onions	1.09	1.07	1.28	25.7	23.1	23.7	24.0	18.2
Tomatoes	1.57	1.54	1.84	30.1	27.1	19.2	19.6	14.7
Strawberries	4.03	3.98	4.57	55.6	50.1	13.8	14.0	11.0

	TOTAL GREENHOUSE GAS (tons CO2 equivalents)							
	RPCs			DRCs		Percent Difference*		
	avg	avg with 80% BH	conserv	avg	conserv	avg DRC, avg RPC	avg DRC, avg RPC w/80% BH	conserv
Apples	62.7	57.5	64.3	67.1	60.5	7%	15%	-6%
Bell Peppers	81.3	74.7	83.6	113	102	33%	41%	20%
Carrots	37.8	35.6	39.0	61.1	55.1	47%	53%	34%
Grapes	78.3	72.6	80.4	120	108	42%	49%	29%
Lettuce - head	65.9	60.5	67.7	92.8	83.6	34%	42%	21%
Oranges	46.6	42.7	48.1	76.9	69.2	49%	57%	36%
Peaches/Nectarines	49.0	44.9	50.2	80.1	72.2	48%	56%	36%
Onions	38.2	35.7	39.4	67.0	60.3	55%	61%	42%
Tomatoes	57.5	52.5	59.3	77.0	69.3	29%	38%	16%
Strawberries	145	135	148	155	140	7%	14%	-6%

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* Percent difference = (difference between system results)/(average of system results)
Percent difference is considered inconclusive if <10% for total energy or <25% for GHG.
Inconclusive results comparisons in the table are shaded gray.
Average scenario defined as RPC with average use/loss rates (separate results for maximum and 80% backhaul) and reported weight DRC.
Conservative scenario for RPC is use rate at 75% of average and loss rate 2 x the average loss rate. Conservative scenario for DRC is 10% lightweighting.

Energy Results

Energy totals include process energy and transportation energy. For RPCs, total energy also includes the energy content of fuel resources (petroleum and natural gas) used as material feedstocks for the production of plastic resin.

DRCs require more energy than RPCs for cradle-to-production manufacture of containers, transportation of new containers to growers, and end-of-life management. RPCs require more energy for transportation of packed containers from growers to grocery stores. RPCs also require energy for backhauling and washing; there are no corresponding energy requirements for DRCs.

Total energy comparisons are summarized in Table ES-2 and shown graphically in Figures ES-1 for average scenarios and ES-2 for conservative scenarios. All comparisons in all scenarios are lower for RPCs except the conservative scenario comparisons for apples and strawberries, where the differences were inconclusive.

Solid Waste Results

Total solid wastes include process wastes, process fuel-related wastes, fuel-related wastes for container transportation, and postconsumer wastes. Process wastes are wastes that directly result from a process, such as sludges, unusable byproducts, unrecycled off-spec product or trim scrap, etc. Fuel-related wastes are the wastes associated with the production and combustion of fuels used for process energy or for transportation fuel. Postconsumer wastes are the wastes resulting from the end-of-life management of containers and include landfilled containers and ash from containers that are burned.

Comparisons of solid waste by weight are summarized in Table ES-2 and shown graphically in Figure ES-3 for average scenarios and Figure ES-4 for conservative scenarios. RPC systems produce a fraction of the solid wastes produced by corresponding DRC systems. On average, DRCs produce 21 times as many tons of solid waste as average RPCs with maximum and 20% reduced backhaul, and 16 times more solid waste than RPCs in the conservative scenario.

Emissions Results

Detailed lists of the atmospheric and waterborne emissions for each container system in each business unit are shown in Chapter 2. The discussion here focuses on the high priority atmospheric issue of greenhouse gas (GHG) emissions. The primary three atmospheric emissions reported in this analysis that contribute to global warming are fossil fuel-derived carbon dioxide, methane, and nitrous oxide. (Carbon dioxide released from the combustion of wood wastes is considered “climate neutral”, as it simply returns to the atmosphere the carbon dioxide that was taken up by the tree during its growing cycle.) The global warming potential shown in Table ES-2 and Figure ES-3 for each system is the sum of the weights of fossil carbon dioxide, methane, and nitrous oxide emissions multiplied by their 100-year global warming potentials.

A summary of GHG results is shown in Table ES-2. Figure ES-5 shows comparative GHG results for average scenarios, and Figure ES-6 shows comparative results for conservative scenarios. For the average scenarios, total GHG emissions for RPCs are lower than for corresponding DRCs for all applications except apples and strawberries. These are the applications that had the closest energy results. GHG results generally track closely with fossil fuel consumption, since that is the source of the majority of GHG emissions. For the conservative scenario comparisons, RPCs had lower GHG emissions in half the comparisons, and half were inconclusive. Lower RPC use rates and higher loss rates increase the GHG emissions for RPC production, while the container transportation GHG that dominate GHG for RPCs remain constant. Lightweighting DRCs reduces GHG burdens for all life cycle stages – production GHG, which are the dominant source of GHG for DRCs, transportation GHG, and end-of-life GHG.

Figure ES-1. Average Scenario Energy Comparison
(RPC at avg reuse and loss rate, max backhaul and 80% backhaul; DRC at reported weight)

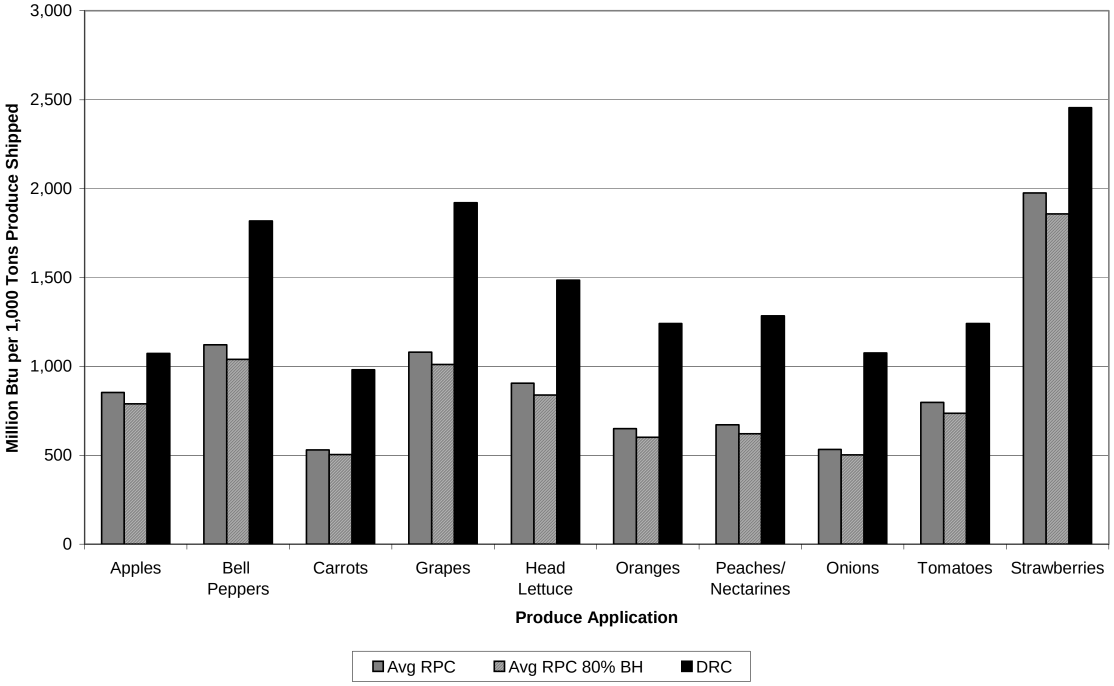


Figure ES-2. Conservative Scenario Energy Comparison
(RPC at 3/4 avg reuse rate and 2x avg loss rate, 10% lightweighted DRC)

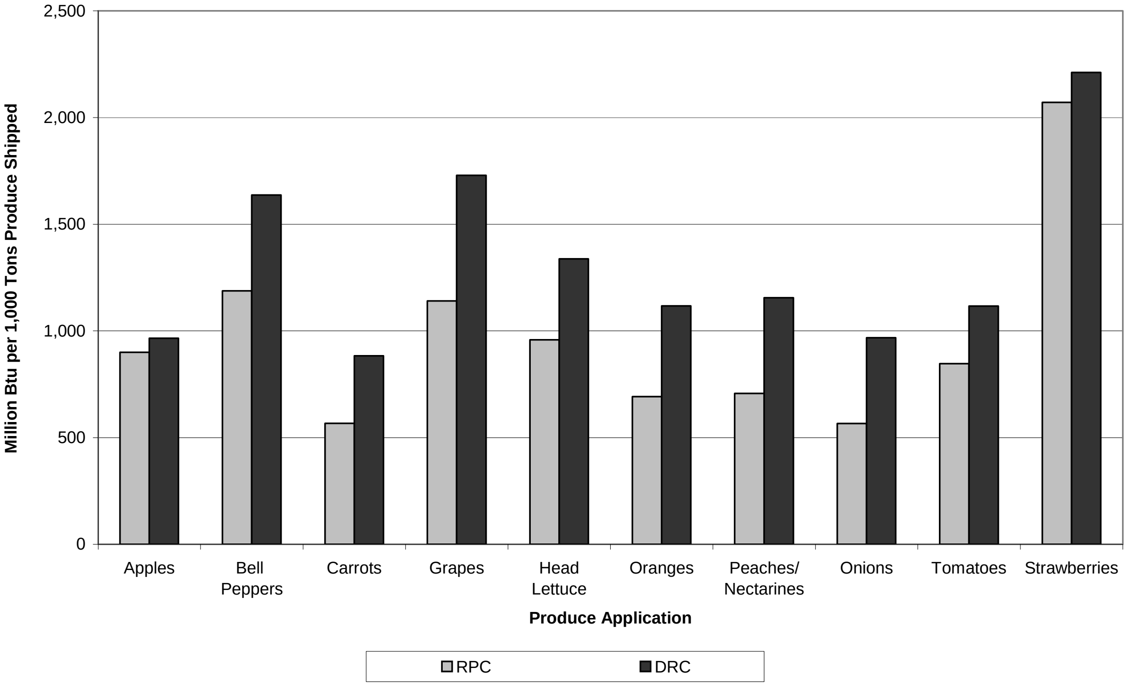


Figure ES-3. Average Scenario Solid Waste Comparison

(RPC at avg reuse and loss rate, max backhaul and 80% backhaul; DRC at reported weight)

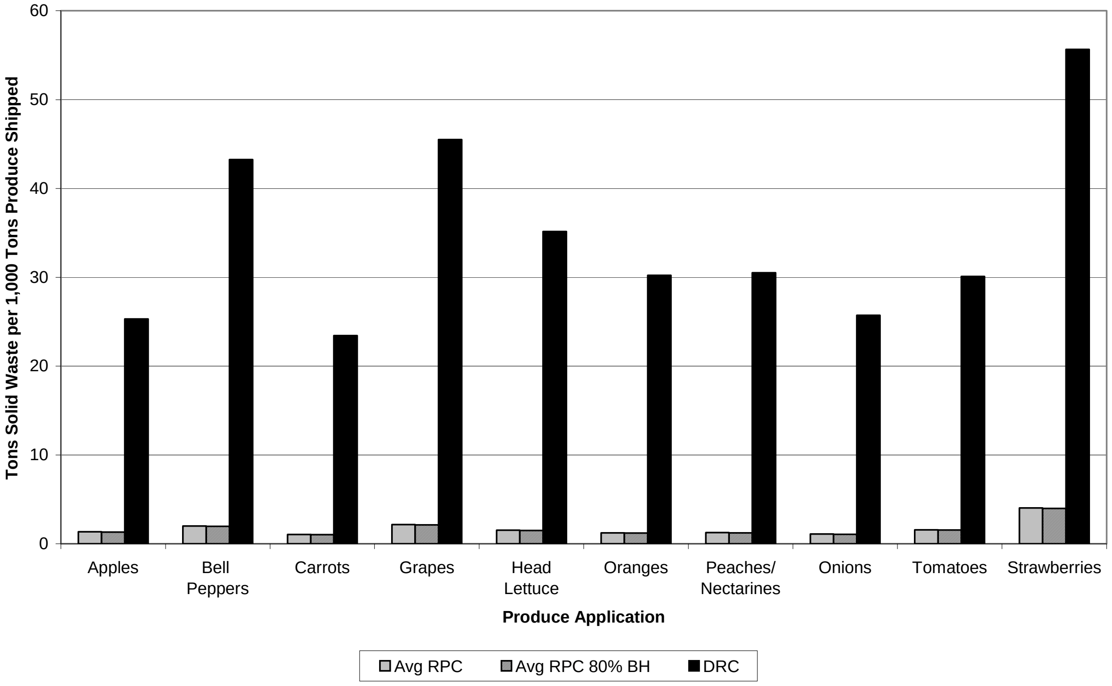


Figure ES-4. Conservative Scenario Solid Waste Comparison

(RPC at 3/4 avg reuse rate and 2x avg loss rate, 10% lightweighted DRC)

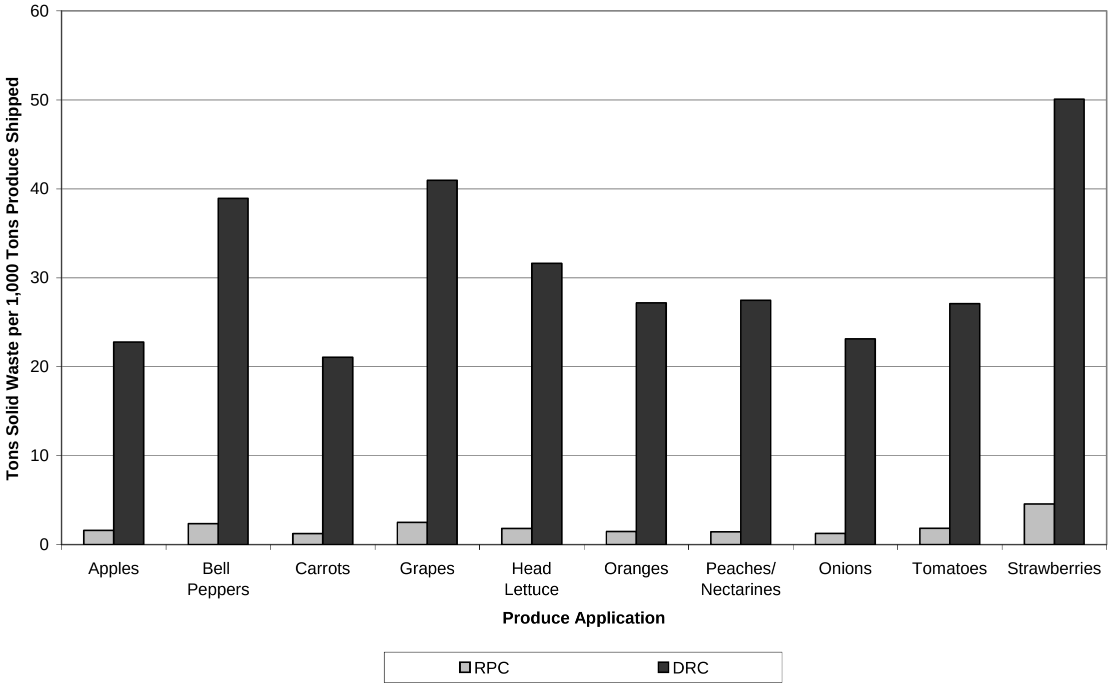


Figure ES-5. Average Scenario GHG Comparison
(RPC at avg reuse and loss rate, max backhaul and 80% backhaul; DRC at reported weight)

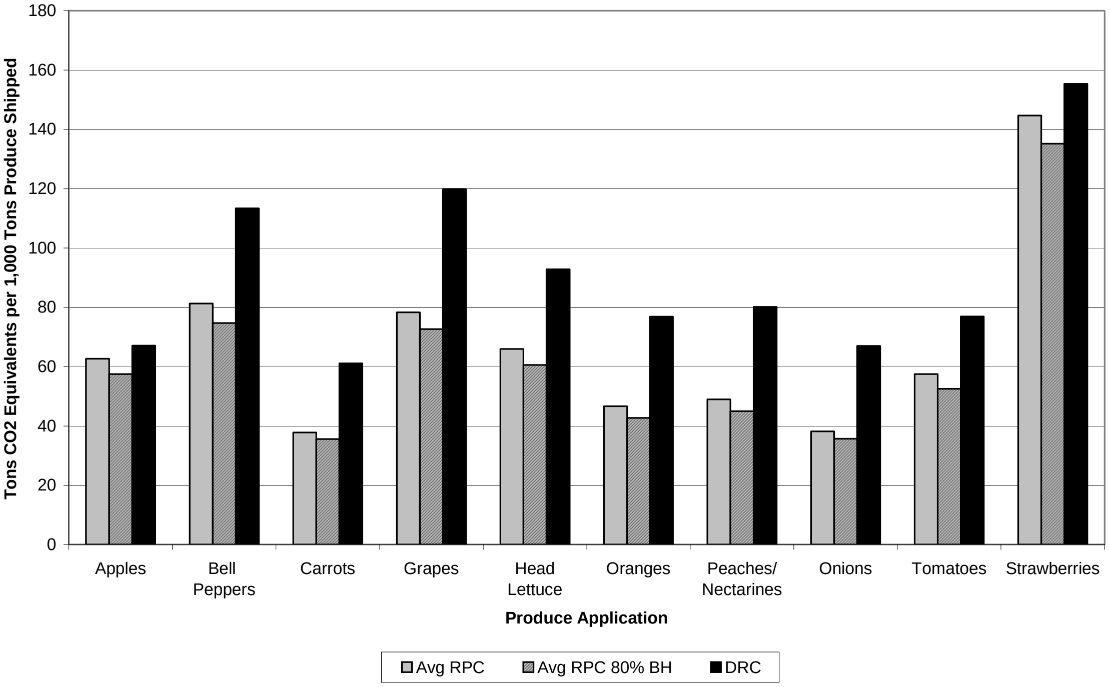
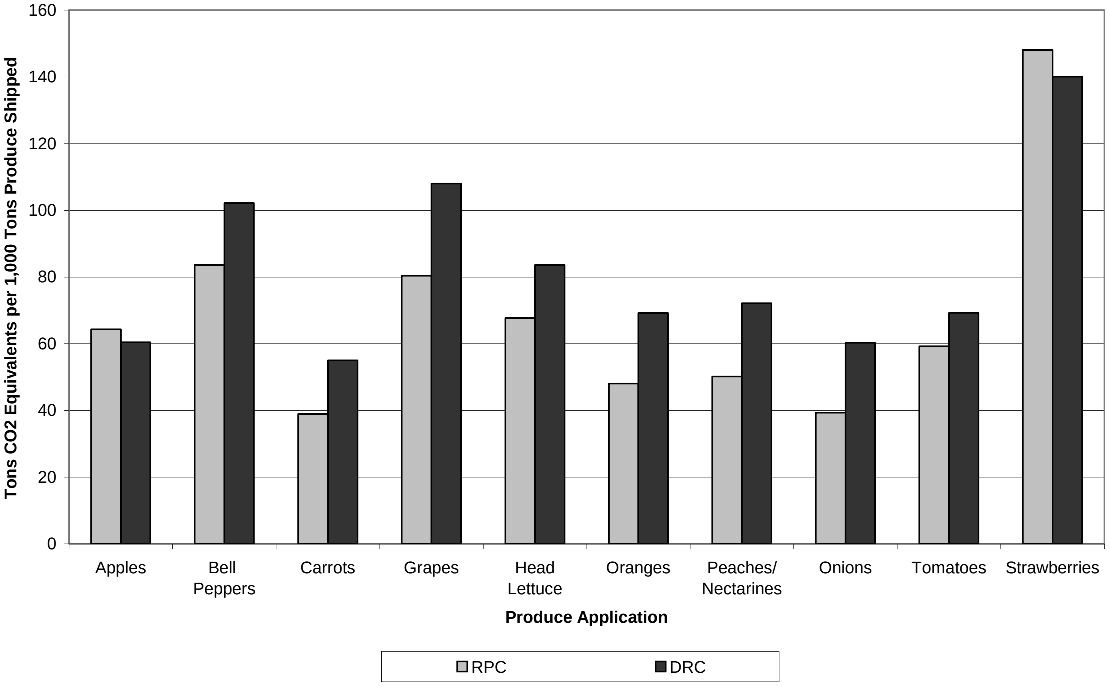


Figure ES-6. Conservative Scenario GHG Comparison
(RPC at 3/4 avg reuse rate and 2x avg loss rate, 10% lightweighted DRC)



CHAPTER 1

STUDY APPROACH AND METHODOLOGY

INTRODUCTION

The life cycle inventory presented in this study quantifies the total energy requirements, energy sources, atmospheric pollutants, waterborne pollutants, and solid waste resulting from the production, use, reuse, recycling, and disposal of reusable plastic containers and corrugated containers used for shipping fresh produce. The methodology used for goal and scope definition and inventory analysis in this study is consistent with the methodology for Life Cycle Inventory (LCI)[3] as described by the Society of Environmental Toxicology and Chemistry (SETAC) and in the ISO 14040 and 14041 Standard documents.

This analysis is not an impact assessment. It does not attempt to determine the fate of emissions, or the relative risk to humans or to the environment due to emissions from the systems. In addition, no judgments are made as to the merit of obtaining natural resources from various sources.

A life cycle inventory quantifies the energy consumption and environmental emissions (i.e., atmospheric emissions, waterborne wastes, and solid wastes) for a given product based upon the study boundaries established. The unique feature of this type of analysis is its focus on the entire life cycle of a product, from raw material acquisition to final disposition, rather than on a single manufacturing step or environmental emission. Figure 1-1 illustrates the general approach used in an LCI analysis.

The information from this type of analysis can be used as the basis for further study of the potential improvement of resource use and environmental emissions associated with a given product. It can also pinpoint areas in the life cycle of a product or process where changes would be most beneficial in terms of reduced energy use or environmental emissions.

GOALS OF THE STUDY

The principal goal of this study is to evaluate the energy, solid wastes, and atmospheric and waterborne emissions associated with the production, use, reuse, recycling, and disposal of reusable plastic containers and corrugated containers used for shipping fresh produce.

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[3] SETAC. 1991. **A Technical Framework for Life-Cycle Assessment.** Workshop report from the Smugglers Notch, Vermont, USA, workshop held August 18-23, 1990.

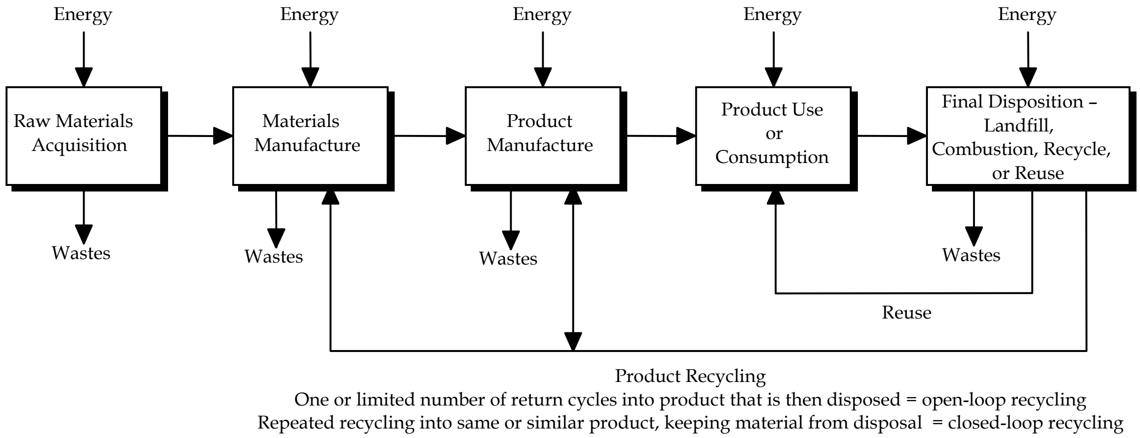

Figure 1-1. General materials flow for "cradle-to-grave" analysis of a product

STUDY SCOPE

Functional Unit

In order to provide a basis for comparison of different products, a common reference unit must be defined. The reference unit for an LCI is described in detail in the standards ISO 14040 and 14041. The reference unit is based upon the function of the products, so that comparisons of different products are made on a uniform basis of providing consumer utility. This common basis, or functional unit, is used to normalize the inputs and outputs of the LCI.

For this study, the functional unit for each system is shipment of 1,000 short tons (two million pounds) of various types of fresh produce using RPCs and DRCs. This functional unit encompasses the production, use, and end-of-life management of the containers of each type required to ship the produce, as well as the transportation burdens for packed containers and empty containers that are allocated to the containers based on their percentage of the vehicle load weight.

System Boundaries

Beginning with acquisition of initial raw materials from the earth, this study examines the sequence of processing steps for the production, use, reuse, recycling, and disposal of containers used to ship fresh produce, including transportation steps. The analysis includes backhauling, washing, and reissue of RPCs and recycling of RPCs and DRCs.

Description of Data Categories

Key elements of the LCI methodology include the resource inventory (raw materials and energy), emissions inventory (atmospheric, waterborne, and solid waste), and disposal practices.

Figure 1-2 illustrates the basic approach to data development for each major process in an LCI analysis. This approach provides the essential building blocks of data used to construct a complete resource and environmental emissions inventory profile for the entire life cycle of a product. Using this approach, each individual process included in the study is examined as a closed system, or “black box”, by fully accounting for all resource inputs and process outputs associated with that particular process. Resource inputs accounted for in the LCI include raw materials and energy use, while process outputs accounted for include products manufactured and environmental emissions to land, air, and water.

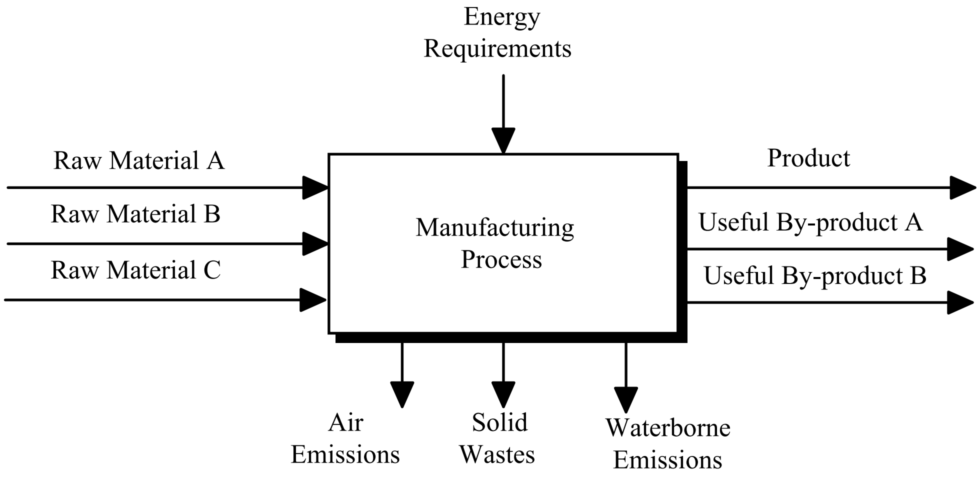

Figure 1-2. "Black box" concept for developing LCI data.

Material Requirements. Once the LCI study boundaries have been defined and the individual processes identified, a material balance is performed for each individual process. This analysis identifies and quantifies the input raw materials required per standard unit of output, such as 1,000 pounds, for each individual process included in the LCI. The purpose of the material balance is to determine the appropriate weighting factors used in calculating the total energy requirements and environmental emissions associated with the systems studied. Energy requirements and environmental emissions are determined and expressed in terms of the standard unit of output.

Once the detailed material balance has been established for a standard unit of output for each process included in the LCI, a comprehensive material balance for the entire life cycle of the system is constructed. This analysis determines the quantity of materials required from each process to produce and dispose of the required quantity of each system component and is typically illustrated as a flow chart. Data must be gathered for each process shown in the flow diagram, and the weight relationships of inputs and outputs for the various processes must be developed.

Energy Requirements. The average energy requirements for each industrial process are first quantified in terms of fuel or electricity units such as cubic feet of natural gas, gallons of diesel fuel, or kilowatt-hours (kWh) of electricity. Transportation requirements are developed in the conventional units of ton-miles by each transport mode (e.g. truck, rail, barge, etc.). Statistical data for the average efficiency of each transportation mode are used to convert from ton-miles to fuel consumption.

Once the fuel consumption for each industrial process and transportation step is quantified, the fuel units are converted to British thermal units (Btu) using conversion factors. These conversion factors have been developed to account for the energy required to extract, transport, and process the fuels and to account for the energy content of the fuels. The energy to extract, transport, and process fuels into a usable form is referred to in this report as “precombustion energy” (precombustion energy is also commonly referred to in the life cycle literature as “upstream energy”). For electricity, precombustion energy calculations include adjustments for the average efficiency of conversion of fuel to electricity and for transmission losses in power lines.

The LCI methodology assigns raw materials that are derived from fossil fuels with their fuel-energy equivalent. Therefore, the total energy requirement for coal, natural gas, or petroleum-based raw materials includes the fuel energy of the material (called energy of material resource or inherent energy). No fuel-energy equivalent is assigned to combustible materials, such as wood, that are not major fuel sources in the United States. For example, in an LCI of paperboard, the calorific value of the wood fiber that is used to make the paperboard would not be included in the energy analysis.

The Btu values for fuels and electricity consumed in each industrial process are summed and categorized into an energy profile according to the six major energy sources listed below:

- Natural gas
- Petroleum
- Coal
- Hydropower
- Nuclear
- Wood-derived

Also included in the systems energy profile are the Btu values for all transportation steps and all fossil fuel-derived raw materials. An additional electricity generation category “Other” includes the portion of electricity generated from sources such as wind and solar power.

Environmental Emissions. Environmental emissions include air pollutants, solid wastes, and waterborne wastes. Through various data sources identified later in this chapter, every effort is made to obtain actual industry data. Emission standards are often used as a guide when operating data are not available.

It is not uncommon for data provided by some individual plants to be more complete than that submitted by others. Other factors, such as the measuring and reporting methods used, also affect the quality of air and waterborne emissions data. This makes comparison of the air and waterborne emissions between the systems more difficult. Comparisons of LCA databases have shown that airborne and waterborne pollutant emissions for a particular material production inventory can easily vary by 200%. Energy and solid waste values are generally more agreeable between databases. The best use of the detailed air and waterborne emissions data at this point in time is for internal improvement. A close look at the reason for certain air or waterborne pollutants within each system may identify areas where process or material changes could reduce emissions.

Substances may be reported in speciated or unspeciated form, depending on the compositional information available. General categories such as “Acid” and “Metal Ion” are used to report unspeciated data. Emissions are reported only in the most descriptive single category applicable; speciated data are not reported again in the broadly applicable unspeciated category. For example, emissions reported as “HCl” are not additionally reported under the category “Acid,” nor are emissions reported as “Chromium” additionally reported under “Metal Ion.”

The scope of this analysis is to identify what wastes are generated through a cradle-to-grave analysis of the systems being examined. No attempt has been made to determine the relative environmental effects of these pollutants.

Atmospheric Emissions. These emissions include carbon dioxide and all other substances classified as air pollutants. Emissions are reported as pounds of pollutant per functional unit. The amounts reported represent actual discharges into the atmosphere after existing emission control devices. The emissions associated with the combustion of fuel for process or transportation energy as well as the process emissions are included in the analysis. Some of the most commonly reported atmospheric emissions are particulates, nitrogen oxides, hydrocarbons, sulfur oxides, and carbon monoxide.

The following are Franklin Associates' definitions of some of the major atmospheric pollutants:

Nitrogen oxides (NOx): Compounds of nitrogen and oxygen produced by the burning of fossil fuels, or any other combustion process taking place in air. The two most important oxides in this category are nitrogen oxide (NO) and nitrogen dioxide (NO_2). Nitrous oxide (N_2O), however, is reported separately.

Sulfur oxides (SOx): Compounds of sulfur and oxygen, such as sulfur dioxide (SO_2) and sulfur trioxide (SO_3).

Hydrocarbons: A subcategory of organic compounds which contain only hydrogen and carbon. These compounds may exist in either the gaseous, liquid, or solid phase, and have a molecular structure that varies from the simple to the very heavy and very complex. The category Non-Methane Hydrocarbons is sometimes used when methane is reported separately.

Other organics: Compounds containing carbon combined with hydrogen and other elements such as oxygen, nitrogen, sulfur, or others. Compounds containing only carbon and hydrogen are classified as hydrocarbons and are not included in this category.

Particulate matter (Particulates): Small solid particles or liquid droplets suspended in the atmospheric, ranging in size from 0.005 to 500 microns.

Particulates are usually characterized as primary or secondary. Primary particulates, usually 0.1 to 20 microns in size, are those injected directly into the atmosphere by chemical or physical processes. Secondary particulates are produced as a result of chemical reactions that take place in the atmosphere. In our reports, particulates refer only to primary particulates.

Particulates reported by Franklin Associates are not categorized by size range and are sometimes called total suspended particulates (TSP). The category PM-10 refers to all particulates less than 10 microns in (aerodynamic) diameter. This classification is sometimes used when health effects are being considered, since the human nasal passages will filter and reject particles larger than 10 microns. PM 2.5 (less than 2.5 microns in diameter) is now considered the size range of most concern for human health effects.

Waterborne Wastes. As with atmospheric emissions, waterborne wastes include all substances classified as pollutants. Waterborne wastes are reported as pounds of pollutant per functional unit. The values reported are the average quantity of pollutants still present in the wastewater stream after wastewater treatment and represent discharges into receiving waters. Some of the most commonly reported waterborne wastes are biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids, dissolved solids, iron, chromium, acid, and ammonia.

Solid Wastes. This category includes solid wastes generated from all sources that are landfilled or disposed in some other way. This also includes materials that are burned to ash at combustion facilities. It does not include materials that are recycled or coproducts. When a product is evaluated on an environmental basis, attention is often focused on postconsumer wastes. Industrial wastes generated during the manufacture of the product are sometimes overlooked. Industrial solid wastes include wastewater treatment sludges, solids collected in air pollution control devices, trim or waste materials from manufacturing operations that are not recycled, fuel combustion residues such as the ash generated by burning coal or wood, and mineral extraction wastes. Waste materials that are left on-site or diverted from landfill and returned to the land without treatment (e.g., overburden returned to mine site, forest residues left in the forest to decompose) are not reported as wastes.

Inclusion of Inputs and Outputs

Franklin Associates commonly uses a mass basis to decide if materials should be included in an analysis; however, it is recognized that use of mass exclusion criteria could result in oversight of minor constituents that are highly toxic. Before the decision is made to exclude a material from the study based on its mass, the analyst evaluates the likelihood of significant energy, solid waste, or emissions burdens associated with the material. Any material less than one percent of the mass in the system is generally considered negligible if its contributions are estimated to be negligible, based on the information available to the analyst. In some cases materials that have small mass but potentially significant burdens may have to be excluded from the study because of the unavailability of LCI data, particularly for proprietary or chemically complex substances; in such cases, the exclusions are specifically noted in the study limitations.

Further discussion on this topic specific to this study can be found later in this chapter in the section **System Components Not Included,** subsection **Miscellaneous Materials and Additives.**

Data Quality Requirements

Standards for data procurement and quality are described in ISO Standards 14040-14042. Franklin Associates' methods in this area have been in place for many years, and the ISO Standards are in part drawn from our experience in developing these methods.

The accuracy of the study is only as good as the quality of input data. The development of methodology for the collection of data is essential to obtaining quality data. Careful adherence to that methodology determines not only data quality but also objectivity. Documentation of the methodology for data collection is currently the most widely used method for communicating data quality. The use of single values for individual data points that may actually have wide ranges (such as process energy requirements or component weights) is done to make the calculation process manageable.

Data necessary for conducting this analysis are separated into two categories: process-related data and fuel-related data.

Process Data

Methodology for Collection/Verification. The process of gathering data is an iterative one. The data-gathering process for each system begins with a literature search to identify raw materials and processes necessary to produce the final product. The search is then extended to identify the raw materials and processes used to produce these raw materials. In this way, a flow diagram is systematically constructed to represent the production pathway of each system.

Each process identified during the construction of the flow diagram is then researched to identify potential industry sources for data. Each source for process data is contacted and worksheets are provided to assist in gathering the necessary process data for their product. Each worksheet is accompanied by a description of the process boundaries.

Upon receipt of the completed worksheets, the data are evaluated for completeness and reviewed for any material inputs that are additions or changes to the flow diagram. In this way, the flow diagram is revised to represent current industrial practices. Data suppliers are contacted again to discuss the data, process technology, waste treatment, identify coproducts, and any assumptions necessary to understand the data and boundaries.

After each data set has been completed and verified, the data sets for each process are aggregated together into a single set of data for that process. The method of aggregation for each process is determined on a case-by-case basis. For example, if more than one process technology is involved, market shares for these processes are used to create a weighted average. In this way, a representative set of data can be estimated from a limited number of data sources. Process technologies and assumptions are then documented and returned with the aggregated data to each data supplier for their review. The data and documentation may also be provided to other industry and academic experts for comment. This provides an opportunity for experts on each process to review the completed data for accuracy, reasonableness of assumptions, and representativeness.

Confidentiality. The data requested in the worksheets are often considered proprietary by potential suppliers of data. The method used to collect and review data provides each supplier the opportunity to review the aggregated average data calculated from all data supplied by industry. This allows each supplier to verify that their company's data are not being published and that the averaged data are not aggregated in such a way that individual company data can be calculated or identified.

Objectivity. Each process is researched independently of all other processes. No calculations are performed to link processes together with the production of their raw materials until after data gathering and review is complete. The procedure of providing the aggregated data and documentation to suppliers and other industry experts provides several opportunities to review the individual data sets without affecting the objectivity of the research. This process serves as an external expert review of each process. Also, because these data are reviewed individually, assumptions are reviewed based on their relevance to the process rather than their effect on the overall outcome of the study.

Sources. Most process data used in this study were drawn from Franklin Associates' U.S. LCI database, which was developed using the data collection and review process described above. In addition, some data were developed specifically for this study. Data on RPC systems, including RPC weights, reuse and loss rates, loading, transportation modes and distances, and washing, were provided by RPCC member companies. Weights and loading for DRCs were provided by a DRC producer.

Fuel Data. The energy and emissions released when fuels are burned are only one part of the energy and emissions associated with the use of a fuel. Before each fuel is usable, it must be mined, as in the case of coal or uranium, or extracted from the earth in some manner. Further processing is often necessary before the fuel is usable. Coal is crushed or pulverized and sometimes cleaned. Crude oil is refined to produce fuel oils and liquefied petroleum gases.

To avoid confusion regarding environmental emissions from the combustion of fuels and emissions resulting from the fuel production process, it is necessary to define terms to describe the different emissions. The combustion products of fuels are defined as "combustion data." Energy consumption and emissions which result from the mining, refining, and transportation of fuels are defined as "precombustion data." Precombustion data and combustion data together are referred to as "fuel-related data."

Fuel-related data are developed for fuels that are burned directly in industrial furnaces, boilers, and transport vehicles. Fuel-related data are also developed for the production of electricity. These data are assembled into a database from which the energy requirements and environmental emissions for the production and combustion of process fuels are calculated.

Fuels and energy are required to extract, produce, and deliver fuels. Energy data are developed to identify and quantify the units of primary fuel inputs required per output unit of each fuel type. For electricity production, statistics from the International Energy Agency provided data for the amount of fuel required to produce electricity from each fuel source, and the total amount of electricity generated from petroleum, natural gas, coal, nuclear, hydropower, and other (solar, geothermal, etc.). Literature sources and international statistical records provided data for the emissions resulting from the combustion of fuels in utility boilers, industrial boilers, stationary equipment such as pumps and compressors, and transportation equipment. Because electricity is required to produce primary fuels, which are in turn used to generate electricity, a circular loop is created. Iteration techniques are utilized to resolve this loop.

Data Accuracy. An important issue in considering the use of this study is the reliability of the calculations. In a complex study with literally thousands of numbers, the accuracy of the data and how it affects conclusions is truly a complex subject, and one that does not lend itself to standard error analysis techniques. Techniques such as Monte Carlo analysis can be used to study uncertainty, but the greatest challenge is the lack of uncertainty data or probability distributions for key parameters, which are often only available as single point estimates. However, the reliability of the study can be assessed in other ways.

An important consideration is whether the conclusions are correct. There are many processes in each system, so there are many numbers added together to arrive at the total values (energy, solid waste, etc.) for each system. Each number by itself may contribute little to the total (depending on the magnitude of the uncertainty for each parameter and the sensitivity of the final result to changes in each parameter). There is no analytical method for assessing the accuracy of each number to any degree of confidence. In many cases, data represent actual plant data reported by plant personnel. The data reported may represent operations for the previous year or may be representative of the upcoming year. All data are scrutinized when they are received to evaluate whether or not they are representative of the type of operation or process being evaluated.

There are several other important points with regard to data accuracy. Each number generally contributes a small part to the total value, so a large error in one data point does not necessarily create a problem. For process steps that make a larger than average contribution to the total, special care is taken with the data quality. It is assumed that with careful scrutiny of the data, any errors will be random. That is, some numbers will be a little high due to errors, and some will be slightly low, but in the summing process these random high and low errors will offset each other to some extent.

There is another dimension to the reliability of the data. Certain numbers do not stand alone, but rather affect several numbers in the system. An example is the amount of a raw material required for a process. This number will affect every step in the production sequence prior to the process. Errors such as this that propagate throughout the system are more significant in steps that are closest to the end of the production sequence.

Data Quality Indicators and Uncertainty Analysis

ISO Standards 14040, 14041, and 14042 provide guidance on various data quality issues for life cycle studies. Data quality considerations are essential to study credibility. In particular, when product systems are compared, the estimates of uncertainty in the results are essential to determine if two numbers are most likely the same or different. No standard methods have been adopted for this activity, but Franklin Associates has developed methods that have been peer reviewed in technical journals and are described in part in the SETAC documents “Life Cycle Assessment Data Quality: A Conceptual Framework,” 1992, and “Life Cycle Impact Assessment: The State of the Art,” 1997.

Life Cycle Inventories are an attempt to determine all of the inputs (in terms of energy and natural resource use) and all of the outputs (in terms of products, coproducts, and environmental emissions to the air, water, and soil) over the entire life of a product or service, within the boundaries of the study. Thousands of data points are needed in a typical LCI, including values for the extraction of raw materials, the manufacturing of intermediate materials, the fabrication of the product, the use/reuse/maintenance of the product, and the ultimate disposal or recycling of the product.

In the best of possible worlds, classical statistics could be used to determine the uncertainties in Life Cycle Inventories. Classical statistics, however, requires that the data conform to several restrictive assumptions such as independence, randomness, and representativeness.

In LCIs, as in many areas of complex assessments, data often do not meet the stringent requirements of classical statistics. There may be no option to control the representativeness of samples, the number of data points, or the randomness of the data collected. In that case, expert judgment becomes important.

ISO Standard 14042 specifies three techniques of data quality analysis to be used to assist in resolving these complexities. Franklin Associates employs all of these in assessing results.

- Gravity analysis – identifies those data which give the greatest contribution to end results so that they can be more intensively scrutinized.
- Uncertainty analysis – describes statistical variability in data sets in order to assist in determination of significant differences.
- Sensitivity analysis – measures the extent to which changes in data or assumptions influence results.

Recent research has shown that expert judgment can be translated into quantifiable statements about data quality and uncertainty with high reproducibility.[4,5] While this introduces subjectivity into the uncertainty analysis, it is presently the best available methodology. It brings to LCI assessments valuable information that has historically been missing. It has the potential of greatly increasing the credibility of comparative LCI results and making the database in a research project as sound as possible.

Franklin Associates has developed methodologies to deal with the issues of uncertainty and data quality in Life Cycle Inventory. In traditional LCIs, single point estimates of input variables (such as fuel requirements) are used to determine single point estimates for the output variables (such as total energy used or solid waste generated). These point estimates contain no information about the uncertainty of the data; therefore they give a false sense of precision. Analysis of meaningful differences in LCI results obtained using point value modeling thus relies upon the experience and expert judgment of the practitioner.

The Franklin Associates methodology has been adapted to allow for the assignment of data quality indicators (DQIs) to the variables used as inputs to LCI computer models. These indicators can then be used as a basis for modeling input values as distributions rather than as single point estimates. This approach more accurately

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[4] Kennedy, D.J., D.C. Montgomery, and B.H. Quay, **Stochastic Environmental Life Cycle Assessment Modeling: A Probabilistic Approach to Incorporating Variable Input Data Quality.** Int. J. LCA 1(4) pp. 199-207 (1996).

[5] Kusko, Bruce H. and Robert G. Hunt, **Managing Uncertainty in Life Cycle Inventories.** Published by the Society of Automotive Engineers, Inc. Paper No. 970693 1997.

reflects the level of confidence in the values. The deterministic model is therefore changed into a stochastic model. This means that the output of the model is also a distribution of values, rather than a single point estimate. It is then easier to judge, for example, whether two values for total solid waste are the same or different. This stochastic approach requires considerable additional modeling time and expense, however, and is outside the scope of this project.

METHODOLOGY

There is general consensus among life cycle practitioners on the fundamental methodology for performing LCIs, as described in ISO Standards 14040-14041, and the series of documents developed under the leadership of SETAC in Europe and the U.S[6]. For some specific aspects of life cycle inventory, however, there is more than one methodological approach that may be used. These areas include: the method used to allocate energy requirements and environmental releases among more than one useful product produced by a process; the method used to account for the energy contained in material feedstocks; recycling of materials; and greenhouse gas accounting. LCI practitioners vary to some extent in their approaches to these issues. The following sections describe the approach to each issue used in this study and the justification for the approach used.

Coproduct Credit

One unique feature of life cycle inventories is that the quantification of inputs and outputs are related to a specific amount of product from a process. However, controversy in LCI studies often occurs because it is sometimes difficult or impossible to identify which inputs and outputs are associated with one of multiple products from a process. The practice of allocating inputs and outputs among multiple products from a process is often referred to as “coproduct credit”[7] or “partitioning”[8].

Coproduct credit is done out of necessity when raw materials and emissions cannot be directly attributed to one of several product outputs from a system. It has long been recognized that the practice of giving coproduct credit is less desirable than being able to identify which inputs lead to particular outputs.

It is possible to divide a larger process into sub-processes. To use this approach, data must be available for sub-processes. In many cases, this may not be possible either due to the nature of the process or to less detailed data. Eventually, a sub-process will be reached where it is necessary to allocate energy and emissions among multiple products based on some calculated ratio. The method of calculating this ratio is subject to much

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[6] SETAC. 1993. **Guidelines for Life-Cycle Assessment: A “Code of Practice.”** 1st ed. Workshop report from the Sesimbra, Portugal, workshop held March 31 through April 3, 1993.

[7] Hunt, Robert G., Sellers, Jere D., and Franklin, William E. **Resource and Environmental Profile Analysis: A Life Cycle Environmental Assessment for Products and Procedures.** Environmental Impact Assessment Review. 1992; 12:245-269.

[8] Boustead, Ian. **Eco-balance Methodology for Commodity Thermoplastics.** A report for The Centre for Plastics in the Environment (PWMI). Brussels, Belgium. December, 1992.

discussion among LCA researchers, and various methods of calculating this ratio are discussed in literature.[9,10,11,12,13]

Where allocation of energy and emissions among multiple products based on a calculated ratio is necessary in this study, the ratio is calculated based on the relative **mass** outputs of products, which is the most common approach by experienced practitioners. Figure 1-3 illustrates the concept of coproduct allocation on a mass basis.

Energy of Material Resource

For some raw materials, such as petroleum, natural gas, and coal, the amount consumed in all applications as fuel far exceeds the amount consumed as raw materials (feedstock) for products. The primary use of these materials is for energy. The total amount of these materials can be viewed as an energy pool or reserve. This concept is illustrated in Figure 1-4.

The use of a certain amount of these materials as feedstocks for products, rather than as fuels, removes that amount of material from the energy pool, thereby reducing the amount of energy available for consumption. This use of available energy as feedstock is called the “energy of material resource” and is included in the inventory. The energy of material resource represents the amount the energy pool is reduced by the consumption of fuel materials as raw materials in products and is quantified in energy units.

The energy of material resource is the energy content of the fuel materials *input* as raw materials or feedstocks. The energy of material resource assigned to a material is *not* the energy value of the final product, but is the energy value of the raw material at the point of extraction from its natural environment. For fossil fuels, this definition is straightforward. For instance, petroleum is extracted in the form of crude oil. Therefore, the energy of material resource for petroleum is the higher heating value of crude oil.

Once the feedstock is converted to a product, there is energy content that could be recovered, for instance through combustion in a waste-to-energy waste disposal facility. The energy that can be recovered in this manner is always somewhat less than the feedstock energy because the steps to convert from a gas or liquid to a solid material reduces the amount of energy left in the product itself.

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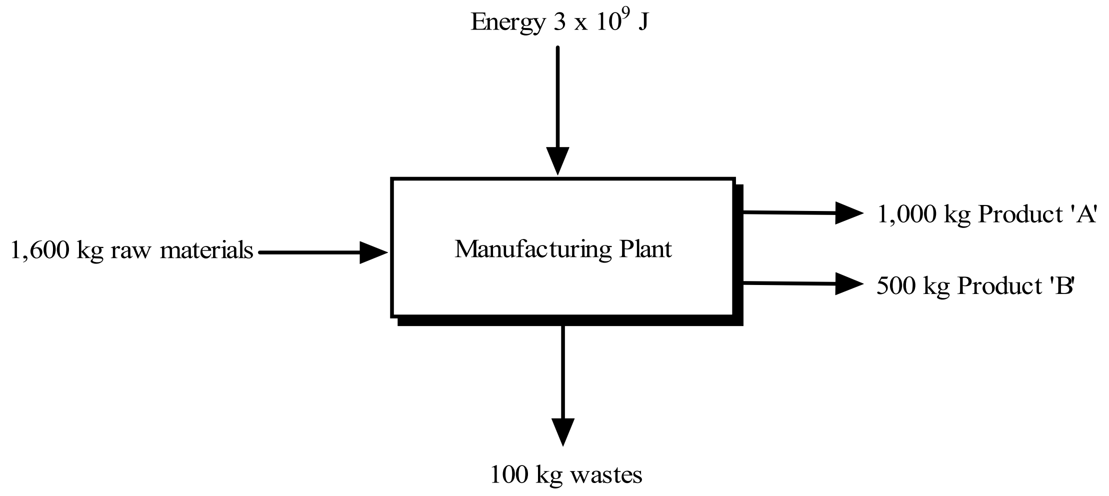
[9] Hunt, Robert G., Sellers, Jere D., and Franklin, William E. **Resource and Environmental Profile Analysis: A Life Cycle Environmental Assessment for Products and Procedures.** Environmental Impact Assessment Review. 1992; 12:245-269.

[10] Boustead, Ian. **Eco-balance Methodology for Commodity Thermoplastics.** A report for The Centre for Plastics in the Environment (PWMI). Brussels, Belgium. December, 1992.

[11] SETAC. 1993. **Guidelines for Life-Cycle Assessment: A “Code of Practice.”** 1st ed. Workshop report from the Sesimbra, Portugal, workshop held March 31 through April 3, 1993.

[12] **Life-Cycle Assessment: Inventory Guidelines and Principles.** Risk Reduction Engineering Laboratory, Office of Research and Development, United States Environmental Protection Agency. EPA/600/R-92/245. February, 1993.

[13] **Product Life Cycle Assessment–Principles and Methodology.** Nord 1992:9.
ISBN 92 9120 012 3.



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

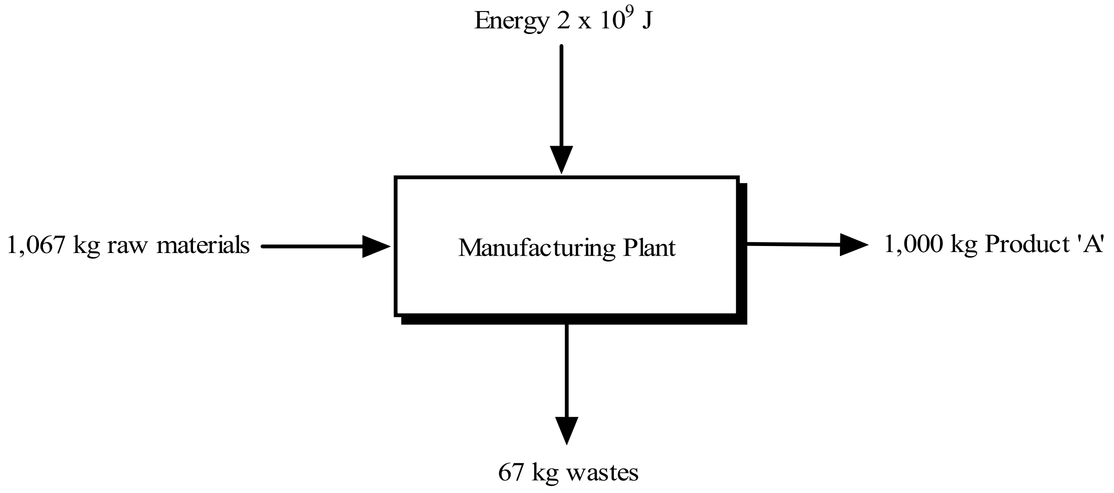


Figure 1-3. Flow diagrams illustrating coproduct allocation for product 'A'.

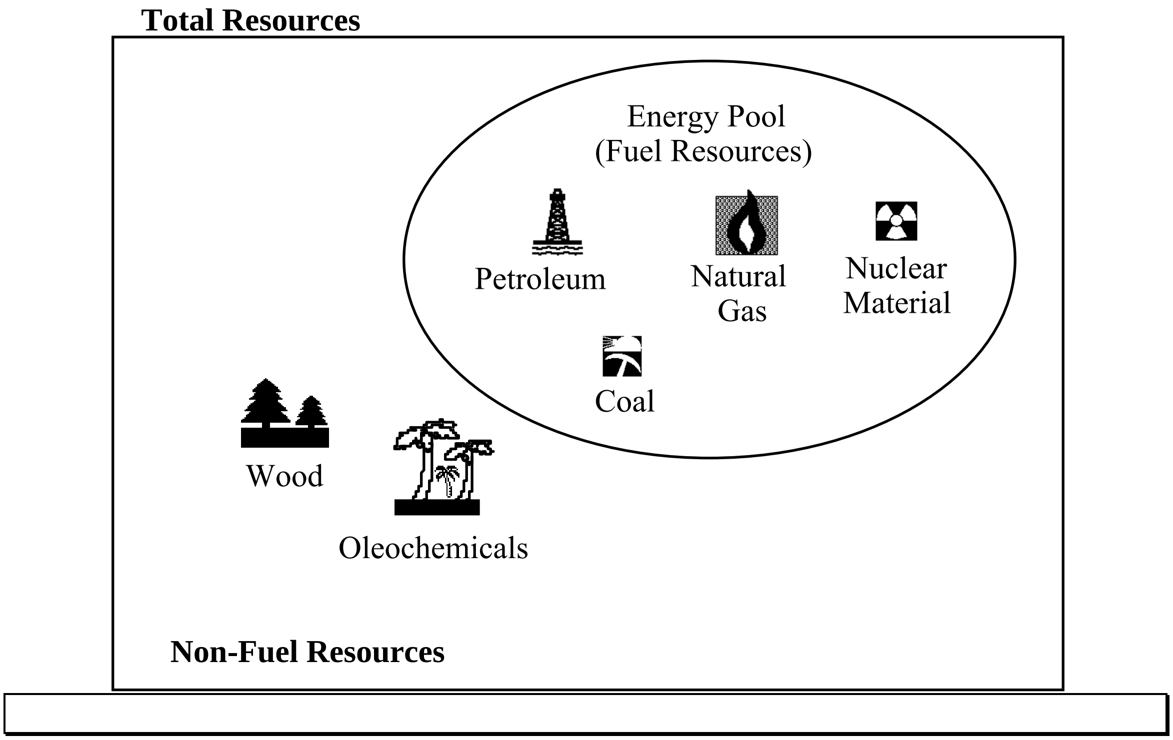


Figure 1-4. Illustration of the Energy of Material Resource concept.

The materials which are primarily used as fuels can change over time and with location. In the industrially developed countries included in this analysis, the material resources whose primary use is for fuel are petroleum, natural gas, coal, and nuclear material. While some wood is burned for energy, the primary use for wood is as a material input for products such as paper and lumber. Similarly, some oleochemical oils such as palm oils are burned for fuels, often referred to as "bio-diesel." However, as in the case of wood, their primary consumption is as raw materials for products such as soaps, surfactants, cosmetics, etc.

Recycling

Recycling is evaluated as a means to reduce the environmental burdens for production of container materials and to divert containers from the municipal solid waste stream at end of life. This analysis uses a shared approach for allocating environmental burdens among product systems with recycled content. In this approach, the burdens for virgin material production and end-of-life disposal are allocated among all systems that use the material, whether it is the first system using the virgin material or the last system using postconsumer material recovered from a previous useful life. Each useful life of the material carries its own fabrication and use burdens. Material production burdens for recycled material are allocated to each useful life of the material using the equation $M/(n+1)$, where M is the virgin material production burdens and n is the number of times the material is recycled; thus $(n+1)$ is the total number of useful lives of the material, i.e., initial use + recycled use(s). Similarly, recovery and reprocessing burdens are allocated to each useful life of the recycled material using the equation (R x n)/(n+1), where R is the recycling burdens.

For material that is recovered and recycled once (open-loop recycling), n=1 and (n+1) = 2; thus, half the material production burdens and recycling burdens are allocated to each useful life of the material. For material that is recovered and recycled repeatedly (closed-loop recycling), n becomes very large; as a result, the material production burdens allocated to any individual useful life become very small. Similarly, in the recycling allocation equation, as n becomes larger, n/(n+1) approaches 1, and the recycling burdens allocated to any individual useful life approach R x 1.

Based on paperboard industry statistics[14,15,16,17], the overall recycled content of an average corrugated box is 38 percent closed-loop and 62 percent open-loop. For every 1,000 pounds of average recycled content corrugated produce boxes recovered at a rate of 95 percent, 50 pounds (5% of 1,000) are unrecovered, with full disposal burdens charged to the produce use of the box. Disposal of the other 950 pounds are allocated to the produce box based on the total number of useful lives of the material in the box. For the 38% closed-loop content, the disposal burdens are allocated over many useful lives and become negligible, while for the 62% open-loop content, the disposal burdens are allocated over two useful lives. As a result, the total disposal burdens allocated to 1,000 lb of produce boxes are 50 + (950 x .62/2) = 345 lb.

Although produce boxes are recovered at a high rate, once a box is recovered and repulped, the recycled fiber can go to any type of secondary application. Some products utilizing recovered fiber will be recovered and recycled at end of life, while others will be disposed; but there is no way to predetermine into what product the recovered fiber from a produce box will go and how that product will be managed at the end of its useful life. Thus, the fate of the fiber from recovered produce boxes is modeled based on paperboard industry statistics for open-loop and closed-loop recycling of boxes.

Greenhouse Gas Accounting

Emissions that contribute to global warming include carbon dioxide, methane, and nitrous oxide. Carbon dioxide emissions generally dominate life cycle greenhouse gas emission profiles.

Although carbon dioxide emissions can come from a variety of life cycle processes, the predominant sources are combustion of fuels for process and transportation

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[14] **2001 Statistics, Data Through 2000: Paper, Paperboard, & Wood Pulp.** American Forest & Paper Association. October 2001. pp. 24-27, 38, 43, 81.

[15] **Capacity and Fiber Consumption: Paper, Paperboard, Pulp. 42nd Annual Survey 2000-2004.** American Forest & Paper Association. December 2001. Page 24 “Recovered Paper Consumed in Paper and Paperboard Manufacture.”

[16] **2001 Annual Statistical Summary, Recovered Paper Utilization. Fifteenth Edition**. Paper Recycling Group, American Forest & Paper Association. April 2001. Page 85.

[17] **Annual Report 2001.** Fibre Box Association. Tables “Consumption by Corrugator Plants” and “Containerboard Production and Consumption.”

energy. Because trees and other biomass take up carbon dioxide from the atmosphere during their growing cycle, carbon dioxide released from the combustion or aerobic decomposition of wood and wood-derived products (e.g., paper and paperboard) is considered part of the natural carbon cycle and is not counted as a net contributor to GHG. This methodology is consistent with the approach used by the U.S. EPA (documented in the report EPA530–R-02-006, **Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks,** 2nd edition, May 2002).

Unlike the methodology described in the EPA GHG report, the Franklin Associates life cycle methodology does not give credits for carbon sequestration resulting from use of recycled materials. The carbon sequestration credit described in the EPA report is based on a series of complex forestry models. It is beyond the scope of this study to attempt to evaluate the applicability of the EPA methodology and models to the specific packaging components studied in this analysis. The methodology used in this report does not account for end-of-life carbon sequestration in landfills.

GENERAL DECISIONS

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

Geographic Scope

The systems in this analysis were modeled using Franklin Associates' proprietary life cycle inventory databases and models. The Franklin Associates databases and models are based on U.S. data.

In the Franklin Associates' database, there are a few data sets that include some non-U.S. processes. Data for these processes are generally not available. This is usually only a consideration for the production of oil that is obtained from overseas. In cases such as this, the energy requirements and emissions are assumed to be the same as if the materials originated in the United States. Since foreign standards and regulations vary from those of the United States, it is acknowledged that this assumption will likely introduce error. Emissions data for oil production include U.S. data for unflared methane emissions but do not include fossil carbon dioxide emissions from flaring of natural gas. In the U.S. flaring is usually done as a last resort to minimize the global warming impact of methane releases that are unavoidable or are too small to capture economically; however, methane flaring may be practiced to a greater extent in overseas countries. Fuel usage for transportation of materials from overseas locations is included in the study.

Precombustion Energy and Emissions

In addition to the energy obtained from combustion of a fuel, energy is required for resource extraction, processing, and transportation to deliver the fuel in the form in which it is used. In this study, this additional energy is called precombustion energy. Precombustion energy refers to all the energy that must be expended to prepare and deliver the primary fuel. Adjustments for losses during transmission, spills, leaks, exploration, and drilling/mining operations are incorporated into the calculation of precombustion energy.

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

Electricity Fuel Profile

In general, detailed data do not exist on the fuels used to generate the electricity consumed by each industry. Electricity production and distribution systems in the United States are interlinked and are not easily separated. Users of electricity, in general, cannot specify the fuels used to produce their share of the electric power grid. Therefore, the national average fuel consumption by electrical utilities is assumed.

Electricity generated on-site at a manufacturing facility is represented in the process data by the fuels used to produce it. A portion of on-site generated electricity is sold to the electricity grid. This portion is accounted for in the calculations for the fuel mix in the grid.

Postconsumer Waste Disposal and Combustion

The energy released from the combustion of postconsumer containers is shown separately in the results as a potential energy credit offsetting some of the total energy requirements of the system. The gross energy credit is calculated based on the pounds of each material burned and the higher heating value of the material. Postconsumer solid waste for the system includes landfilled material and the ash from the quantity of material burned in combustion facilities.

No emissions credits are assigned to the energy credit because (1) no assumptions are made as to what fuel is displaced by the energy from combustion of postconsumer containers, so the emissions from combustion of that fuel are not specified, and (2) the net emissions credit would be (emissions from displaced fuel) – (emissions from postconsumer container combustion), and the emissions from postconsumer container combustion are not included in this analysis, as discussed in the following section.

System Components Not Included

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

Emissions from Combustion and Decomposition of Postconsumer Containers. Combustion of postconsumer containers in waste-to-energy facilities produces atmospheric and waterborne emissions; however, these emissions are not included in this study. The analysis did not include characterization of the operation of various facilities that burn postconsumer containers for energy recovery. Operation of these types of facilities may vary widely in energy recovery efficiency and emissions controls.

This analysis does not include modeling of atmospheric and waterborne emissions associated with the decomposition of landfilled products. Emissions associated with fuel use for transportation of waste to landfills and combustion facilities and operation of landfill equipment are included in the analysis.

Capital Equipment. The energy and wastes associated with the manufacture of capital equipment are not included. This includes equipment to manufacture buildings, motor vehicles, and industrial machinery. These types of capital equipment are used to produce large quantities of product output over a useful life of many years. Thus, energy and emissions associated with production of these facilities and equipment generally become negligible when allocated to 1,000-pound product output modules.

Space Conditioning. The fuels and power consumed to heat, cool, and light manufacturing establishments are omitted from the calculations in most cases. Space conditioning was not explicitly included in the scope of the study; however, primary LCI unit process data are often based on overall facility utility use and may include some space conditioning data.

For most industries, space conditioning energy is quite low compared to process energy. A possible exception may be processes that are relatively low in energy requirements but occupy large amounts of plant floor space, such as assembly line operations. U.S. Department of Energy data for the industrial sector indicates that non-process energy use including HVAC and lighting accounts for 10 -15 percent of the total end use fuel energy consumption in the case of electricity and natural gas (http://www.eia.doe.gov/emeu/mecs/mecs98/datatables/d98n6_4.htm). A significant amount of the overall industrial HVAC and lighting energy is likely for office areas, cafeteria space, etc. not directly associated with specific unit processes (see Support Personnel Requirements, below), as opposed to HVAC and lighting requirements for the plant floor space associated with specific unit processes.

Support Personnel Requirements. The energy and wastes associated with research and development, sales, and administrative personnel or related activities have not been included in this study. Similar to space conditioning, energy requirements and related emissions are assumed to be quite small for support personnel activities.

Miscellaneous Materials and Additives. Selected materials such as catalysts, pigments, or other additives which total less than one percent of the net process inputs are often excluded from the inventory if their contributions are estimated to be negligible. Omitting miscellaneous materials and additives helps keep the scope of the study focused and manageable within budget and time constraints.

In this study it was agreed from the outset to model the entire weight of each container as either polypropylene (RPCs) or corrugated (DRCs). No pigments or other resin additives or ancillary components such as labels were included in the analysis, nor were paints, labels, or printing inks that may be applied to boxes or labels.

RPC Washing Chemicals. Data for the production of some chemicals used in the washing of RPCs was excluded from the study, due to (1) lack of identification of the specific chemical composition, and (2) very small use rates. A previous LCI study that included washing of reusable containers showed that the environmental burdens for production of chemicals used in washing were inconsequential in comparison to the burdens associated with the energy consumption for the washing process.

CHAPTER 2

ENERGY AND ENVIRONMENTAL RESULTS FOR REUSABLE PLASTIC CONTAINERS AND DISPLAY-READY CORRUGATED CONTAINERS USED FOR FRESH PRODUCE APPLICATIONS

INTRODUCTION

A life cycle inventory (LCI) quantifies the energy use and environmental emissions associated with the life cycle of specific products. This study examines the environmental profiles of two types of containers used for shipping fresh produce. The two types of containers considered in the analysis are reusable plastic containers (RPCs) and display-ready common footprint corrugated containers (DRCs). The analysis includes different sizes and weights of containers used in ten produce applications.

The results presented in this report comprise a full LCI, beginning with extraction of raw materials from the earth and continuing through container production, backhauling and washing of RPCs, recycling of DRCs and RPCs, and disposal, including all associated transportation steps.

PURPOSE OF THE STUDY

The purpose of this study is to identify and quantify the energy, solid wastes, and atmospheric and waterborne emissions associated with RPCs and DRCs used for shipping fresh produce. Ten different high-volume produce applications were analyzed.

SYSTEMS STUDIED

Two general types of container systems are analyzed in this study: RPCs and DRCs. Various sizes and weights of containers are analyzed in the study for use in ten fresh produce applications. The produce applications studied were selected from high-volume commodities representing a range of product sizes and weights and a range of container sizes used for packing. Table 2-1 shows the container weights and packing data for each fresh produce application.

The corrugated containers analyzed in this study are “common footprint” containers that have the same base dimensions as RPCs; thus, the pallet and truck loading are very similar for RPCs and DRCs in corresponding produce applications. There are some minor loading differences due to variations in container heights. Also, in some applications trucks pack out by weight sooner with RPCs compared to corresponding DRCs due to the heavier container weight for RPCs.

Table 2-1

CONTAINER WEIGHTS AND PACKING

	Average Weight per Empty Container (lb)		Pounds of Produce per Container		Thousand Container Movements Required to Ship 1,000 Tons of Produce	
	RPC	DRC	RPC	DRC	RPC	DRC
Apples	5.4	1.8	41	40	48.5	50.0
Bell Peppers	4.8	2.0	25	26	79.4	76.9
Carrots	5.1	2.0	48	48	41.7	41.7
Grapes	3.3	1.7	19	21	105	95.2
Lettuce - head	5.3	2.5	35	40	56.8	50.0
Oranges	4.8	2.2	40	40	50.0	50.0
Peaches/Nectarines	3.5	1.9	34	35	58.4	57.1
Onions	3.9	1.8	40	40	50.0	50.0
Tomatoes	3.9	1.5	28	28	71.4	71.4
Strawberries	2.5	0.9	9	9	222	222

The RPCs analyzed in this study operate in a closed pooling system. In this type of system, ownership of the containers is maintained by a company (the pooler) that operates depots at various locations across the country. The depots are the locations where containers are issued to users and returned from users. The user leases the containers from the pooler, and the pooler inspects containers after use, cleans them, and keeps them in good repair so they can be used over and over again. In addition to high reuse rates, another benefit of maintained ownership is that the pooler maintains control of the containers for end-of-life management. Damaged containers are removed from service by the pooler and sent to RPC manufacturers to be reground and made back into containers.

RPCs are modeled at the average weight, lifetime use rate, and loss rate reported by four poolers. DRCs are modeled at the reported container weight for one-piece folded boxes. Additional scenarios are evaluated for sensitivity analysis, to examine the effects of reduced backhaul distance for RPCs, a lower reuse rate and higher loss rate for RPCs, and container lightweighting for DRCs.

FUNCTIONAL UNIT

In order to insure a valid basis for comparison for the container systems studied, a common functional unit is essential. For this study, the functional unit for each system is shipment of 1,000 short tons (two million pounds) of each type of produce using RPCs and DRCs. This functional unit encompasses the production, use, and end-of-life management of the containers of each type required to ship the produce, as well as the transportation burdens for packed containers and empty containers that are allocated to the containers based on their percentage of the vehicle load weight.

SCOPE AND BOUNDARIES

The produce container system models include the following steps:

- Production of virgin polypropylene resin (beginning with raw material extraction) and RPC manufacture
- Production of corrugated containers with industry average recycled content (including collection and processing of postconsumer corrugated boxes and industrial scrap as well as virgin inputs to box manufacture)
- Transportation of containers to growers
- Transportation of packed containers from growers to retail
- Backhauling, washing, and reissue of RPCs
- Recycling and disposal of DRCs at end of life
- Recycling of RPCs retired from service
- Disposal of RPCs lost during use

The analysis does not include environmental burdens for growing the produce, nor is any additional packaging of produce (e.g., plastic film bags, individual strawberry containers, etc.) included in the analysis. Printing of corrugated boxes and labeling of RPCs is not included. The analysis does not attempt to evaluate differences in produce damage and spoilage associated with use of the different types of containers. The analysis does not include any analysis of differences in labor associated with the different containers.

DATA SOURCES

Data on RPC systems, including RPC weights, reuse and loss rates, loading, transportation modes and distances, and washing, were provided by RPCC member companies. Weights and loading for DRCs were provided by a DRC producer. DRC weights were validated using Corrugated Packaging Alliance (CPA) case studies on three produce applications that correspond to applications analyzed in this study.

Production of RPCs was modeled using industry average data for the production of polypropylene resin and RPC fabrication data provided by RPC producers. Production of DRCs was modeled using industry average data for the production of the various virgin and recycled paperboard inputs to linerboard and medium, production of linerboard and medium, and box fabrication, recovery, and recycling. Paperboard industry statistics were used to model the composition and recycled content of linerboard and medium and the iterative cycles associated with recovery and recycling of boxes at end of life.

MODELING APPROACH

Key data and issues in modeling the container systems include RPC lifetime trip rates, pooling system operation, RPC backhauling, DRC box weights, and end-of-life management of containers.

RPC Lifetime Trip Rates

Data on average RPC lifetime trip rates were provided for this study by RPCC member companies involved in produce shipping using pooled RPCs. The total number of lifetime trips for an RPC is equal to the number of trips ("turns") per year times the number of years the container remains in service. The number of turns per year depends on the transportation distances and handling logistics, not on the properties of the RPC itself.

This study uses the standard LCI basis of product functionality, which in this case is the average number of trips an RPC is expected to make before it is removed from service for wear or damage, regardless of the number of years it takes to make that number of trips. The lifetime trip rate affects the modeling of the number of RPCs (and associated resin) that must be produced to replace the RPCs "used up" for shipping 1,000 tons of produce, as described in the following section.

RPC Pooling Operation

An important assumption in the modeling of RPC systems in this analysis is the assumption that the pooling system is a shared-use pool operating at steady state. That is, it is assumed that a pool of RPCs is already in existence and available for any and all applications (produce or other) that use each size of RPCs. Thus, each produce system is charged with replacing the number of RPCs "used up" by shipping that commodity, based on the number of shipments in RPCs required to move the produce divided by the useful lives per RPC, plus replacement of losses of RPCs during use, e.g., due to theft.

This reflects the way that pooling systems actually operate. Although an excess supply of RPCs ("float") must be in place throughout the system in order to ensure that a sufficient number of RPCs are circulating to and from growers and retailers within the time frame to meet their needs, these RPCs are available for any and all uses of each size RPC rather than designated specifically for a certain type of produce. Thus, the same pool of RPCs can be utilized for shipping produce with sequential or concurrent growing seasons. For example, RPCs filled with oranges from Florida might be delivered to a store in Illinois, then transported to the closest pooling location where they are washed and sent to a Michigan apple grower, while the orange grower in Florida receives a shipment of RPCs from a pooling location in Tennessee where empty RPCs were returned from a different commodity use.

Depending on the size of the existing pool of RPCs, it may be necessary to initially add some RPCs to expand the pool to accommodate an added use application; however, once added, these RPCs are available for use by any application. Thus, for a shared-use pool of RPCs, any use of the RPCs for any application is withdrawing RPC **uses** from the pool rather than individual containers. To calculate the number of RPCs "used up" for shipping 1,000 tons of produce, the number of RPC trips required to ship 1,000 tons is divided by the number of lifetime trips per RPC and adjusted for the loss rate to determine the number of RPCs that must be produced to replace the RPC uses withdrawn from the pool.

RPC Backhauling

The pooling system operates nationwide, enabling growers to obtain RPCs from the nearest pooling location, regardless of where the RPCs were used prior to arrival at that pooling location. The RPCs may have returned to the pooler from an end use location 20 miles, 200 miles, or 2,000 miles away. Because of the infinite possible combinations of end user, pooler, and new user locations in a shared-use pool, there is no way to determine a representative return distance for RPCs from end use location to pooler to grower. Therefore, the return distance for RPCs was modeled using a "worst case" scenario in which poolers reported the full distance from produce retailer to pooler back to grower (including routing through a washing facility) *specific to each produce application*. In other words, the modeling did not account for shorter RPC return/issue distances associated with shared-use pool operation.

In reality, taking into account movements of RPCs from all uses to all pooling locations, the average distance from an end user to a pooling location to a grower is likely considerably shorter. For example, a grape grower in California may get empty RPCs from a pooling location 250 miles away where the RPCs had been returned from a different commodity use, rather than empty RPCs that were used to deliver grapes to a grocery store in New York City. However, because it is not possible to estimate with certainty where the empty RPCs came from to the pooling location, this analysis modeled RPC backhauling for each commodity based on returns from grocery stores nationwide to pooling locations, routing through washing locations, transfers of RPCs between pooling locations, and reissue from pooling locations to growers of that specific commodity. This would be the maximum backhaul distance. For sensitivity analysis, each commodity is also evaluated at 20% reduced backhaul distance to illustrate the probable effect of shared-use pool operation.

DRC Box Weights

The weights of DRCs used in the average scenario are the weights reported by a producer of DRC containers and represent the weight of a one-piece folded box, which is the more prevalent DRC used in produce applications according to a contact at the CPA. Bliss boxes are another type of DRC container that can be used. Bliss boxes provide more strength per unit weight, but are more expensive and require that the user purchase equipment to convert the blank into a box by folding and gluing.

The DRC box weights provided by the DRC producer were compared to box weights in three case studies on costs of produce shipping in RPCs and corrugated published by the CPA. For the three produce applications (apples, oranges, and grapes), the corrugated box weights used in the CPA studies were 10 to 20 percent higher than the box weights modeled in the LCI study for the same produce applications. Thus, the weights used in the LCI study for the "average" DRC scenario already appear to be somewhat conservative for corrugated. In addition, to account for potential lightweighting of corrugated containers (e.g., achieved through redesign or perhaps use of a bliss box), the conservative scenario in the LCI evaluated DRCs at 10 percent lightweighting, i.e., 90 percent of the weight reported by the DRC producer.

End-of-life Management

RPCs. Poolers report that RPCs that are removed from service are returned to RPC producers, where they are reground and used to produce new RPCs, which will in turn be recycled when they are retired from service. This is considered closed-loop recycling. No burdens for disposal are assigned to the RPCs that remain in the system and are repeatedly recycled back into RPCs when they are removed from service after each multi-trip, multi-year life cycle. Retired RPCs that are not recycled back into RPCs would most likely be recycled into durable products such as plastic lumber, indefinitely diverting the material from disposal.

Although the material in the RPCs may ultimately be recycled many times, this analysis uses a conservative approach and allocates the burdens for production of the virgin material between the initial use and the first recycled use, rather than allocating over a larger number of lifetime cycles of RPC use and recycling.

All RPCs that are lost from the system during use are modeled as entering the municipal solid waste stream, where they are managed by a combination of landfilling and waste-to-energy incineration, as described below.

DRCs. The recovery rate for corrugated containers is about 70 percent overall in the U.S.[18]; however, recovery of corrugated containers from grocery stores is much higher and is modeled in this study at a rate of 95 percent. Thus, only 5 percent of corrugated containers are modeled as being disposed after use. For the 95 percent of boxes that are recovered, burdens for production and disposal of the box are allocated between the produce box and secondary uses of the recovered fiber based on the percentages of open- and closed-loop recycled content in the box. Further explanation of this allocation can be found in the Recycling Allocation section of Chapter 1.

For RPCs and DRCs that are disposed, disposal is modeled as 80 percent landfill and 20 percent waste-to-energy incineration[19]. An energy credit is assigned to each system based on the weight of containers burned and the higher heating value of the material.

LCI RESULTS

The tables and figures in this section include results and comparisons for several scenarios for RPCs and DRCs:

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[18] U.S. Environmental Protection Agency. **Municipal Solid Waste in the United States: 2001 Facts and Figures.** EPA/530-R-03-011. October 2003. Table 22.

[19] Ibid. Table 29.

- Average RPC (average reuse and loss rate) at maximum backhaul distance compared to average DRC (i.e., reported weight for folded box)
- Average RPC (average reuse and loss rate) at 20% reduced backhaul distance ("80% BH" in tables) compared to average DRC
- Conservative scenario: RPC at 75% of average reuse rate, twice the average loss rate, maximum backhaul distance compared to DRC with 10% lightweighting

Energy Results

Energy results for each system include process energy, transportation energy, and energy of material resource. **Process energy** includes energy requirements for all processes used to extract, transform, fabricate, clean, or otherwise effect changes on containers or container materials throughout their life cycle. **Transportation energy** is the energy used to move containers or container materials from location to location during its journey from raw material through end of life. **Energy of material resource** is not an expended energy but the energy value of fuel resources withdrawn from the planet's finite fossil reserves and used as material inputs for materials such as plastic resins. Use of fuel resources as a material input is a depletion of fuel resources just as the combustion of fuels for energy is. In this study, energy of material resource is reported for the RPCs. Natural gas and petroleum are the primary material feedstocks for resin production. For virgin RPC containers, about 45 percent of cradle-to-production energy is energy of material resource.

No energy of material resource is assigned to wood used as a material input for corrugated boxes because wood's primary use in the United States is as a material input, not as a fuel resource. Wood combusted for energy (such as bark and black liquor burned for fuel in virgin pulp and paper mills) is counted as process energy. A significant portion of the energy used at virgin paper(board) mills is derived from wood wastes and black liquor, while recycled paper(board) mills rely heavily on purchased energy. Overall, for average recycled content corrugated boxes at 95 percent recovery/recycling, about 28 percent of the total cradle-to-production energy is from wood.

For DRC systems, fossil fuels (petroleum, natural gas, and coal) account for about 68 percent of the total energy requirements. Almost one-third of the total energy requirements are derived from wood wastes, hydropower, nuclear energy, and other non-fossil sources. The high percentage of non-fossil fuel energy for DRCs is due largely to the use of wood materials for energy in paper mills, as described in the preceding paragraph. For RPCs, 97 percent of total energy is from fossil fuels. However, because the overall energy requirements for RPCs are lower than DRCs in most of the produce applications studied, the magnitude of fossil fuel energy use for DRCs is higher than RPCs for 8 of the 10 basic scenarios.

Transportation energy requirements shown in Table 2-2 are the total energy requirements allocated to the container based on its weight percentage of the total weight of the vehicle load. That is, for transportation from grower to retail, energy requirements are allocated among the produce, the containers, and the pallets based on their weight contributions to the truck or rail car load. On average, RPCs account for about 12 percent of the total weight of a load of packed produce, while DRCs account for around 6 percent. For transportation of new (empty) containers from manufacturer to grower and backhauling of empty RPCs, all transportation energy requirements are allocated to the container.

Energy results are shown by life cycle stage in Table 2-2. Table 2-2 also includes an energy credit for the energy recovered from the postconsumer containers that enter the waste stream and are managed by waste-to-energy combustion.

Material production and fabrication energy requirements for RPCs are lower than for DRCs, despite the fact that RPCs are heavier. At first glance this may seem counterintuitive, but the material production and container fabrication burdens for RPCs are allocated over their total number of useful lives, while DRCs have only one useful life before they are recycled or disposed.

Container transportation dominates total energy requirements for RPC systems, ranging from 68 to 79 percent of total energy for all RPC applications and scenarios. On average, RPC production and recycling accounts for 17 percent of total energy requirements, while RPC washing is about 10 percent of the total.

For a lower reuse rate and higher loss rate, more RPCs must be produced to make the same number of produce shipments, and more RPCs are recycled and disposed. The corresponding increase in energy requirements can be seen by comparing results by life cycle stage for “avg” and “conserv” RPC scenarios in Table 2-2.

For DRC systems, total energy is dominated by container production and recycling burdens, at over 80 percent of total energy for all applications and scenarios, followed by transportation at an average of 11 percent of total energy.

Table 2-2 (page 1 of 3)
Energy (million Btu/1,000 tons produce shipped)

		Container Transportation Steps									Percent of Total				
	Cradle-to-mfr	Mfr to grower (1)	Grower to retail (2)	Retail to pooler to grower (RPC)	RPC washing	RPC recycling (transp + proc)	Disposal	TOTAL ENERGY	Energy Credit (3)	Net Energy	Cradle-to-mfr + recycle	Ctr transp steps	RPC Washing	Disposal	Total
Apples															
RPC															
Avg	119	3.02	352	320	57.7	1.63	0.027	**853**	0.31	853	14%	79%	7%	0.003%	100%
Avg - 80% BH	119	3.02	352	256	57.7	1.63	0.027	**789**	0.31	789	15%	77%	7%	0.003%	100%
Conserv	163	4.11	352	320	57.7	2.19	0.073	**900**	0.84	899	18%	75%	6%	0.008%	100%
DRC															
Avg	940	7.83	121	0	0	0	5.18	**1,073**	49.5	1,024	88%	12%		0.5%	100%
Conserv	846	7.05	109	0	0	0	4.67	**966**	44.5	922	88%	12%		0.5%	100%
Bell Peppers															
RPC															
Avg	173	1.96	441	408	94.5	2.57	0.039	**1,121**	0.45	1,121	16%	76%	8%	0.004%	100%
Avg - 80% BH	173	1.96	441	326	94.5	2.57	0.039	**1,040**	0.45	1,039	17%	74%	9%	0.004%	100%
Conserv	239	2.68	441	408	94.5	3.45	0.11	**1,188**	1.23	1,187	20%	72%	8%	0.009%	100%
DRC															
Avg	1,606	13.4	189	0	0	0	8.86	**1,818**	84.6	1,733	88%	11%		0.5%	100%
Conserv	1,446	12.1	171	0	0	0	7.98	**1,637**	76.1	1,561	88%	11%		0.5%	100%
Carrots															
RPC															
Avg	96.0	0.37	251	132	49.6	1.37	0.022	**531**	0.25	530	18%	72%	9%	0.004%	100%
Avg - 80% BH	96.0	0.37	251	106	49.6	1.37	0.022	**504**	0.25	504	19%	71%	10%	0.004%	100%
Conserv	132	0.50	251	132	49.6	1.84	0.059	**567**	0.68	567	24%	68%	9%	0.010%	100%
DRC															
Avg	870	7.25	98.8	0	0	0	4.80	**981**	45.8	935	89%	11%		0.5%	100%
Conserv	783	6.53	89.3	0	0	0	4.32	**883**	41.2	842	89%	11%		0.5%	100%
Grapes															
RPC															
Avg	158	1.19	443	350	125	2.29	0.036	**1,080**	0.41	1,080	15%	74%	12%	0.003%	100%
Avg - 80% BH	158	1.19	443	280	125	2.29	0.036	**1,010**	0.41	1,010	16%	72%	12%	0.004%	100%
Conserv	218	1.62	443	350	125	3.08	0.098	**1,141**	1.12	1,140	19%	70%	11%	0.009%	100%
DRC															
Avg	1,691	14.1	206	0	0	0	9.33	**1,920**	89.0	1,831	88%	11%		0.5%	100%
Conserv	1,522	12.7	187	0	0	0	8.39	**1,729**	80.1	1,649	88%	12%		0.5%	100%

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(1) Cradle-to-manufacture data for corrugated includes recovery and recycling of postconsumer boxes and industrial scrap used as inputs to linerboard and medium.

(2) Transportation energy for shipment from grower to retail is based on refrigerated transport with energy allocated to containers based on their share of the load weight. All other transportation steps are non-refrigerated and allocated entirely to the container, since the load consists only of empty containers.

(3) On average, 20% of municipal solid waste in the US remaining after diversion for reuse or recycling is disposed by waste-to-energy incineration. The energy credit shown reflects the higher heating value of the material and incineration of 20% of the containers that are disposed.

Table 2-2 (page 2 of 3)
Energy (million Btu/1,000 tons produce shipped)

		Container Transportation Steps									Percent of Total				
	Cradle-to-mfr	Mfr to grower (1)	Grower to retail (2)	Retail to pooler to grower (RPC)	RPC washing	RPC recycling (transp + proc)	Disposal	TOTAL ENERGY	Energy Credit (3)	Net Energy	Cradle-to-mfr + recycle	Ctr transp steps	RPC Washing	Disposal	Total
Lettuce - head															
RPC															
Avg	136	1.39	365	333	67.6	1.90	0.031	**905**	0.36	905	15%	77%	7%	0.003%	100%
Avg - 80% BH	136	1.39	365	266	67.6	1.90	0.031	**839**	0.36	838	16%	75%	8%	0.004%	100%
Conserv	188	1.89	365	333	67.6	2.55	0.085	**958**	0.97	957	20%	73%	7%	0.009%	100%
DRC															
Avg	1,305	10.9	162	0	0	0	7.20	**1,485**	68.7	1,416	88%	12%		0.5%	100%
Conserv	1,175	9.79	147	0	0	0	6.48	**1,338**	61.8	1,276	88%	12%		0.5%	100%
Oranges															
RPC															
Avg	109	0.83	234	245	59.5	1.62	0.025	**650**	0.28	649	17%	74%	9%	0.004%	100%
Avg - 80% BH	109	0.83	234	196	59.5	1.62	0.025	**601**	0.28	600	18%	72%	10%	0.004%	100%
Conserv	150	1.13	234	245	59.5	2.17	0.068	**692**	0.77	691	22%	69%	9%	0.010%	100%
DRC															
Avg	1,122	9.36	103	0	0	0	6.19	**1,241**	59.1	1,182	90%	9%		0.5%	100%
Conserv	1,010	8.42	93.2	0	0	0	5.57	**1,117**	53.2	1,064	90%	9%		0.5%	100%
Peaches/Nectarines															
RPC															
Avg	93.6	0.58	257	249	69.6	1.30	0.021	**671**	0.24	671	14%	75%	10%	0.003%	100%
Avg - 80% BH	93.6	0.58	257	199	69.6	1.30	0.021	**621**	0.24	621	15%	74%	11%	0.003%	100%
Conserv	129	0.78	257	249	69.6	1.75	0.058	**707**	0.66	706	18%	72%	10%	0.008%	100%
DRC															
Avg	1,134	9.45	135	0	0	0	6.25	**1,284**	59.7	1,224	88%	11%		0.5%	100%
Conserv	1,020	8.51	122	0	0	0	5.63	**1,156**	53.7	1,102	88%	11%		0.5%	100%
Onions															
RPC															
Avg	87.2	0.56	227	157	59.5	1.15	0.020	**533**	0.23	532	17%	72%	11%	0.004%	100%
Avg - 80% BH	87.2	0.56	227	126	59.5	1.15	0.020	**501**	0.23	501	18%	70%	12%	0.004%	100%
Conserv	120	0.77	227	157	59.5	1.54	0.054	**566**	0.62	566	21%	68%	11%	0.010%	100%
DRC															
Avg	955	7.96	106	0	0	0	5.27	**1,075**	50.3	1,025	89%	11%		0.5%	100%
Conserv	860	7.17	96.3	0	0	0	4.74	**968**	45.3	923	89%	11%		0.5%	100%

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(1) Cradle-to-manufacture data for corrugated includes recovery and recycling of postconsumer boxes and industrial scrap used as inputs to linerboard and medium.

(2) Transportation energy for shipment from grower to retail is based on refrigerated transport with energy allocated to containers based on their share of the load weight. All other transportation steps are non-refrigerated and allocated entirely to the container, since the load consists only of empty containers.

(3) On average, 20% of municipal solid waste in the US remaining after diversion for reuse or recycling is disposed by waste-to-energy incineration. The energy credit shown reflects the higher heating value of the material and incineration of 20% of the containers that are disposed.

Table 2-2 (page 3 of 3)
Energy (million Btu/1,000 tons produce shipped)

		Container Transportation Steps									Percent of Total				
	Cradle-to-mfr	Mfr to grower (1)	Grower to retail (2)	Retail to pooler to grower (RPC)	RPC washing	RPC recycling (transp + proc)	Disposal	TOTAL ENERGY	Energy Credit (3)	Net Energy	Cradle-to-mfr + recycle	Ctr transp steps	RPC Washing	Disposal	Total
Tomatoes															
RPC															
Avg	125	3.81	275	308	85.0	1.64	0.028	**797**	0.32	797	16%	74%	11%	0.004%	100%
Avg - 80% BH	125	3.81	275	246	85.0	1.64	0.028	**736**	0.32	736	17%	71%	12%	0.004%	100%
Conserv	172	5.18	275	308	85.0	2.21	0.077	**846**	0.88	845	21%	69%	10%	0.009%	100%
DRC															
Avg	1,119	9.33	107	0	0	0	6.17	**1,241**	58.9	1,182	90%	9%		0.5%	100%
Conserv	1,007	8.39	96.4	0	0	0	5.55	**1,117**	53.0	1,064	90%	9%		0.5%	100%
Strawberries															
RPC															
Avg	247	5.83	868	586	264	4.40	0.056	**1,975**	0.64	1,974	13%	74%	13%	0.003%	100%
Avg - 80% BH	247	5.83	868	468	264	4.40	0.056	**1,858**	0.64	1,857	14%	72%	14%	0.003%	100%
Conserv	340	7.94	868	586	264	5.91	0.15	**2,071**	1.75	2,070	17%	71%	13%	0.007%	100%
DRC															
Avg	2,065	17.2	361	0	0	0	11.4	**2,455**	109	2,346	84%	15%		0.5%	100%
Conserv	1,859	15.5	328	0	0	0	10.3	**2,212**	97.9	2,114	84%	16%		0.5%	100%

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(1) Cradle-to-manufacture data for corrugated includes recovery and recycling of postconsumer boxes and industrial scrap used as inputs to linerboard and medium.

(2) Transportation energy for shipment from grower to retail is based on refrigerated transport with energy allocated to containers based on their share of the load weight. All other transportation steps are non-refrigerated and allocated entirely to the container, since the load consists only of empty containers.

(3) On average, 20% of municipal solid waste in the US remaining after diversion for reuse or recycling is disposed by waste-to-energy incineration. The energy credit shown reflects the higher heating value of the material and incineration of 20% of the containers that are disposed.

An energy credit for the energy recovered from containers that are incinerated at end of life is shown in Table 2-2. Although the energy content per pound of plastic is higher than the energy content per pound of corrugated, the energy credit is higher for DRCs because more DRCs are disposed.

Comparative energy results for RPCs and DRCs for average and conservative scenarios are shown in Figures 2-1 and 2-2 and summarized in Table 2-3. Based on the uncertainties in LCI energy data, energy differences between systems are not considered meaningful unless the percent difference between system results is greater than 10 percent. (Percent difference between systems is defined as the difference between energy totals divided by the average of the two system totals.) This minimum percent difference criterion was developed based on the experience and professional judgment of the analysts and supported by sample statistical calculations (see Chapter 3). If the percent difference between two systems' results is less than 10 percent, the comparison is considered inconclusive. Inconclusive comparisons are shaded in gray in Table 2-3.

Table 2-3 shows that RPCs have lower total energy requirements than corresponding DRCs in all comparisons for all scenarios except for the conservative scenario comparisons for apples and strawberries, where the percent difference is too small to be considered meaningful.

Solid Waste

Solid waste results for individual business units are shown in Tables 2-4 and 2-5. Solid wastes are broadly categorized into process wastes, fuel-related wastes, and postconsumer wastes. **Process wastes** are the solid wastes generated by the various processes used to extract, transform, fabricate, clean, or otherwise effect changes on containers or container materials throughout their life cycle. **Fuel-related wastes** are the wastes from the production and combustion of fuels used for process energy and transportation energy. Solid wastes for process fuel and transportation fuel are shown separately in the tables. **Postconsumer wastes** include postconsumer containers that are landfilled after they are removed from service, as well as ash from municipal waste combustion of a percentage of the postconsumer containers that enter the solid waste stream.

Differences in solid waste results between systems are not considered meaningful unless the percent difference is greater than 25 percent for process and fuel-related wastes, or greater than 10 percent for postconsumer wastes. (Percent difference between systems is defined as the difference between solid waste totals divided by the average of the two system totals.) This minimum percent difference criterion was developed based on the experience and professional judgment of the analysts and supported by sample statistical calculations (see Chapter 3). However, the differences in solid waste between RPCs and DRCs are large enough that a percent difference comparison is not required. In all cases, RPC systems produce a fraction of the solid wastes produced by corresponding DRC systems.

Figure 2-1. Average Scenario Energy Comparison
(RPC at avg reuse and loss rate, max backhaul and 80% backhaul; DRC at reported weight)

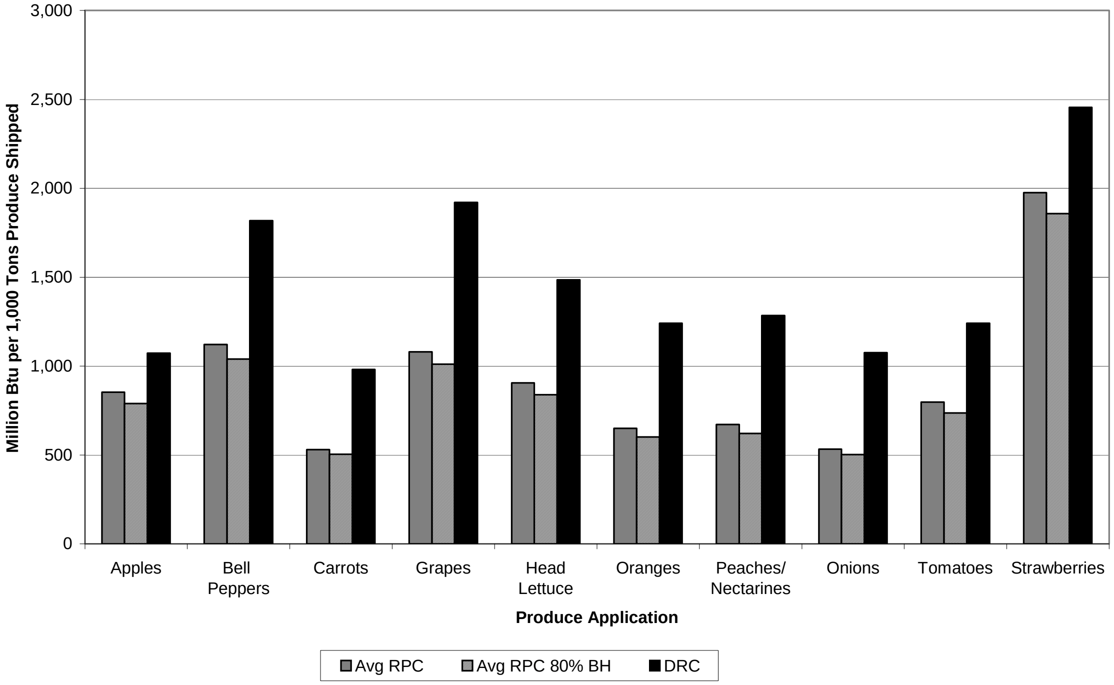

Figure 2-2. Conservative Scenario Energy Comparison
(RPC at 3/4 avg reuse rate and 2x avg loss rate, 10% lightweighted DRC)

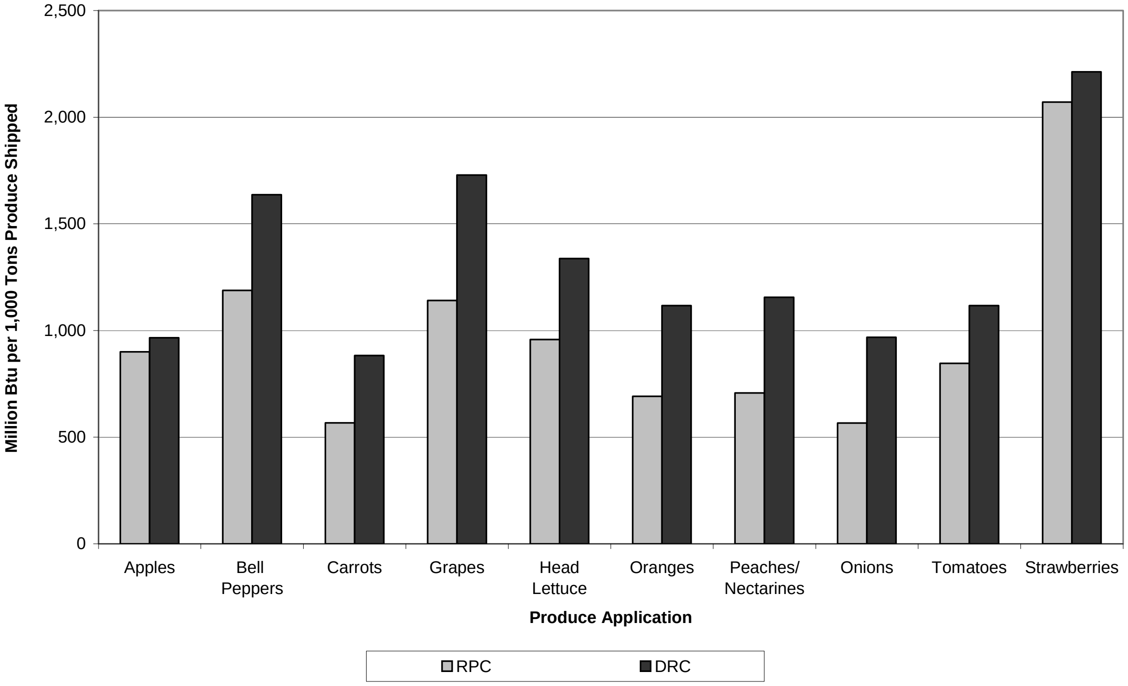

Table 2-3
Comparative Energy Summary
(Results reported on the basis of 1,000 tons of produce shipped.)

	RPC Total Energy (million Btu)			DRC Total Energy (million Btu)		Percent Difference* (DRC - RPC)/(avg of DRC and RPC)		
	avg	avg with 80% BH	conserv	avg	conserv	avg DRC, avg RPC	avg DRC, avg RPC w/80% BH	conserv
Apples	853	789	900	1,073	966	23%	31%	7%
Bell Peppers	1,121	1,040	1,188	1,818	1,637	47%	54%	32%
Carrots	531	504	567	981	883	60%	64%	44%
Grapes	1,080	1,010	1,141	1,920	1,729	56%	62%	41%
Lettuce - head	905	839	958	1,485	1,338	49%	56%	33%
Oranges	650	601	692	1,241	1,117	63%	70%	47%
Peaches/Nectarines	671	621	707	1,284	1,156	63%	70%	48%
Onions	533	501	566	1,075	968	67%	73%	52%
Tomatoes	797	736	846	1,241	1,117	44%	51%	28%
Strawberries	1,975	1,858	2,071	2,455	2,212	22%	28%	7%

Source: Franklin Associates.

* Percent difference = (difference between systems)/(average of systems). Positive value indicates that DRC is higher.
Percent difference must be at least 10% to consider energy difference meaningful. Inconclusive comparisons are shaded in gray.

Solid Waste by Weight. Table 2-5 shows solid waste by weight broken out into the categories of process waste, process fuel-related waste, transportation fuel-related waste, and postconsumer waste. For produce applications for all scenarios, the DRC systems produce more process solid waste, process fuel-related solid waste, and postconsumer solid waste. RPCs have higher fuel-related solid wastes for container transportation, due to the heavier container weight and backhauling.

On average, for RPCs in all applications and scenarios, total solid waste is dominated by process fuel-related waste (72 percent of total), followed by container transportation fuel-related wastes (16 percent), process wastes (9 percent), and postconsumer wastes (3 percent). Because of the closed-loop operation of the RPC pooling system, only those RPCs lost from the system end up as postconsumer solid waste; RPCs removed from service by the pooler are recycled.

The solid waste profile for DRCs is quite different. Even at 95 percent recovery and recycling, postconsumer containers account for half of the total solid waste, followed by process fuel-related waste (38 percent) and process wastes (12 percent). Container transportation fuel-related wastes are less than one percent of the total weight of solid waste

Table 2-4 (page 1 of 2)
Solid Waste by Weight

	SOLID WASTE WEIGHT										
	Pounds of SW per 1,000 Tons Produce Shipped						Percent of Total SW Weight				
	Process	Fuel for Process	Fuel for Ctr Transp	Post-consumer	Total lb of SW	Tons SW	Process	Fuel for Process	Fuel for Ctr Transp	Post-consumer	Total
Apples											
RPC											
Avg	241	1,819	568	62.5	2,691	**1.35**	9%	68%	21%	2%	100%
Avg - 80% BH	241	1,819	514	62.5	2,637	**1.32**	9%	69%	19%	2%	100%
Conserv	332	2,137	569	170	3,208	**1.60**	10%	67%	18%	5%	100%
DRC											
Avg	6,187	19,088	108	25,226	50,609	**25.3**	12%	38%	0%	50%	100%
Conserv	5,568	17,179	97.5	22,703	45,548	**22.8**	12%	38%	0%	50%	100%
Bell Peppers											
RPC											
Avg	354	2,829	716	91.4	3,990	**1.99**	9%	71%	18%	2%	100%
Avg - 80% BH	354	2,829	647	91.4	3,921	**1.96**	9%	72%	17%	2%	100%
Conserv	486	3,294	717	249	4,746	**2.37**	10%	69%	15%	5%	100%
DRC											
Avg	10,575	32,629	170	43,121	86,496	**43.2**	12%	38%	0%	50%	100%
Conserv	9,518	29,366	154	38,809	77,848	**38.9**	9%	27%	0%	64%	100%
Carrots											
RPC											
Avg	196	1,521	323	50.6	2,090	**1.04**	9%	73%	15%	2%	100%
Avg - 80% BH	196	1,521	300	50.6	2,067	**1.03**	9%	74%	15%	2%	100%
Conserv	269	1,778	323	138	2,508	**1.25**	11%	71%	13%	5%	100%
DRC											
Avg	5,728	17,674	89.2	23,357	46,849	**23.4**	12%	38%	0%	50%	100%
Conserv	5,155	15,907	80.6	21,022	42,165	**21.1**	9%	27%	0%	64%	100%
Grapes											
RPC											
Avg	325	3,227	668	83.3	4,303	**2.15**	8%	75%	16%	2%	100%
Avg - 80% BH	325	3,227	609	83.3	4,245	**2.12**	8%	76%	14%	2%	100%
Conserv	445	3,651	669	227	4,992	**2.50**	9%	73%	13%	5%	100%
DRC											
Avg	11,129	34,339	185	45,380	91,033	**45.5**	12%	38%	0%	50%	100%
Conserv	10,016	30,905	168	40,842	81,931	**41.0**	9%	27%	0%	64%	100%
Lettuce - head											
RPC											
Avg	278	2,114	588	71.9	3,052	**1.53**	9%	69%	19%	2%	100%
Avg - 80% BH	278	2,114	532	71.9	2,996	**1.50**	9%	71%	18%	2%	100%
Conserv	382	2,480	589	196	3,647	**1.82**	10%	68%	16%	5%	100%
DRC											
Avg	8,592	26,511	145	35,036	70,285	**35.1**	12%	38%	0%	50%	100%
Conserv	7,733	23,860	131	31,533	63,257	**31.6**	9%	27%	0%	64%	100%

Table 2-4 (page 2 of 2)
Solid Waste by Weight

	SOLID WASTE WEIGHT										
	Pounds of SW per 1,000 Tons Produce Shipped						Percent of Total SW Weight				
	Process	Fuel for Process	Fuel for Ctr Transp	Post-consumer	Total lb of SW	Tons SW	Process	Fuel for Process	Fuel for Ctr Transp	Post-consumer	Total
Oranges											
RPC											
Avg	223	1,781	403	57.5	2,465	**1.23**	9%	72%	16%	2%	100%
Avg - 80% BH	223	1,781	362	57.5	2,423	**1.21**	9%	73%	15%	2%	100%
Conserv	306	2,074	404	157	2,940	**1.47**	10%	71%	14%	5%	100%
DRC											
Avg	7,390	22,800	94.6	30,131	60,415	**30.2**	12%	38%	0%	50%	100%
Conserv	6,651	20,520	85.5	27,118	54,374	**27.2**	9%	27%	0%	64%	100%
Peaches/Nectarines											
RPC											
Avg	192	1,835	426	49.3	2,502	**1.25**	8%	73%	17%	2%	100%
Avg - 80% BH	192	1,835	384	49.3	2,460	**1.23**	8%	75%	16%	2%	100%
Conserv	263	2,086	426	134	2,910	**1.45**	9%	72%	15%	5%	100%
DRC											
Avg	7,463	23,027	121	30,431	61,043	**30.5**	12%	38%	0%	50%	100%
Conserv	6,717	20,724	109	27,388	54,939	**27.5**	9%	27%	0%	64%	100%
Onions											
RPC											
Avg	179	1,622	324	46.0	2,170	**1.09**	8%	75%	15%	2%	100%
Avg - 80% BH	179	1,622	297	46.0	2,144	**1.07**	8%	76%	14%	2%	100%
Conserv	245	1,856	324	125	2,550	**1.28**	10%	73%	13%	5%	100%
DRC											
Avg	6,290	19,406	96.2	25,646	51,439	**25.7**	12%	38%	0%	50%	100%
Conserv	5,661	17,466	87.0	23,082	46,295	**23.1**	9%	27%	0%	64%	100%
Tomatoes											
RPC											
Avg	255	2,317	493	65.7	3,131	**1.57**	8%	74%	16%	2%	100%
Avg - 80% BH	255	2,317	441	65.7	3,079	**1.54**	8%	75%	14%	2%	100%
Conserv	350	2,651	494	179	3,675	**1.84**	10%	72%	13%	5%	100%
DRC											
Avg	7,365	22,724	97.5	30,031	60,217	**30.1**	12%	38%	0%	50%	100%
Conserv	6,628	20,452	88.2	27,028	54,196	**27.1**	9%	27%	0%	64%	100%
Strawberries											
RPC											
Avg	511	6,185	1,227	130	8,054	**4.03**	6%	77%	15%	2%	100%
Avg - 80% BH	511	6,185	1,129	130	7,956	**3.98**	6%	78%	14%	2%	100%
Conserv	700	6,847	1,230	354	9,131	**4.57**	8%	75%	13%	4%	100%
DRC											
Avg	13,595	41,947	318	55,435	111,295	**55.6**	12%	38%	0%	50%	100%
Conserv	12,236	37,752	289	49,891	100,168	**50.1**	9%	27%	0%	64%	100%

Table 2-5 (page 1 of 2)
Solid Waste by Volume

	SOLID WASTE VOLUME Cu ft of SW per 1,000 Tons Produce Shipped					Percent of Total SW Volume				
	Process	**Fuel for Process**	**Fuel for Ctr Transp**	**Post-consumer**	**Total cu ft of SW**	**Process**	**Fuel for Process**	**Fuel for Ctr Transp**	**Post-consumer**	**Total cu ft of SW**
Apples										
RPC										
Avg	4.83	36.4	11.4	4.75	57.3	8%	63%	20%	8%	100%
Avg - 80% BH	4.83	36.4	10.3	4.75	56.2	9%	65%	18%	8%	100%
Conserv	6.64	42.7	11.4	12.9	73.7	9%	58%	15%	18%	100%
DRC										
Avg	124	382	2.16	903	1,411	9%	27%	0%	64%	100%
Conserv	111	344	1.95	813	1,270	9%	27%	0%	64%	100%
Bell Peppers										
RPC										
Avg	7.07	56.6	14.3	6.95	84.9	8%	67%	17%	8%	100%
Avg - 80% BH	7.07	56.6	12.9	6.95	83.5	8%	68%	15%	8%	100%
Conserv	9.72	65.9	14.3	18.9	109	9%	61%	13%	17%	100%
DRC										
Avg	212	653	3.40	1,544	2,411	9%	27%	0%	64%	100%
Conserv	190	587	3.08	1,389	2,170	9%	27%	0%	64%	100%
Carrots										
RPC										
Avg	3.91	30.4	6.45	3.85	44.6	9%	68%	14%	9%	100%
Avg - 80% BH	3.91	30.4	6.01	3.85	44.2	9%	69%	14%	9%	100%
Conserv	5.38	35.6	6.46	10.5	57.9	9%	61%	11%	18%	100%
DRC										
Avg	115	353	1.78	836	1,306	9%	27%	0%	64%	100%
Conserv	103	318	1.61	753	1,175	9%	27%	0%	64%	100%
Grapes										
RPC										
Avg	6.50	64.5	13.4	6.34	90.7	7%	71%	15%	7%	100%
Avg - 80% BH	6.50	64.5	12.2	6.34	89.6	7%	72%	14%	7%	100%
Conserv	8.91	73.0	13.4	17.3	113	8%	65%	12%	15%	100%
DRC										
Avg	223	687	3.70	1,625	2,538	9%	27%	0%	64%	100%
Conserv	200	618	3.35	1,462	2,284	9%	27%	0%	64%	100%
Lettuce - head										
RPC										
Avg	5.56	42.3	11.8	5.47	65.1	9%	65%	18%	8%	100%
Avg - 80% BH	5.56	42.3	10.6	5.47	64.0	9%	66%	17%	9%	100%
Conserv	7.64	49.6	11.8	14.9	83.9	9%	59%	14%	18%	100%
DRC										
Avg	172	530	2.91	1,254	1,959	9%	27%	0%	64%	100%
Conserv	155	477	2.63	1,129	1,763	9%	27%	0%	64%	100%

Table 2-5 (page 2 of 2)
Solid Waste by Volume

Solid Waste by Volume

	Cu ft of SW per 1,000 Tons Produce Shipped					Percent of Total SW Volume				
	Process	**Fuel for Process**	**Fuel for Ctr Transp**	**Post-consumer**	**Total cu ft of SW**	**Process**	**Fuel for Process**	**Fuel for Ctr Transp**	**Post-consumer**	**Total cu ft of SW**
Oranges										
RPC										
Avg	4.45	35.6	8.07	4.38	52.5	8%	68%	15%	8%	100%
Avg - 80% BH	4.45	35.6	7.24	4.38	51.7	9%	69%	14%	8%	100%
Conserv	6.12	41.5	8.08	11.9	67.6	9%	61%	12%	18%	100%
DRC										
Avg	148	456	1.89	1,079	1,684	9%	27%	0%	64%	100%
Conserv	133	410	1.71	971	1,516	9%	27%	0%	64%	100%
Peaches/Nectarines										
RPC										
Avg	3.84	36.7	8.52	3.75	52.8	7%	69%	16%	7%	100%
Avg - 80% BH	3.84	36.7	7.68	3.75	52.0	7%	71%	15%	7%	100%
Conserv	5.27	41.7	8.53	10.2	65.7	8%	63%	13%	16%	100%
DRC										
Avg	149	461	2.42	1,089	1,702	9%	27%	0%	64%	100%
Conserv	134	414	2.19	981	1,532	9%	27%	0%	64%	100%
Onions										
RPC										
Avg	3.57	32.4	6.47	3.50	46.0	8%	71%	14%	8%	100%
Avg - 80% BH	3.57	32.4	5.94	3.50	45.5	8%	71%	13%	8%	100%
Conserv	4.90	37.1	6.48	9.52	58.0	8%	64%	11%	16%	100%
DRC										
Avg	126	388	1.92	918	1,434	9%	27%	0%	64%	100%
Conserv	113	349	1.74	826	1,291	9%	27%	0%	64%	100%
Tomatoes										
RPC										
Avg	5.10	46.3	9.86	5.00	66.3	8%	70%	15%	8%	100%
Avg - 80% BH	5.10	46.3	8.82	5.00	65.3	8%	71%	14%	8%	100%
Conserv	7.01	53.0	9.89	13.6	83.5	8%	63%	12%	16%	100%
DRC										
Avg	147	454	1.95	1,075	1,679	9%	27%	0%	64%	100%
Conserv	133	409	1.76	968	1,511	9%	27%	0%	64%	100%
Strawberries										
RPC										
Avg	10.2	124	24.5	9.89	168	6%	73%	15%	6%	100%
Avg - 80% BH	10.2	124	22.6	9.89	166	6%	74%	14%	6%	100%
Conserv	14.0	137	24.6	26.9	202	7%	68%	12%	13%	100%
DRC										
Avg	272	839	6.36	1,985	3,102	9%	27%	0%	64%	100%
Conserv	245	755	5.77	1,786	2,792	9%	27%	0%	64%	100%

Solid Waste by Volume. While solid waste generation is commonly reported in terms of weight, solid waste volume is the important issue in landfills. Weights of solid waste are converted to volume by dividing by their landfill density. An average density factor for industrial solid waste is used for process wastes, fuel-related wastes, and landfill ash. The landfill densities of RPCs and DRCs are based on densities for similar types of packaging determined by extensive sampling by the University of Arizona. [20]

Table 2-6 shows that postconsumer solid waste accounts for a larger percentage of solid waste by volume compared to solid waste by weight; consequently, the volume percentages for other solid waste categories decrease relative to their weight percentages. On average, for all RPC scenarios and applications, process fuel-related waste accounts for 67 percent of the total volume of solid waste, followed by container transportation fuel-related waste (14 percent), postconsumer waste (11 percent), and process waste (8 percent). For DRCs, postconsumer solid waste is 64 percent of the total volume of solid waste, followed by process fuel-related solid waste (27 percent), and process solid waste (9 percent).

Comparative results for solid waste by weight for RPCs and DRCs for average and conservative scenarios are shown in Figures 2-3 and 2-4 and summarized in Table 2-6. On average DRCs produce 21 times as many tons of solid waste as average RPCs with maximum backhaul or 20% reduced backhaul, and 16 times more solid waste than RPCs in the conservative scenario.

Environmental Emissions

Atmospheric and waterborne emissions for each system include emissions that result directly from processes (e.g., gases released from chemical reactions) and those associated with the combustion of fuels. As noted in Chapter 1, this analysis does not include atmospheric or waterborne emissions associated with landfilling or incineration of RPCs or DRCs at end of life; thus, the emissions analysis does not include emissions associated with the energy credits shown in Table 2-2.

The emissions tables in this section present emission quantities based upon the best data available. However, some of the data are reported from industrial sources, some are from standard emissions tables, and some have been calculated. This means there are significant uncertainties with regards to the application of the data to these particular container systems. Because of these uncertainties, the difference in two systems' emissions of a given substance are not considered meaningful unless the percent difference exceeds 25 percent. (Percent difference is defined as the difference between two system totals divided by their average.) This minimum percent difference criterion was developed based on the experience and professional judgment of the analysts and supported by sample statistical calculations (see Chapter 3). If the percent difference between two systems' results is less than 25 percent, the comparison is considered inconclusive.

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[20] **Estimates of the Volume of MSW and Selected Components in Trash Cans and Landfills.** Prepared for The Council for Solid Waste Solutions by Franklin Associates, Ltd. and The Garbage Project. February 1990.

Table 2-6
Comparative Solid Waste Summary
(Results reported on the basis of 1,000 tons of produce shipped.)

	RPC Total Solid Waste (tons)			DRC Total Solid Waste (tons)		DRC/RPC		
	avg	avg with 80% BH	conserv	avg	conserv	avg DRC, avg RPC	avg DRC, avg RPC w/80% BH	conserv
Apples	1.35	1.32	1.60	25.3	22.8	18.8	19.2	14.2
Bell Peppers	1.99	1.96	2.37	43.2	38.9	21.7	22.1	16.4
Carrots	1.04	1.03	1.25	23.4	21.1	22.4	22.7	16.8
Grapes	2.15	2.12	2.50	45.5	41.0	21.2	21.4	16.4
Lettuce - head	1.53	1.50	1.82	35.1	31.6	23.0	23.5	17.3
Oranges	1.23	1.21	1.47	30.2	27.2	24.5	24.9	18.5
Peaches/Nectarines	1.25	1.23	1.45	30.5	27.5	24.4	24.8	18.9
Onions	1.09	1.07	1.28	25.7	23.1	23.7	24.0	18.2
Tomatoes	1.57	1.54	1.84	30.1	27.1	19.2	19.6	14.7
Strawberries	4.03	3.98	4.57	55.6	50.1	13.8	14.0	11.0
				average for all produce applications:		**21.3**	**21.6**	**16.2**

Source: Franklin Associates.

Substances are reported in the tables in speciated or unspeciated form, depending on the compositional information available. General categories such as “Acid” and “Metal Ion” are used to report unspeciated data. Emissions are reported only in the most descriptive single category applicable; speciated data are not reported again in the broadly applicable unspeciated category. For example, emissions reported as “HCl” are not additionally reported under the category “Acid,” nor are emissions reported as “Chromium” additionally reported under “Metal Ion.”

It is important to realize that interpretation of air and water emission data requires great care. The effects of the various emissions on humans and on the environment are not fully known. The degree of potential environmental disruption due to environmental releases is not related to the weight of the releases in a simple way, but also depends on the time frame, concentration, location, human exposure, etc. associated with the releases. This information is not readily available in an LCI; thus, the LCI analysis is limited to a comparison of the total quantities of each substance released over the life cycle of each container system, with no attempt to assess the potential impacts of these releases on human health or the environment. An exception is made in the case of greenhouse gases, for which widely accepted global warming potential equivalence factors are available for individual substances.

Atmospheric Emissions. This analysis tracks over 40 different process and fuel-related atmospheric emissions for each system. It is not practical to attempt to discuss all these individual atmospheric emission categories; therefore, most of the following discussion focuses on the high priority atmospheric issue of greenhouse gas emissions. The primary three atmospheric emissions reported in this analysis that contribute to global warming are fossil fuel-derived carbon dioxide, methane, and nitrous oxide.

Figure 2-3. Average Scenario Solid Waste Comparison

(RPC at avg reuse and loss rate, max backhaul and 80% backhaul; DRC at reported weight)

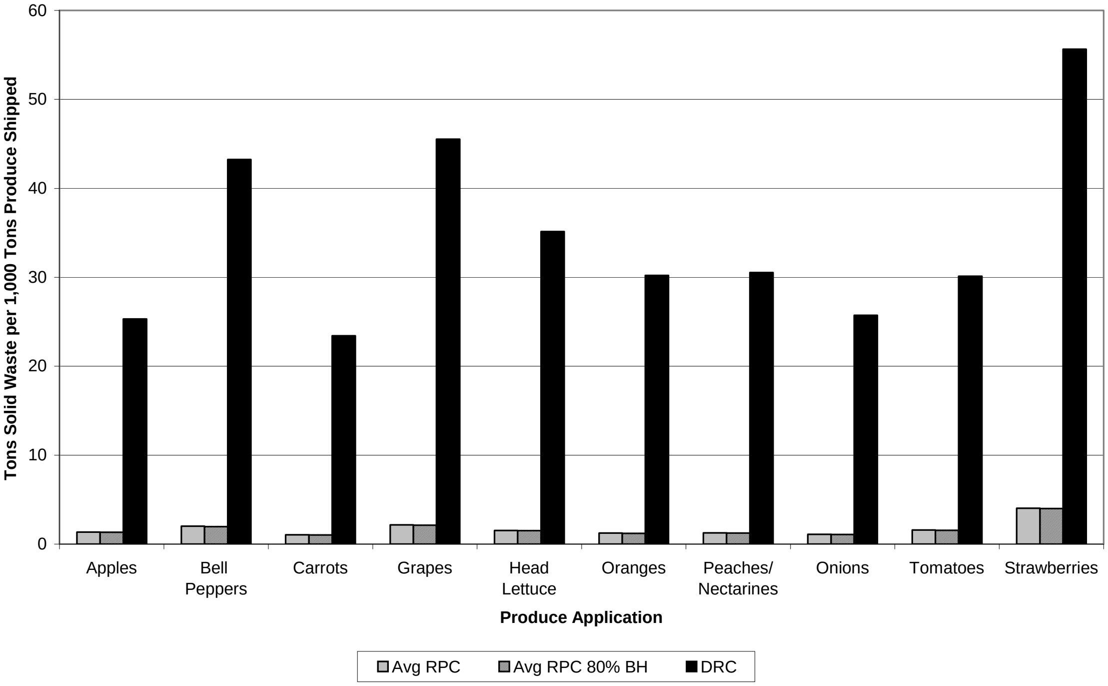
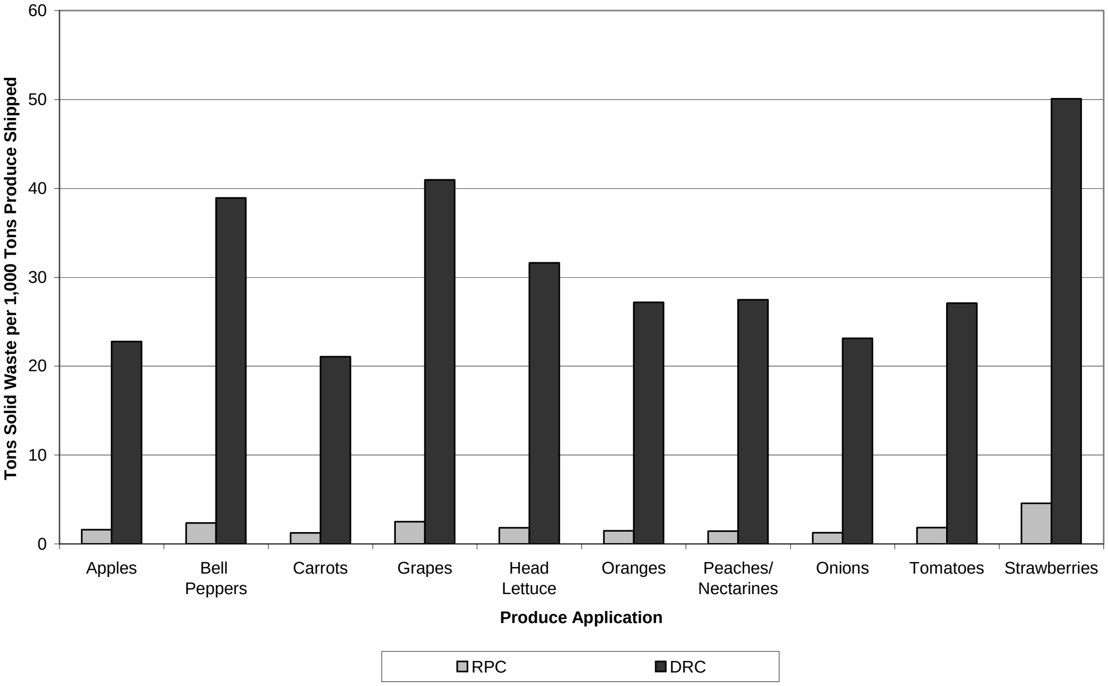


Figure 2-4. Conservative Scenario Solid Waste Comparison

(RPC at 3/4 avg reuse rate and 2x avg loss rate, 10% lightweighted DRC)



From the International Panel on Climate Change (IPCC) 2001 report, the 100-year global warming potential for the three GHG emissions in this analysis are: carbon dioxide 1, methane 23, and nitrous oxide 296. The global warming potential represents the relative global warming contribution of a pound of a particular greenhouse gas compared to a pound of carbon dioxide. The weights of each of these substances are multiplied by their global warming potential and totaled to arrive at the greenhouse gas (GHG) totals shown in Table 2-7.

Greenhouse gas emissions generally track closely with fossil fuel energy requirements, since the majority of GHG emissions are carbon dioxide from the combustion of fossil fuels used for process and transportation energy over the life cycle of the container systems. There are no GHG emissions associated with the energy of material resource for the RPC systems, since energy of material resource is a measure of the energy content of the material rather than combusted energy. For DRCs, carbon dioxide emissions from the use of wood-derived energy in paper(board) mills are considered part of the natural carbon cycle and are not included in the GHG totals as a net contribution to atmospheric carbon dioxide. As noted in Chapter 1, the GHG emissions reported in this study do not include emissions from burning of containers with mixed municipal solid waste or from decomposition of landfilled containers.

Table 2-7 shows that greenhouse gas emissions for the RPC systems are dominated by emissions associated with transportation fuel use, while the majority of GHG emissions for DRC systems are associated with process fuel use. Fuel-related emissions associated with container transportation are higher for RPCs due to RPCs' heavier container weights and backhauling requirements. Process fuel-related emissions are higher for DRCs due to the greater quantity of containers that must be produced.

Comparative GHG results for RPCs and DRCs for average and conservative scenarios are shown in Figures 2-5 and 2-6 and summarized in Table 2-8. In the comparison of average DRCs with average RPCs at maximum and 80% backhaul, GHG emissions are lower for RPCs compared to corresponding DRCs in all cases except apples and strawberries, where the comparison is inconclusive. These are the produce applications in which the energy results are also the closest. As noted earlier, GHG emissions closely track fossil energy use; energy of material resource (for RPCs) and wood combustion emissions (for DRCs) do not contribute to GHG although these energy categories are included in the total system energy requirements.

For the conservative scenario comparisons, RPCs had lower GHG emissions in half the comparisons, and half were inconclusive. Lower RPC use rates and higher loss rates increase the GHG emissions for RPC production, while the container transportation GHG that dominate GHG for RPCs remain constant. Lightweighting DRCs reduces GHG burdens for all life cycle stages – production GHG, which are the dominant source of GHG for DRCs, transportation GHG, and end-of-life GHG.

Table 2-7 (page 1 of 2)
Greenhouse Gas Emissions

	(lb CO2 equivalents/1,000 tons produce shipped)					**Percent of Total GHG**			
	Process	**Fuel for Process**	**Fuel for Ctr Transp**	**Total GHG**	**Tons GHG**	**Process**	**Fuel for Process**	**Fuel for Ctr Transp**	**Total**
Apples									
RPC									
Avg	366	15,524	109,493	125,384	**62.7**	0.3%	12%	87%	100%
Avg - 80% BH	366	15,524	99,121	115,011	**57.5**	0.3%	13%	86%	100%
Conserv	506	18,405	109,727	128,638	**64.3**	0.4%	14%	85%	100%
DRC									
Avg	197	113,293	20,801	134,292	**67.1**	0.1%	84%	15%	100%
Conserv	178	101,964	18,795	120,937	**60.5**	0.1%	84%	16%	100%
Bell Peppers									
RPC									
Avg	536	24,076	137,990	162,602	**81.3**	0.3%	15%	85%	100%
Avg - 80% BH	536	24,076	124,775	149,387	**74.7**	0.4%	16%	84%	100%
Conserv	740	28,288	138,199	167,227	**83.6**	0.4%	17%	83%	100%
DRC									
Avg	338	193,664	32,785	226,787	**113**	0.1%	85%	14%	100%
Conserv	304	174,298	29,694	204,296	**102**	0.1%	85%	15%	100%
Carrots									
RPC									
Avg	297	12,957	62,258	75,512	**37.8**	0.4%	17%	82%	100%
Avg - 80% BH	297	12,957	57,960	71,214	**35.6**	0.4%	18%	81%	100%
Conserv	410	15,289	62,329	78,027	**39.0**	0.5%	20%	80%	100%
DRC									
Avg	183	104,901	17,188	122,272	**61.1**	0.1%	86%	14%	100%
Conserv	165	94,411	15,525	110,101	**55.1**	0.1%	86%	14%	100%
Grapes									
RPC									
Avg	488	27,234	128,891	156,614	**78.3**	0.3%	17%	82%	100%
Avg - 80% BH	488	27,234	117,530	145,253	**72.6**	0.3%	19%	81%	100%
Conserv	674	31,074	129,044	160,792	**80.4**	0.4%	19%	80%	100%
DRC									
Avg	355	203,808	35,674	239,837	**120**	0.1%	85%	15%	100%
Conserv	320	183,428	32,325	216,072	**108**	0.1%	85%	15%	100%
Lettuce - head									
RPC									
Avg	422	18,032	113,409	131,863	**65.9**	0.3%	14%	86%	100%
Avg - 80% BH	422	18,032	102,629	121,082	**60.5**	0.3%	15%	85%	100%
Conserv	582	21,347	113,558	135,487	**67.7**	0.4%	16%	84%	100%
DRC									
Avg	274	157,352	27,997	185,623	**92.8**	0.1%	85%	15%	100%
Conserv	247	141,617	25,330	167,194	**83.6**	0.1%	85%	15%	100%

Table 2-7 (page 2 of 2)
Greenhouse Gas Emissions

	(lb CO2 equivalents/1,000 tons produce shipped)					Percent of Total GHG			
	Process	**Fuel for Process**	**Fuel for Ctr Transp**	**Total GHG**	**Tons GHG**	**Process**	**Fuel for Process**	**Fuel for Ctr Transp**	**Total**
Oranges									
RPC									
Avg	337	15,158	77,779	93,274	**46.6**	0.4%	16%	83%	100%
Avg - 80% BH	337	15,158	69,849	85,344	**42.7**	0.4%	18%	82%	100%
Conserv	466	17,809	77,886	96,161	**48.1**	0.5%	19%	81%	100%
DRC									
Avg	236	135,323	18,223	153,782	**76.9**	0.2%	88%	12%	100%
Conserv	212	121,791	16,475	138,478	**69.2**	0.2%	88%	12%	100%
Peaches/Nectarines									
RPC									
Avg	289	15,507	82,140	97,936	**49.0**	0.3%	16%	84%	100%
Avg - 80% BH	289	15,507	74,062	89,859	**44.9**	0.3%	17%	82%	100%
Conserv	399	17,780	82,219	100,398	**50.2**	0.4%	18%	82%	100%
DRC									
Avg	238	136,672	23,334	160,244	**80.1**	0.1%	85%	15%	100%
Conserv	214	123,004	21,099	144,317	**72.2**	0.1%	85%	15%	100%
Onions									
RPC									
Avg	270	13,733	62,412	76,415	**38.2**	0.4%	18%	82%	100%
Avg - 80% BH	270	13,733	57,316	71,318	**35.7**	0.4%	19%	80%	100%
Conserv	372	15,852	62,485	78,709	**39.4**	0.5%	20%	79%	100%
DRC									
Avg	201	115,182	18,550	133,933	**67.0**	0.1%	86%	14%	100%
Conserv	181	103,664	16,762	120,606	**60.3**	0.1%	86%	14%	100%
Tomatoes									
RPC									
Avg	385	19,618	95,057	115,060	**57.5**	0.3%	17%	83%	100%
Avg - 80% BH	385	19,618	85,091	105,094	**52.5**	0.4%	19%	81%	100%
Conserv	532	22,645	95,336	118,513	**59.3**	0.4%	19%	80%	100%
DRC									
Avg	235	134,873	18,794	153,903	**77.0**	0.2%	88%	12%	100%
Conserv	212	121,386	16,992	138,590	**69.3**	0.2%	88%	12%	100%
Strawberries									
RPC									
Avg	762	51,872	236,712	289,347	**145**	0.3%	18%	82%	100%
Avg - 80% BH	762	51,872	217,735	270,370	**135**	0.3%	19%	81%	100%
Conserv	1,053	57,865	237,229	296,146	**148**	0.4%	20%	80%	100%
DRC									
Avg	434	248,966	61,300	310,700	**155**	0.1%	80%	20%	100%
Conserv	390	224,069	55,617	280,077	**140**	0.1%	80%	20%	100%

Figure 2-5. Average Scenario GHG Comparison
(RPC at avg reuse and loss rate, max backhaul and 80% backhaul; DRC at reported weight)

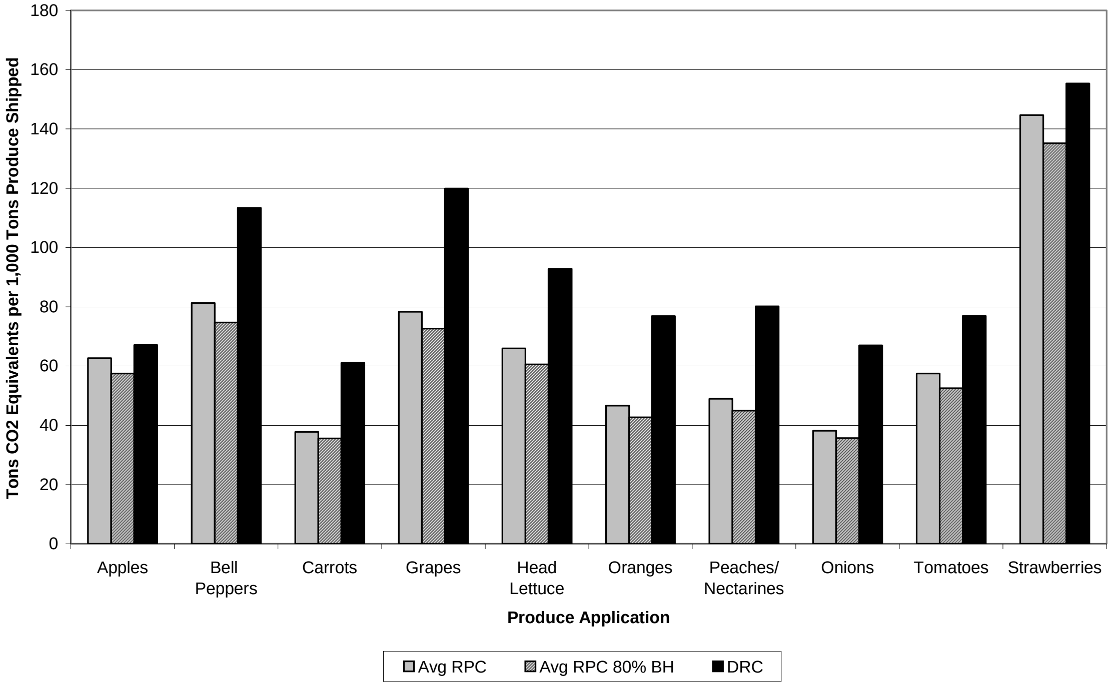


Figure 2-6. Conservative Scenario GHG Comparison
(RPC at 3/4 avg reuse rate and 2x avg loss rate, 10% lightweighted DRC)

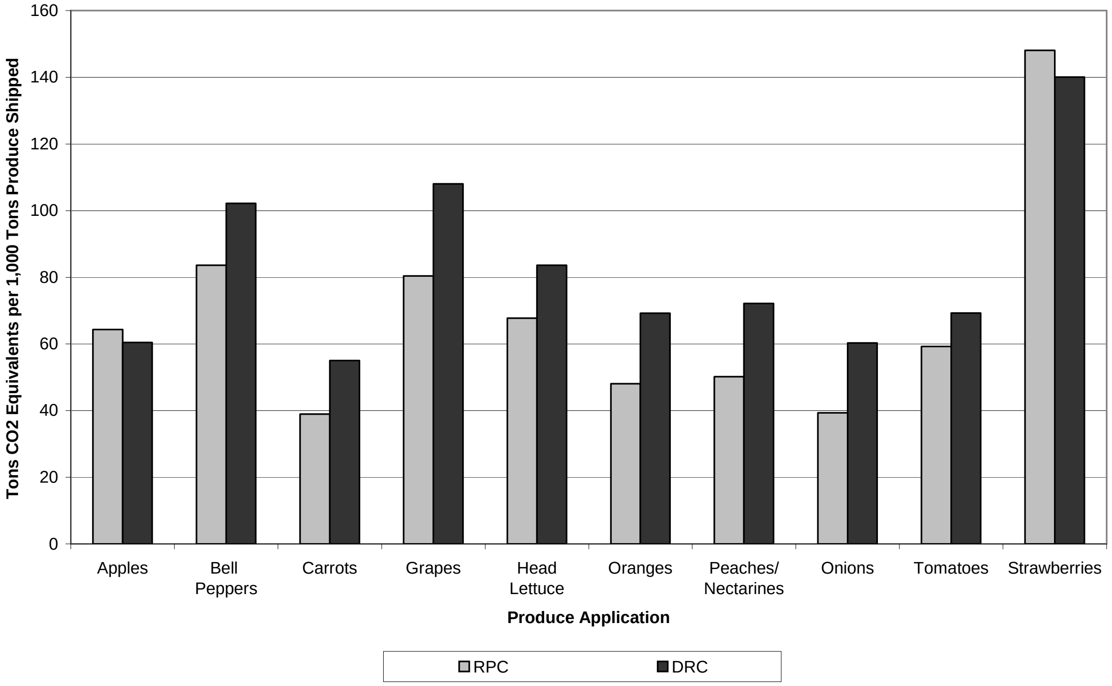


Table 2-8
Comparative Greenhouse Gas Summary
(Results reported on the basis of 1,000 tons of produce shipped.)

	RPC Total GHG (tons CO2 equiv)			DRC Total GHG (tons CO2 equiv)		Percent Difference* (DRC - RPC)/(avg of DRC and RPC)		
	avg	avg with 80% BH	conserv	avg	conserv	avg DRC, avg RPC	avg DRC, avg RPC w/80% BH	conserv
Apples	62.7	57.5	64.3	67.1	60.5	7%	15%	-6%
Bell Peppers	81.3	74.7	83.6	113	102	33%	41%	20%
Carrots	37.8	35.6	39.0	61.1	55.1	47%	53%	34%
Grapes	78.3	72.6	80.4	120	108	42%	49%	29%
Lettuce - head	65.9	60.5	67.7	92.8	83.6	34%	42%	21%
Oranges	46.6	42.7	48.1	76.9	69.2	49%	57%	36%
Peaches/Nectarines	49.0	44.9	50.2	80.1	72.2	48%	56%	36%
Onions	38.2	35.7	39.4	67.0	60.3	55%	61%	42%
Tomatoes	57.5	52.5	59.3	77.0	69.3	29%	38%	16%
Strawberries	145	135	148	155	140	7%	14%	-6%

Source: Franklin Associates.

* Percent difference = (difference between systems)/(average of systems). Positive value indicates that DRC is higher.
Percent difference must be at least 25% to consider greenhouse gas difference meaningful. Inconclusive comparisons are shaded in gray.

In addition to emissions of greenhouse gases, this report evaluates many other atmospheric emissions. Table 2-9 (5 pages) presents atmospheric emissions results for the container scenarios evaluated for each produce application.

For both RPC and DRC systems, the dominant emission categories by weight (but not necessarily by environmental impact) are carbon dioxide from fossil and non-fossil sources, nitrogen oxides, carbon monoxide, sulfur oxides, hydrocarbons, other organics, particulates, and methane. Emissions of fossil carbon dioxide, nitrogen oxides, and carbon monoxide are roughly comparable in magnitude for average scenario RPCs and DRCs. RPCs produce more hydrocarbons and other organics (predominantly from RPC backhaul steps by truck), while DRCs have higher emissions of non-fossil carbon dioxide, sulfur oxides, particulates, and methane. Almost all of the DRC non-fossil carbon dioxide and methane emissions are fuel-related emissions associated with the steps in the production of corrugated boxes, including the combustion of wood wastes for energy at virgin paper (board) mills. The majority of sulfur oxide emissions are either box production process emissions (25 percent) or process fuel-related emissions (71 percent). Particulates emissions are fairly evenly divided between box production process emissions (48 percent) and process fuel-related emissions (44 percent). Container transportation fuel-related emissions account for the remaining 4 percent of sulfur oxides emissions and 8 percent of particulates for DRCs.

Waterborne Emissions. Waterborne emissions results are shown in Table 2-10 (5 pages) for the container scenarios evaluated for each produce application. Over 35 different substances are tracked for each system.

Table 2-9 (page 1 of 5)
Atmospheric Emissions for Produce Container Systems
(pounds per 1,000 tons of produce shipped)

	Apples					Bell Peppers				
	Avg RPC	Avg RPC 80% BH	Conserv RPC	Avg DRC	Conserv DRC	Avg RPC	Avg RPC 80% BH	Conserv RPC	Avg DRC	Conserv DRC
Atmospheric Emissions										
Particulates	176	157	178	288	260	215	193	218	489	441
Nitrogen Oxides	1,027	931	1,040	765	689	1,297	1,178	1,315	1,284	1,157
Hydrocarbons	470	427	487	183	165	593	541	618	303	273
Sulfur Oxides	493	467	551	1,169	1,052	679	647	765	1,991	1,793
Carbon Monoxide	895	818	904	885	797	1,153	1,051	1,164	1,489	1,342
Aldehydes	25.7	23.2	25.8	7.17	6.47	32.4	29.3	32.5	11.6	10.5
Methane	68.6	67.0	81.2	225	203	100	97.9	118	384	346
Other Organics	429	396	430	124	112	566	518	567	200	181
Odorous Sulfur	0	0	0	1.39	1.25	0	0	0	2.37	2.13
Kerosene	0.0035	0.0035	0.0040	0.014	0.012	0.0053	0.0053	0.0061	0.023	0.021
Ammonia	0.21	0.19	0.21	2.40	2.16	0.27	0.25	0.28	4.10	3.69
Hydrogen Fluoride	0.096	0.095	0.11	0.37	0.33	0.15	0.14	0.17	0.63	0.57
Lead	0.0010	9.4E-04	0.0011	0.038	0.034	0.0014	0.0013	0.0015	0.065	0.059
Mercury	3.4E-04	3.3E-04	3.8E-04	0.0040	0.0036	5.0E-04	4.8E-04	5.6E-04	0.0068	0.0061
Chlorine	0.0068	0.0062	0.0069	0.23	0.21	0.0086	0.0078	0.0087	0.39	0.35
HCl	0.70	0.69	0.81	2.67	2.40	1.06	1.05	1.21	4.55	4.10
CO2 (fossil)	123,780	113,446	126,741	128,788	115,983	160,264	147,097	164,459	217,388	195,836
CO2 (non-fossil)	30.6	28.1	31.4	61,262	55,136	39.8	36.7	41.1	104,721	94,249
Metals (unspecified)	0.012	0.011	0.013	25.0	22.5	0.016	0.015	0.017	42.7	38.4
Antimony	2.2E-04	2.1E-04	2.4E-04	3.8E-04	3.4E-04	3.0E-04	2.8E-04	3.2E-04	6.5E-04	5.8E-04
Arsenic	7.6E-04	7.3E-04	8.4E-04	0.022	0.020	0.0011	0.0010	0.0012	0.037	0.034
Beryllium	7.4E-05	7.1E-05	8.2E-05	0.0023	0.0020	1.1E-04	1.0E-04	1.2E-04	0.0039	0.0035
Cadmium	6.2E-04	5.7E-04	6.4E-04	0.0063	0.0057	8.1E-04	7.5E-04	8.4E-04	0.011	0.0097
Chromium	0.0011	0.0010	0.0012	0.040	0.036	0.0015	0.0015	0.0017	0.068	0.061
Cobalt	6.3E-04	5.9E-04	6.6E-04	0.0011	9.6E-04	8.4E-04	7.9E-04	8.9E-04	0.0018	0.0016
Manganese	0.0018	0.0018	0.0020	0.33	0.29	0.0027	0.0026	0.0030	0.56	0.50
Nickel	0.0090	0.0083	0.0094	0.049	0.044	0.012	0.011	0.012	0.084	0.076
Selenium	0.0012	0.0011	0.0013	0.0039	0.0035	0.0017	0.0017	0.0019	0.0066	0.0060
Acreolin	1.4E-04	1.4E-04	1.6E-04	5.3E-04	4.8E-04	2.1E-04	2.1E-04	2.4E-04	9.0E-04	8.1E-04
Nitrous Oxide	0.087	0.086	0.10	1.10	0.99	0.13	0.13	0.15	1.88	1.69
Benzene	2.3E-04	2.3E-04	2.6E-04	0.11	0.10	3.4E-04	3.4E-04	3.9E-04	0.19	0.17
Perchloroethylene	1.3E-04	1.3E-04	1.5E-04	5.0E-04	4.5E-04	2.0E-04	2.0E-04	2.3E-04	8.6E-04	7.7E-04
Trichloroethylene	1.3E-04	1.3E-04	1.5E-04	5.0E-04	4.5E-04	2.0E-04	2.0E-04	2.3E-04	8.5E-04	7.7E-04
Methylene Chloride	5.9E-04	5.8E-04	6.8E-04	0.0022	0.0020	8.9E-04	8.8E-04	0.0010	0.0038	0.0034
Carbon Tetrachloride	2.7E-04	2.6E-04	3.0E-04	8.7E-04	7.8E-04	3.9E-04	3.8E-04	4.4E-04	0.0015	0.0013
Phenols	8.6E-04	8.1E-04	9.1E-04	1.13	1.02	0.0012	0.0011	0.0013	1.93	1.74
Naphthalene	3.8E-05	3.5E-05	3.9E-05	0.068	0.062	5.0E-05	4.6E-05	5.2E-05	0.12	0.11
Dioxins	7.6E-10	7.5E-10	8.7E-10	2.9E-09	2.6E-09	1.1E-09	1.1E-09	1.3E-09	4.9E-09	4.4E-09
n-nitrosodimethlamine	2.9E-05	2.9E-05	3.4E-05	1.1E-04	1.0E-04	4.4E-05	4.4E-05	5.1E-05	1.9E-04	1.7E-04
Radionuclides	0.0024	0.0024	0.0027	0.0090	0.0081	0.0036	0.0036	0.0041	0.015	0.014
Greenhouse Gas Summary (lb CO2 equivalents/1,000 tons produce)										
Fossil CO2	123,780	113,446	126,741	128,788	115,983	160,264	147,097	164,459	217,388	195,836
Methane	1,578	1,540	1,868	5,178	4,661	2,300	2,251	2,723	8,842	7,958
Nitrous oxide	25.7	25.3	29.5	326	293	38.9	38.5	44.4	557	501
Total lbs	125,384	115,011	128,638	134,292	120,937	162,602	149,387	167,227	226,787	204,296
Total tons	62.7	57.5	64.3	67.1	60.5	81.3	74.7	83.6	113	102

Table 2-9 (page 2 of 5)
Atmospheric Emissions for Produce Container Systems
(pounds per 1,000 tons of produce shipped)

	Carrots					**Grapes**				
	Avg RPC	**Avg RPC 80% BH**	**Conserv RPC**	**Avg DRC**	**Conserv DRC**	**Avg RPC**	**Avg RPC 80% BH**	**Conserv RPC**	**Avg DRC**	**Conserv DRC**
Atmospheric Emissions										
Particulates	108	98.7	110	264	238	222	200	225	517	465
Nitrogen Oxides	605	563	614	691	622	1,249	1,142	1,265	1,361	1,227
Hydrocarbons	288	268	301	162	146	584	534	606	323	291
Sulfur Oxides	338	328	386	1,077	970	676	648	754	2,098	1,889
Carbon Monoxide	506	478	512	802	722	1,049	968	1,059	1,577	1,421
Aldehydes	14.6	13.6	14.7	6.16	5.56	30.2	27.6	30.3	12.5	11.3
Methane	52.3	51.6	62.4	208	187	104	102	121	405	364
Other Organics	231	222	232	106	95.5	484	453	485	216	195
Odorous Sulfur	0	0	0	1.28	1.16	0	0	0	2.50	2.25
Kerosene	0.0028	0.0028	0.0032	0.013	0.011	0.0059	0.0059	0.0066	0.024	0.022
Ammonia	0.13	0.12	0.13	2.22	2.00	0.26	0.24	0.27	4.31	3.88
Hydrogen Fluoride	0.077	0.076	0.088	0.34	0.31	0.16	0.16	0.18	0.66	0.60
Lead	6.8E-04	6.5E-04	7.4E-04	0.035	0.032	0.0014	0.0014	0.0015	0.069	0.062
Mercury	2.6E-04	2.5E-04	2.9E-04	0.0037	0.0033	5.4E-04	5.3E-04	5.9E-04	0.0071	0.0064
Chlorine	0.0039	0.0037	0.0040	0.21	0.19	0.0080	0.0074	0.0081	0.41	0.37
HCl	0.56	0.56	0.64	2.47	2.22	1.19	1.18	1.33	4.79	4.31
CO2 (fossil)	74,290	70,008	76,568	117,183	105,521	154,183	142,864	157,970	229,942	207,166
CO2 (non-fossil)	18.6	17.5	19.2	56,724	51,051	38.6	35.9	39.7	110,207	99,186
Metals (unspecified)	0.0076	0.0072	0.0078	23.1	20.8	0.016	0.015	0.016	44.9	40.4
Antimony	1.4E-04	1.4E-04	1.5E-04	3.5E-04	3.2E-04	3.0E-04	2.8E-04	3.1E-04	6.8E-04	6.2E-04
Arsenic	5.5E-04	5.4E-04	6.1E-04	0.020	0.018	0.0012	0.0011	0.0013	0.039	0.035
Beryllium	5.5E-05	5.4E-05	6.2E-05	0.0021	0.0019	1.2E-04	1.1E-04	1.3E-04	0.0041	0.0037
Cadmium	3.8E-04	3.6E-04	4.0E-04	0.0058	0.0052	7.9E-04	7.3E-04	8.2E-04	0.011	0.010
Chromium	7.9E-04	7.8E-04	8.9E-04	0.037	0.033	0.0017	0.0016	0.0018	0.071	0.064
Cobalt	4.0E-04	3.9E-04	4.3E-04	9.8E-04	8.9E-04	8.4E-04	7.9E-04	8.8E-04	0.0019	0.0017
Manganese	0.0014	0.0014	0.0016	0.30	0.27	0.0029	0.0029	0.0033	0.59	0.53
Nickel	0.0056	0.0053	0.0059	0.046	0.041	0.012	0.011	0.012	0.089	0.080
Selenium	8.8E-04	8.7E-04	0.0010	0.0036	0.0032	0.0019	0.0018	0.0021	0.0070	0.0063
Acreolin	1.1E-04	1.1E-04	1.3E-04	4.9E-04	4.4E-04	2.3E-04	2.3E-04	2.6E-04	9.5E-04	8.5E-04
Nitrous Oxide	0.069	0.069	0.080	1.02	0.92	0.15	0.15	0.16	1.98	1.78
Benzene	1.8E-04	1.8E-04	2.0E-04	0.10	0.094	3.8E-04	3.7E-04	4.1E-04	0.20	0.18
Perchloroethylene	1.1E-04	1.0E-04	1.2E-04	4.7E-04	4.2E-04	2.2E-04	2.2E-04	2.5E-04	9.1E-04	8.1E-04
Trichloroethylene	1.0E-04	1.0E-04	1.2E-04	4.6E-04	4.2E-04	2.2E-04	2.2E-04	2.5E-04	9.0E-04	8.1E-04
Methylene Chloride	4.7E-04	4.7E-04	5.4E-04	0.0021	0.0019	0.0010	9.9E-04	0.0011	0.0040	0.0036
Carbon Tetrachloride	2.0E-04	2.0E-04	2.3E-04	8.0E-04	7.2E-04	4.3E-04	4.2E-04	4.7E-04	0.0016	0.0014
Phenols	5.8E-04	5.5E-04	6.2E-04	1.05	0.94	0.0012	0.0012	0.0013	2.04	1.83
Naphthalene	2.4E-05	2.2E-05	2.5E-05	0.063	0.057	4.9E-05	4.6E-05	5.1E-05	0.12	0.11
Dioxins	6.0E-10	6.0E-10	6.9E-10	2.7E-09	2.4E-09	1.3E-09	1.3E-09	1.4E-09	5.2E-09	4.7E-09
n-nitrosodimethlamine	2.3E-05	2.3E-05	2.7E-05	1.0E-04	9.3E-05	4.9E-05	4.9E-05	5.5E-05	2.0E-04	1.8E-04
Radionuclides	0.0019	0.0019	0.0022	0.0083	0.0075	0.0040	0.0040	0.0045	0.016	0.015
Greenhouse Gas Summary (lb CO2 equivalents/1,000 tons produce)										
Fossil CO2	74,290	70,008	76,568	117,183	105,521	154,183	142,864	157,970	229,942	207,166
Methane	1,202	1,186	1,436	4,787	4,309	2,387	2,346	2,773	9,309	8,379
Nitrous oxide	20.5	20.4	23.6	302	271	43.5	43.1	48.6	586	527
Total lbs	75,512	71,214	78,027	122,272	110,101	156,614	145,253	160,792	239,837	216,072
Total tons	37.8	35.6	39.0	61.1	55.1	78.3	72.6	80.4	120	108

Table 2-9 (page 3 of 5)
Atmospheric Emissions for Produce Container Systems
(pounds per 1,000 tons of produce shipped)

	Head Lettuce					**Oranges**				
	Avg RPC	**Avg RPC 80% BH**	**Conserv RPC**	**Avg DRC**	**Conserv DRC**	**Avg RPC**	**Avg RPC 80% BH**	**Conserv RPC**	**Avg DRC**	**Conserv DRC**
Atmospheric Emissions										
Particulates	179	161	182	399	360	128	114	130	336	303
Nitrogen Oxides	1,065	966	1,079	1,055	951	744	671	755	857	772
Hydrocarbons	487	444	507	251	226	347	315	363	195	176
Sulfur Oxides	538	512	605	1,621	1,459	406	386	460	1,380	1,242
Carbon Monoxide	938	857	947	1,222	1,100	642	583	649	1,001	902
Aldehydes	26.6	24.1	26.7	9.76	8.81	18.3	16.4	18.3	7.02	6.34
Methane	77.3	75.6	91.8	313	281	61.5	60.2	73.1	268	241
Other Organics	456	419	456	169	153	305	278	305	118	107
Odorous Sulfur	0	0	0	1.93	1.73	0	0	0	1.66	1.49
Kerosene	0.0040	0.0040	0.0046	0.019	0.017	0.0033	0.0033	0.0038	0.016	0.015
Ammonia	0.22	0.20	0.23	3.33	3.00	0.16	0.14	0.16	2.86	2.57
Hydrogen Fluoride	0.11	0.11	0.13	0.51	0.46	0.091	0.090	0.10	0.44	0.39
Lead	0.0011	0.0010	0.0012	0.053	0.048	8.2E-04	7.8E-04	8.9E-04	0.046	0.041
Mercury	3.8E-04	3.7E-04	4.3E-04	0.0055	0.0049	3.0E-04	3.0E-04	3.4E-04	0.0047	0.0042
Chlorine	0.0071	0.0064	0.0071	0.32	0.29	0.0049	0.0044	0.0049	0.27	0.25
HCl	0.80	0.79	0.92	3.70	3.33	0.66	0.65	0.76	3.18	2.86
CO2 (fossil)	130,055	119,314	133,341	177,982	160,316	91,835	83,934	94,453	147,232	132,583
CO2 (non-fossil)	32.2	29.7	33.2	85,086	76,578	22.9	21.0	23.7	73,173	65,856
Metals (unspecified)	0.013	0.012	0.014	34.7	31.2	0.0093	0.0086	0.0097	29.8	26.9
Antimony	2.4E-04	2.2E-04	2.5E-04	5.3E-04	4.8E-04	1.7E-04	1.6E-04	1.9E-04	4.5E-04	4.0E-04
Arsenic	8.5E-04	8.1E-04	9.3E-04	0.030	0.027	6.6E-04	6.3E-04	7.3E-04	0.026	0.023
Beryllium	8.3E-05	8.0E-05	9.3E-05	0.0031	0.0028	6.6E-05	6.4E-05	7.4E-05	0.0027	0.0024
Cadmium	6.5E-04	6.0E-04	6.8E-04	0.0087	0.0078	4.7E-04	4.3E-04	4.9E-04	0.0075	0.0067
Chromium	0.0012	0.0012	0.0013	0.055	0.049	9.4E-04	9.2E-04	0.0011	0.047	0.043
Cobalt	6.7E-04	6.3E-04	7.1E-04	0.0015	0.0013	4.9E-04	4.6E-04	5.2E-04	0.0013	0.0011
Manganese	0.0020	0.0020	0.0023	0.45	0.41	0.0016	0.0016	0.0019	0.39	0.35
Nickel	0.0096	0.0089	0.010	0.068	0.062	0.0069	0.0064	0.0072	0.059	0.053
Selenium	0.0013	0.0013	0.0015	0.0054	0.0049	0.0010	0.0010	0.0012	0.0046	0.0042
Acreolin	1.6E-04	1.6E-04	1.8E-04	7.3E-04	6.6E-04	1.3E-04	1.3E-04	1.5E-04	6.3E-04	5.7E-04
Nitrous Oxide	0.10	0.098	0.11	1.53	1.38	0.082	0.081	0.093	1.31	1.18
Benzene	2.6E-04	2.6E-04	3.0E-04	0.16	0.14	2.1E-04	2.1E-04	2.4E-04	0.13	0.12
Perchloroethylene	1.5E-04	1.5E-04	1.7E-04	7.0E-04	6.3E-04	1.2E-04	1.2E-04	1.4E-04	6.0E-04	5.4E-04
Trichloroethylene	1.5E-04	1.5E-04	1.7E-04	6.9E-04	6.2E-04	1.2E-04	1.2E-04	1.4E-04	5.9E-04	5.3E-04
Methylene Chloride	6.7E-04	6.7E-04	7.7E-04	0.0031	0.0028	5.5E-04	5.5E-04	6.3E-04	0.0027	0.0024
Carbon Tetrachloride	3.0E-04	2.9E-04	3.4E-04	0.0012	0.0011	2.4E-04	2.3E-04	2.7E-04	0.0010	9.3E-04
Phenols	9.3E-04	8.8E-04	0.0010	1.57	1.41	7.0E-04	6.6E-04	7.5E-04	1.35	1.22
Naphthalene	4.0E-05	3.7E-05	4.2E-05	0.095	0.085	2.9E-05	2.7E-05	3.0E-05	0.082	0.074
Dioxins	8.6E-10	8.5E-10	9.9E-10	4.0E-09	3.6E-09	7.1E-10	7.0E-10	8.1E-10	3.4E-09	3.1E-09
n-nitrosodimethlamine	3.3E-05	3.3E-05	3.8E-05	1.5E-04	1.4E-04	2.8E-05	2.7E-05	3.1E-05	1.3E-04	1.2E-04
Radionuclides	0.0027	0.0027	0.0031	0.012	0.011	0.0022	0.0022	0.0026	0.011	0.0096
Greenhouse Gas Summary (lb CO2 equivalents/1,000 tons produce)										
Fossil CO2	130,055	119,314	133,341	177,982	160,316	91,835	83,934	94,453	147,232	132,583
Methane	1,779	1,740	2,112	7,189	6,470	1,415	1,386	1,681	6,161	5,545
Nitrous oxide	29.4	29.0	33.7	453	407	24.2	23.9	27.7	389	350
Total lbs	131,863	121,082	135,487	185,623	167,194	93,274	85,344	96,161	153,782	138,478
Total tons	65.9	60.5	67.7	92.8	83.6	46.6	42.7	48.1	76.9	69.2

Table 2-9 (page 4 of 5)
Atmospheric Emissions for Produce Container Systems
(pounds per 1,000 tons of produce shipped)

	Peaches/Nectarines					Onions				
	Avg RPC	**Avg RPC 80% BH**	**Conserv RPC**	**Avg DRC**	**Conserv DRC**	**Avg RPC**	**Avg RPC 80% BH**	**Conserv RPC**	**Avg DRC**	**Conserv DRC**
Atmospheric Emissions										
Particulates	129	116	131	346	311	107	96.9	109	290	261
Nitrogen Oxides	776	703	786	908	818	606	557	615	756	681
Hydrocarbons	353	322	367	214	193	285	263	297	177	159
Sulfur Oxides	409	389	455	1,406	1,265	340	327	383	1,182	1,064
Carbon Monoxide	685	623	691	1,053	948	511	475	517	878	791
Aldehydes	19.3	17.4	19.3	8.24	7.44	14.7	13.5	14.7	6.69	6.03
Methane	60.9	59.7	70.9	271	244	52.9	52.1	62.2	228	206
Other Organics	335	306	335	142	128	237	223	237	115	104
Odorous Sulfur	0	0	0	1.67	1.51	0	0	0	1.41	1.27
Kerosene	0.0034	0.0034	0.0038	0.016	0.015	0.0030	0.0030	0.0034	0.014	0.012
Ammonia	0.16	0.15	0.17	2.89	2.60	0.13	0.12	0.13	2.44	2.19
Hydrogen Fluoride	0.094	0.093	0.11	0.44	0.40	0.082	0.081	0.092	0.37	0.34
Lead	8.5E-04	8.1E-04	9.1E-04	0.046	0.042	7.0E-04	6.7E-04	7.5E-04	0.039	0.035
Mercury	3.1E-04	3.1E-04	3.5E-04	0.0048	0.0043	2.7E-04	2.6E-04	3.0E-04	0.0040	0.0036
Chlorine	0.0051	0.0046	0.0052	0.28	0.25	0.0039	0.0036	0.0040	0.23	0.21
HCl	0.68	0.68	0.77	3.21	2.89	0.59	0.59	0.67	2.71	2.44
CO2 (fossil)	96,509	88,461	98,740	153,610	138,347	75,176	70,098	77,254	128,346	115,578
CO2 (non-fossil)	24.1	22.1	24.7	73,903	66,513	18.8	17.6	19.4	62,283	56,054
Metals (unspecified)	0.0098	0.0090	0.010	30.1	27.1	0.0077	0.0072	0.0079	25.4	22.9
Antimony	1.8E-04	1.7E-04	1.9E-04	4.6E-04	4.1E-04	1.5E-04	1.4E-04	1.5E-04	3.8E-04	3.5E-04
Arsenic	6.8E-04	6.6E-04	7.4E-04	0.026	0.024	5.7E-04	5.6E-04	6.3E-04	0.022	0.020
Beryllium	6.8E-05	6.6E-05	7.5E-05	0.0027	0.0025	5.8E-05	5.7E-05	6.4E-05	0.0023	0.0021
Cadmium	4.9E-04	4.5E-04	5.1E-04	0.0076	0.0068	3.9E-04	3.6E-04	4.0E-04	0.0064	0.0057
Chromium	9.8E-04	9.5E-04	0.0011	0.048	0.043	8.3E-04	8.1E-04	9.2E-04	0.040	0.036
Cobalt	5.1E-04	4.8E-04	5.4E-04	0.0013	0.0012	4.1E-04	3.9E-04	4.4E-04	0.0011	9.7E-04
Manganese	0.0017	0.0017	0.0019	0.39	0.35	0.0015	0.0014	0.0016	0.33	0.30
Nickel	0.0072	0.0067	0.0075	0.059	0.053	0.0057	0.0054	0.0060	0.050	0.045
Selenium	0.0011	0.0011	0.0012	0.0047	0.0042	9.3E-04	9.2E-04	0.0010	0.0040	0.0036
Acreolin	1.3E-04	1.3E-04	1.5E-04	6.4E-04	5.7E-04	1.2E-04	1.2E-04	1.3E-04	5.4E-04	4.8E-04
Nitrous Oxide	0.085	0.084	0.095	1.33	1.19	0.074	0.073	0.083	1.12	1.01
Benzene	2.2E-04	2.1E-04	2.4E-04	0.14	0.12	1.9E-04	1.8E-04	2.1E-04	0.11	0.10
Perchloroethylene	1.3E-04	1.3E-04	1.4E-04	6.1E-04	5.5E-04	1.1E-04	1.1E-04	1.3E-04	5.1E-04	4.6E-04
Trichloroethylene	1.3E-04	1.3E-04	1.4E-04	6.0E-04	5.4E-04	1.1E-04	1.1E-04	1.2E-04	5.1E-04	4.6E-04
Methylene Chloride	5.7E-04	5.7E-04	6.4E-04	0.0027	0.0024	5.0E-04	4.9E-04	5.6E-04	0.0023	0.0020
Carbon Tetrachloride	2.5E-04	2.4E-04	2.7E-04	0.0010	9.4E-04	2.1E-04	2.1E-04	2.4E-04	8.8E-04	7.9E-04
Phenols	7.3E-04	6.9E-04	7.7E-04	1.37	1.23	5.9E-04	5.7E-04	6.4E-04	1.15	1.04
Naphthalene	3.0E-05	2.8E-05	3.1E-05	0.082	0.074	2.4E-05	2.3E-05	2.5E-05	0.070	0.063
Dioxins	7.4E-10	7.3E-10	8.2E-10	3.5E-09	3.1E-09	6.4E-10	6.3E-10	7.2E-10	2.9E-09	2.6E-09
n-nitrosodimethlamine	2.8E-05	2.8E-05	3.2E-05	1.3E-04	1.2E-04	2.5E-05	2.5E-05	2.8E-05	1.1E-04	1.0E-04
Radionuclides	0.0023	0.0023	0.0026	0.011	0.0097	0.0020	0.0020	0.0023	0.0091	0.0082
Greenhouse Gas Summary (lb CO2 equivalents/1,000 tons produce)										
Fossil CO2	96,509	88,461	98,740	153,610	138,347	75,176	70,098	77,254	128,346	115,578
Methane	1,402	1,372	1,630	6,240	5,617	1,217	1,198	1,430	5,255	4,730
Nitrous oxide	25.0	24.8	28.0	393	354	21.8	21.6	24.6	331	298
Total lbs	97,936	89,859	100,398	160,244	144,317	76,415	71,318	78,709	133,933	120,606
Total tons	49.0	44.9	50.2	80.1	72.2	38.2	35.7	39.4	67.0	60.3

Table 2-9 (page 5 of 5)
Atmospheric Emissions for Produce Container Systems
(pounds per 1,000 tons of produce shipped)

	Tomatoes					Strawberries				
	Avg RPC	**Avg RPC 80% BH**	**Conserv RPC**	**Avg DRC**	**Conserv DRC**	**Avg RPC**	**Avg RPC 80% BH**	**Conserv RPC**	**Avg DRC**	**Conserv DRC**
Atmospheric Emissions										
Particulates	160	142	163	336	302	385	351	390	653	588
Nitrogen Oxides	916	824	930	860	774	2,269	2,093	2,296	1,815	1,637
Hydrocarbons	428	386	446	197	178	1,034	955	1,070	455	411
Sulfur Oxides	500	476	562	1,377	1,239	1,228	1,182	1,351	2,606	2,347
Carbon Monoxide	780	706	789	1,003	904	1,968	1,827	1,986	2,076	1,872
Aldehydes	22.3	20.0	22.4	7.15	6.45	55.5	51.1	55.7	19.4	17.6
Methane	76.5	74.9	89.8	267	240	189	186	215	497	448
Other Organics	365	333	366	121	109	948	888	951	345	312
Odorous Sulfur	0	0	0	1.65	1.49	0	0	0	3.05	2.74
Kerosene	0.0043	0.0042	0.0048	0.016	0.015	0.011	0.011	0.012	0.030	0.027
Ammonia	0.19	0.18	0.20	2.85	2.56	0.49	0.46	0.50	5.30	4.77
Hydrogen Fluoride	0.12	0.12	0.13	0.44	0.39	0.31	0.31	0.34	0.81	0.73
Lead	0.0010	9.8E-04	0.0011	0.046	0.041	0.0026	0.0025	0.0028	0.084	0.076
Mercury	3.9E-04	3.8E-04	4.3E-04	0.0047	0.0042	0.0010	0.0010	0.0011	0.0087	0.0078
Chlorine	0.0059	0.0053	0.0060	0.27	0.25	0.015	0.014	0.015	0.51	0.46
HCl	0.86	0.85	0.96	3.17	2.85	2.27	2.25	2.49	5.87	5.28
CO2 (fossil)	113,269	103,339	116,413	147,372	132,712	284,914	266,006	291,102	298,547	269,138
CO2 (non-fossil)	28.3	25.9	29.2	72,930	65,637	71.4	66.9	73.2	134,629	121,167
Metals (unspecified)	0.012	0.011	0.012	29.7	26.8	0.029	0.027	0.030	54.9	49.4
Antimony	2.2E-04	2.0E-04	2.3E-04	4.5E-04	4.0E-04	5.5E-04	5.2E-04	5.8E-04	8.6E-04	7.8E-04
Arsenic	8.4E-04	8.0E-04	9.2E-04	0.026	0.023	0.0022	0.0021	0.0023	0.048	0.043
Beryllium	8.4E-05	8.2E-05	9.3E-05	0.0027	0.0024	2.2E-04	2.2E-04	2.4E-04	0.0050	0.0045
Cadmium	5.8E-04	5.3E-04	6.0E-04	0.0075	0.0067	0.0015	0.0014	0.0015	0.014	0.012
Chromium	0.0012	0.0012	0.0013	0.047	0.042	0.0032	0.0031	0.0034	0.087	0.078
Cobalt	6.1E-04	5.7E-04	6.5E-04	0.0013	0.0011	0.0016	0.0015	0.0016	0.0024	0.0022
Manganese	0.0021	0.0021	0.0024	0.39	0.35	0.0056	0.0055	0.0061	0.72	0.65
Nickel	0.0085	0.0079	0.0089	0.058	0.053	0.021	0.020	0.022	0.11	0.099
Selenium	0.0013	0.0013	0.0015	0.0046	0.0042	0.0036	0.0035	0.0039	0.0086	0.0077
Acreolin	1.7E-04	1.7E-04	1.9E-04	6.3E-04	5.6E-04	4.5E-04	4.4E-04	4.9E-04	0.0012	0.0010
Nitrous Oxide	0.11	0.10	0.12	1.31	1.18	0.28	0.28	0.31	2.42	2.18
Benzene	2.7E-04	2.7E-04	3.0E-04	0.13	0.12	7.2E-04	7.0E-04	7.8E-04	0.25	0.22
Perchloroethylene	1.6E-04	1.6E-04	1.8E-04	6.0E-04	5.4E-04	4.3E-04	4.2E-04	4.7E-04	0.0011	0.0010
Trichloroethylene	1.6E-04	1.6E-04	1.8E-04	5.9E-04	5.3E-04	4.2E-04	4.2E-04	4.6E-04	0.0011	9.9E-04
Methylene Chloride	7.2E-04	7.1E-04	8.1E-04	0.0027	0.0024	0.0019	0.0019	0.0021	0.0049	0.0044
Carbon Tetrachloride	3.1E-04	3.0E-04	3.4E-04	0.0010	9.3E-04	8.1E-04	7.9E-04	8.7E-04	0.0019	0.0017
Phenols	8.8E-04	8.3E-04	9.4E-04	1.35	1.21	0.0023	0.0022	0.0024	2.49	2.24
Naphthalene	3.6E-05	3.3E-05	3.7E-05	0.081	0.073	9.1E-05	8.6E-05	9.4E-05	0.15	0.14
Dioxins	9.2E-10	9.1E-10	1.0E-09	3.4E-09	3.1E-09	2.4E-09	2.4E-09	2.7E-09	6.3E-09	5.7E-09
n-nitrosodimethlamine	3.6E-05	3.5E-05	4.0E-05	1.3E-04	1.2E-04	9.5E-05	9.4E-05	1.0E-04	2.5E-04	2.2E-04
Radionuclides	0.0029	0.0029	0.0033	0.011	0.0096	0.0077	0.0076	0.0084	0.020	0.018
Greenhouse Gas Summary (lb CO2 equivalents/1,000 tons produce)										
Fossil CO2	113,269	103,339	116,413	147,372	132,712	284,914	266,006	291,102	298,547	269,138
Methane	1,760	1,724	2,065	6,143	5,529	4,350	4,281	4,953	11,436	10,294
Nitrous oxide	31.3	31.0	35.3	388	349	83.2	82.6	91.1	717	645
Total lbs	115,060	105,094	118,513	153,903	138,590	289,347	270,370	296,146	310,700	280,077
Total tons	57.5	52.5	59.3	77.0	69.3	145	135	148	155	140

Table 2-10 (page 1 of 5)
Waterborne Emissions for Produce Container Systems
(pounds per 1,000 tons of produce shipped)

	Apples					Bell Peppers				
	Avg RPC	Avg RPC 80% BH	Conserv RPC	Avg DRC	Conserv DRC	Avg RPC	Avg RPC 80% BH	Conserv RPC	Avg DRC	Conserv DRC
Waterborne Wastes										
Acid	0.35	0.35	0.48	0.76	0.69	0.51	0.51	0.71	1.30	1.17
Metal Ion (unspecified)	0.78	0.71	0.79	0.21	0.19	0.99	0.90	1.00	0.34	0.31
Fluorides	0.014	0.014	0.016	0.054	0.049	0.021	0.021	0.024	0.092	0.083
Dissolved Solids	445	431	524	507	456	636	618	751	863	777
Suspended Solids	13.5	13.1	15.2	345	311	19.9	19.5	22.5	590	531
BOD	4.60	4.55	5.79	248	223	6.79	6.72	8.51	423	381
COD	12.3	11.9	14.8	654	589	17.5	17.1	21.2	1,118	1,006
Phenol	0.0025	0.0023	0.0026	0.14	0.13	0.0032	0.0029	0.0032	0.24	0.22
Sulfides	0.16	0.16	0.22	11.6	10.5	0.23	0.23	0.32	19.9	17.9
Oil	8.52	8.19	9.94	20.4	18.4	12.0	11.6	14.1	34.8	31.4
Sulfuric Acid	0.11	0.11	0.12	0.80	0.72	0.16	0.16	0.18	1.37	1.24
Iron	0.55	0.55	0.64	16.1	14.5	0.84	0.83	0.96	27.5	24.8
Cyanide	2.7E-05	2.6E-05	3.2E-05	4.0E-05	3.6E-05	3.8E-05	3.7E-05	4.6E-05	6.8E-05	6.1E-05
Chromium	0.018	0.018	0.022	0.022	0.020	0.026	0.026	0.032	0.037	0.034
Aluminum	0	0	0	8.44	7.60	0	0	0	14.4	13.0
Nickel	0	0	0	7.6E-08	6.8E-08	0	0	0	1.3E-07	1.2E-07
Mercury	1.4E-06	1.4E-06	1.7E-06	1.8E-06	1.6E-06	2.0E-06	2.0E-06	2.4E-06	3.1E-06	2.7E-06
Lead	6.5E-05	5.9E-05	6.6E-05	1.8E-05	1.6E-05	8.3E-05	7.5E-05	8.4E-05	2.8E-05	2.6E-05
Phosphates	0.073	0.071	0.087	6.93	6.23	0.11	0.11	0.13	11.8	10.7
Phosphorus	0	0	0	1.55	1.40	0	0	0	2.66	2.39
Nitrogen	0	0	0	2.60	2.34	0	0	0	4.45	4.00
Zinc	0.010	0.0099	0.013	0.17	0.15	0.014	0.014	0.018	0.29	0.26
Ammonia	0.070	0.064	0.072	1.38	1.24	0.090	0.083	0.093	2.36	2.13
Pesticides	0	0	0	0.078	0.070	0	0	0	0.13	0.12
Dissolved Organics	4.52	4.52	6.24	0	0	6.61	6.61	9.12	0	0
Total Volatile Solids	4.46	4.46	4.46	0	0	7.31	7.31	7.31	0	0
Chlorides	20.2	19.6	23.8	22.2	20.0	29.3	28.6	34.6	37.8	34.1
Cadmium	0.018	0.018	0.022	0.022	0.020	0.026	0.026	0.032	0.037	0.034
Organic Carbon	0.37	0.37	0.52	0	0	0.55	0.55	0.76	0	0
Sulfates	16.5	16.1	19.5	23.6	21.2	23.9	23.4	28.4	40.2	36.2
Sodium	2.23	2.23	2.24	0.021	0.019	3.66	3.66	3.66	0.037	0.033
Calcium	0.0030	0.0030	0.0035	0.012	0.010	0.0046	0.0045	0.0052	0.020	0.018
Manganese	0.31	0.31	0.36	2.75	2.48	0.48	0.47	0.54	4.70	4.23
Nitrates	0.0013	0.0013	0.0015	0.063	0.056	0.0020	0.0020	0.0023	0.11	0.096
Boron	0.44	0.43	0.50	3.22	2.89	0.65	0.64	0.73	5.49	4.94
Other Organics	0.86	0.83	0.96	1.99	1.79	1.23	1.19	1.37	3.39	3.05
Chromates	5.2E-04	4.8E-04	5.4E-04	7.3E-04	6.5E-04	6.8E-04	6.3E-04	7.1E-04	0.0012	0.0011

Table 2-10 (page 2 of 5)
Waterborne Emissions for Produce Container Systems
(pounds per 1,000 tons of produce shipped)

	Carrots					Grapes				
	Avg RPC	**Avg RPC 80% BH**	**Conserv RPC**	**Avg DRC**	**Conserv DRC**	**Avg RPC**	**Avg RPC 80% BH**	**Conserv RPC**	**Avg DRC**	**Conserv DRC**
Waterborne Wastes										
Acid	0.28	0.28	0.39	0.71	0.63	0.47	0.47	0.65	1.37	1.23
Metal Ion (unspecified)	0.45	0.42	0.46	0.18	0.16	0.92	0.85	0.94	0.36	0.33
Fluorides	0.011	0.011	0.013	0.050	0.045	0.024	0.024	0.026	0.097	0.087
Dissolved Solids	329	323	392	467	420	645	629	750	909	819
Suspended Solids	10.3	10.2	11.8	320	288	21.9	21.5	24.2	621	559
BOD	3.64	3.62	4.60	229	206	6.84	6.78	8.42	445	401
COD	9.12	8.98	11.2	606	545	17.3	16.9	20.7	1,177	1,059
Phenol	0.0015	0.0014	0.0015	0.13	0.12	0.0030	0.0027	0.0030	0.25	0.23
Sulfides	0.13	0.13	0.18	10.8	9.69	0.21	0.21	0.29	20.9	18.8
Oil	6.12	5.98	7.27	18.9	17.0	11.9	11.5	13.8	36.7	33.0
Sulfuric Acid	0.084	0.083	0.095	0.74	0.67	0.18	0.17	0.20	1.45	1.30
Iron	0.44	0.44	0.51	14.9	13.4	0.94	0.93	1.05	29.0	26.1
Cyanide	2.0E-05	2.0E-05	2.4E-05	3.7E-05	3.3E-05	3.9E-05	3.8E-05	4.6E-05	7.1E-05	6.4E-05
Chromium	0.014	0.014	0.017	0.020	0.018	0.027	0.026	0.031	0.039	0.035
Aluminum	0	0	0	7.82	7.04	0	0	0	15.2	13.7
Nickel	0	0	0	7.0E-08	6.3E-08	0	0	0	1.4E-07	1.2E-07
Mercury	1.1E-06	1.0E-06	1.3E-06	1.7E-06	1.5E-06	2.0E-06	2.0E-06	2.4E-06	3.2E-06	2.9E-06
Lead	3.8E-05	3.5E-05	3.8E-05	1.5E-05	1.4E-05	7.7E-05	7.1E-05	7.8E-05	3.1E-05	2.8E-05
Phosphates	0.056	0.056	0.068	6.41	5.77	0.11	0.11	0.13	12.5	11.2
Phosphorus	0	0	0	1.44	1.30	0	0	0	2.80	2.52
Nitrogen	0	0	0	2.41	2.17	0	0	0	4.68	4.21
Zinc	0.0076	0.0075	0.0095	0.16	0.14	0.014	0.014	0.017	0.31	0.28
Ammonia	0.042	0.040	0.043	1.28	1.15	0.087	0.080	0.089	2.49	2.24
Pesticides	0	0	0	0.072	0.065	0	0	0	0.14	0.13
Dissolved Organics	3.66	3.66	5.05	0	0	6.02	6.02	8.32	0	0
Total Volatile Solids	3.83	3.83	3.83	0	0	9.68	9.68	9.68	0	0
Chlorides	15.3	15.0	18.2	20.5	18.4	30.3	29.8	35.2	39.9	35.9
Cadmium	0.014	0.013	0.017	0.020	0.018	0.026	0.026	0.031	0.039	0.035
Organic Carbon	0.30	0.30	0.42	0	0	0.50	0.50	0.69	0	0
Sulfates	12.5	12.3	14.9	21.8	19.6	24.7	24.2	28.7	42.4	38.1
Sodium	1.92	1.92	1.92	0.020	0.018	4.85	4.85	4.85	0.039	0.035
Calcium	0.0024	0.0024	0.0028	0.011	0.0097	0.0051	0.0051	0.0057	0.021	0.019
Manganese	0.25	0.25	0.29	2.55	2.29	0.53	0.53	0.60	4.95	4.46
Nitrates	0.0011	0.0010	0.0012	0.058	0.052	0.0022	0.0022	0.0025	0.11	0.10
Boron	0.34	0.33	0.38	2.97	2.68	0.71	0.70	0.79	5.78	5.20
Other Organics	0.62	0.61	0.70	1.83	1.65	1.30	1.26	1.43	3.57	3.21
Chromates	3.2E-04	3.0E-04	3.4E-04	6.7E-04	6.0E-04	6.6E-04	6.2E-04	6.9E-04	0.0013	0.0012

Table 2-10 (page 3 of 5)
Waterborne Emissions for Produce Container Systems
(pounds per 1,000 tons of produce shipped)

	Head Lettuce					**Oranges**				
	Avg RPC	**Avg RPC 80% BH**	**Conserv RPC**	**Avg DRC**	**Conserv DRC**	**Avg RPC**	**Avg RPC 80% BH**	**Conserv RPC**	**Avg DRC**	**Conserv DRC**
Waterborne Wastes										
Acid	0.40	0.40	0.56	1.06	0.95	0.32	0.32	0.45	0.91	0.82
Metal Ion (unspecified)	0.81	0.74	0.82	0.28	0.26	0.56	0.51	0.57	0.20	0.18
Fluorides	0.016	0.016	0.018	0.075	0.067	0.013	0.013	0.015	0.064	0.058
Dissolved Solids	497	482	587	703	633	388	377	461	596	537
Suspended Solids	15.2	14.9	17.2	480	432	12.3	12.0	13.9	412	371
BOD	5.25	5.20	6.61	344	309	4.23	4.19	5.31	296	266
COD	13.7	13.4	16.7	908	818	10.7	10.4	13.1	781	703
Phenol	0.0026	0.0024	0.0027	0.19	0.18	0.0018	0.0016	0.0018	0.17	0.15
Sulfides	0.18	0.18	0.25	16.1	14.5	0.15	0.15	0.20	13.9	12.5
Oil	9.43	9.09	11.1	28.4	25.5	7.25	7.00	8.56	24.2	21.8
Sulfuric Acid	0.12	0.12	0.14	1.12	1.00	0.10	0.098	0.11	0.96	0.86
Iron	0.63	0.63	0.73	22.4	20.1	0.52	0.52	0.60	19.2	17.3
Cyanide	3.0E-05	2.9E-05	3.6E-05	5.5E-05	5.0E-05	2.4E-05	2.3E-05	2.8E-05	4.7E-05	4.2E-05
Chromium	0.021	0.020	0.025	0.030	0.027	0.016	0.016	0.019	0.026	0.023
Aluminum	0	0	0	11.7	10.6	0	0	0	10.1	9.08
Nickel	0	0	0	1.1E-07	9.5E-08	0	0	0	9.0E-08	8.1E-08
Mercury	1.6E-06	1.5E-06	1.9E-06	2.5E-06	2.2E-06	1.2E-06	1.2E-06	1.5E-06	2.1E-06	1.9E-06
Lead	6.8E-05	6.2E-05	6.9E-05	2.4E-05	2.2E-05	4.7E-05	4.2E-05	4.7E-05	1.7E-05	1.5E-05
Phosphates	0.083	0.081	0.098	9.62	8.66	0.066	0.065	0.079	8.27	7.44
Phosphorus	0	0	0	2.16	1.94	0	0	0	1.86	1.67
Nitrogen	0	0	0	3.61	3.25	0	0	0	3.11	2.80
Zinc	0.011	0.011	0.014	0.24	0.21	0.0089	0.0087	0.011	0.20	0.18
Ammonia	0.073	0.067	0.075	1.92	1.73	0.052	0.047	0.054	1.65	1.48
Pesticides	0	0	0	0.11	0.098	0	0	0	0.093	0.084
Dissolved Organics	5.20	5.20	7.18	0	0	4.16	4.16	5.74	0	0
Total Volatile Solids	5.23	5.23	5.23	0	0	4.60	4.60	4.60	0	0
Chlorides	22.7	22.1	26.8	30.8	27.7	18.0	17.6	21.3	26.2	23.6
Cadmium	0.021	0.020	0.025	0.030	0.027	0.016	0.016	0.019	0.026	0.023
Organic Carbon	0.43	0.43	0.60	0	0	0.35	0.35	0.48	0	0
Sulfates	18.5	18.1	22.0	32.7	29.5	14.7	14.4	17.5	27.9	25.1
Sodium	2.62	2.62	2.62	0.030	0.027	2.31	2.31	2.31	0.026	0.023
Calcium	0.0034	0.0034	0.0040	0.016	0.015	0.0028	0.0028	0.0033	0.014	0.013
Manganese	0.36	0.35	0.41	3.82	3.44	0.30	0.29	0.34	3.29	2.96
Nitrates	0.0015	0.0015	0.0017	0.087	0.078	0.0012	0.0012	0.0014	0.075	0.067
Boron	0.50	0.49	0.56	4.46	4.02	0.40	0.39	0.45	3.83	3.45
Other Organics	0.96	0.92	1.07	2.76	2.48	0.74	0.72	0.83	2.35	2.12
Chromates	5.5E-04	5.1E-04	5.7E-04	0.0010	9.1E-04	3.9E-04	3.6E-04	4.1E-04	8.4E-04	7.6E-04

Table 2-10 (page 4 of 5)
Waterborne Emissions for Produce Container Systems
(pounds per 1,000 tons of produce shipped)

	Peaches/Nectarines					**Onions**				
	Avg RPC	**Avg RPC 80% BH**	**Conserv RPC**	**Avg DRC**	**Conserv DRC**	**Avg RPC**	**Avg RPC 80% BH**	**Conserv RPC**	**Avg DRC**	**Conserv DRC**
Waterborne Wastes										
Acid	0.28	0.28	0.38	0.92	0.83	0.26	0.26	0.36	0.77	0.70
Metal Ion (unspecified)	0.59	0.53	0.59	0.24	0.22	0.45	0.41	0.46	0.19	0.18
Fluorides	0.014	0.013	0.015	0.065	0.059	0.012	0.012	0.013	0.055	0.049
Dissolved Solids	383	372	445	609	548	329	322	387	512	461
Suspended Solids	12.7	12.5	14.1	417	375	10.9	10.8	12.2	351	316
BOD	4.01	3.96	4.94	299	269	3.57	3.55	4.44	252	227
COD	10.3	10.0	12.3	789	710	8.96	8.78	10.8	665	598
Phenol	0.0019	0.0017	0.0019	0.17	0.15	0.0015	0.0013	0.0015	0.14	0.13
Sulfides	0.13	0.13	0.17	14.0	12.6	0.12	0.12	0.16	11.8	10.6
Oil	7.13	6.88	8.25	24.6	22.1	6.08	5.91	7.12	20.7	18.6
Sulfuric Acid	0.10	0.10	0.11	0.97	0.87	0.089	0.087	0.099	0.82	0.73
Iron	0.54	0.53	0.60	19.4	17.5	0.47	0.47	0.53	16.4	14.7
Cyanide	2.3E-05	2.2E-05	2.7E-05	4.8E-05	4.3E-05	2.0E-05	1.9E-05	2.4E-05	4.0E-05	3.6E-05
Chromium	0.016	0.015	0.019	0.026	0.024	0.014	0.013	0.016	0.022	0.020
Aluminum	0	0	0	10.2	9.17	0	0	0	8.58	7.73
Nickel	0	0	0	9.1E-08	8.2E-08	0	0	0	7.7E-08	6.9E-08
Mercury	1.2E-06	1.2E-06	1.4E-06	2.2E-06	1.9E-06	1.1E-06	1.0E-06	1.3E-06	1.8E-06	1.6E-06
Lead	4.9E-05	4.5E-05	5.0E-05	2.0E-05	1.8E-05	3.8E-05	3.5E-05	3.8E-05	1.6E-05	1.5E-05
Phosphates	0.066	0.065	0.077	8.36	7.52	0.057	0.057	0.068	7.04	6.34
Phosphorus	0	0	0	1.88	1.69	0	0	0	1.58	1.42
Nitrogen	0	0	0	3.14	2.82	0	0	0	2.64	2.38
Zinc	0.0084	0.0082	0.010	0.21	0.18	0.0073	0.0072	0.0091	0.17	0.16
Ammonia	0.054	0.050	0.056	1.67	1.50	0.042	0.039	0.044	1.40	1.26
Pesticides	0	0	0	0.094	0.085	0	0	0	0.080	0.072
Dissolved Organics	3.57	3.57	4.92	0	0	3.32	3.32	4.59	0	0
Total Volatile Solids	5.38	5.38	5.38	0	0	4.60	4.60	4.60	0	0
Chlorides	17.8	17.4	20.7	26.7	24.0	15.5	15.2	18.1	22.5	20.2
Cadmium	0.016	0.015	0.018	0.026	0.024	0.014	0.013	0.016	0.022	0.020
Organic Carbon	0.30	0.30	0.41	0	0	0.28	0.28	0.38	0	0
Sulfates	14.5	14.2	16.9	28.4	25.6	12.6	12.4	14.8	23.9	21.5
Sodium	2.69	2.69	2.69	0.026	0.023	2.30	2.30	2.31	0.022	0.020
Calcium	0.0029	0.0029	0.0033	0.014	0.013	0.0026	0.0025	0.0029	0.012	0.011
Manganese	0.31	0.30	0.34	3.32	2.99	0.27	0.26	0.30	2.80	2.52
Nitrates	0.0013	0.0013	0.0014	0.075	0.068	0.0011	0.0011	0.0013	0.064	0.057
Boron	0.41	0.41	0.46	3.88	3.49	0.35	0.35	0.40	3.27	2.94
Other Organics	0.77	0.74	0.84	2.39	2.15	0.65	0.63	0.72	2.01	1.81
Chromates	4.1E-04	3.8E-04	4.3E-04	8.7E-04	7.8E-04	3.2E-04	3.0E-04	3.4E-04	7.3E-04	6.6E-04

Table 2-10 (page 5 of 5)
Waterborne Emissions for Produce Container Systems
(pounds per 1,000 tons of produce shipped)

	Tomatoes					Strawberries				
	Avg RPC	**Avg RPC 80% BH**	**Conserv RPC**	**Avg DRC**	**Conserv DRC**	**Avg RPC**	**Avg RPC 80% BH**	**Conserv RPC**	**Avg DRC**	**Conserv DRC**
Waterborne Wastes										
Acid	0.37	0.37	0.51	0.91	0.82	0.73	0.73	1.01	1.67	1.51
Metal Ion (unspecified)	0.68	0.61	0.69	0.21	0.19	1.69	1.56	1.71	0.57	0.51
Fluorides	0.017	0.017	0.019	0.064	0.058	0.045	0.045	0.050	0.12	0.11
Dissolved Solids	478	465	561	595	536	1,162	1,137	1,326	1,135	1,022
Suspended Solids	15.8	15.5	17.6	411	370	41.6	41.0	45.3	759	683
BOD	5.14	5.09	6.38	295	265	12.0	11.9	14.5	544	490
COD	13.0	12.7	15.7	779	701	30.5	29.8	35.8	1,438	1,294
Phenol	0.0022	0.0020	0.0022	0.17	0.15	0.0055	0.0051	0.0055	0.31	0.28
Sulfides	0.17	0.17	0.23	13.8	12.5	0.33	0.33	0.46	25.5	23.0
Oil	8.87	8.55	10.4	24.1	21.7	21.3	20.7	24.2	45.4	40.9
Sulfuric Acid	0.13	0.13	0.14	0.96	0.86	0.34	0.33	0.37	1.77	1.59
Iron	0.67	0.67	0.76	19.2	17.2	1.79	1.78	1.96	35.4	31.8
Cyanide	2.9E-05	2.8E-05	3.4E-05	4.7E-05	4.2E-05	6.9E-05	6.7E-05	8.0E-05	8.8E-05	7.9E-05
Chromium	0.020	0.019	0.024	0.026	0.023	0.047	0.046	0.055	0.049	0.044
Aluminum	0	0	0	10.1	9.05	0	0	0	18.6	16.7
Nickel	0	0	0	9.0E-08	8.1E-08	0	0	0	1.7E-07	1.5E-07
Mercury	1.5E-06	1.5E-06	1.8E-06	2.1E-06	1.9E-06	3.6E-06	3.6E-06	4.2E-06	4.0E-06	3.6E-06
Lead	5.7E-05	5.1E-05	5.8E-05	1.7E-05	1.6E-05	1.4E-04	1.3E-04	1.4E-04	4.8E-05	4.3E-05
Phosphates	0.083	0.082	0.097	8.24	7.42	0.21	0.20	0.23	15.2	13.7
Phosphorus	0	0	0	1.85	1.67	0	0	0	3.42	3.08
Nitrogen	0	0	0	3.10	2.79	0	0	0	5.72	5.14
Zinc	0.011	0.010	0.013	0.20	0.18	0.024	0.024	0.029	0.37	0.34
Ammonia	0.064	0.058	0.066	1.64	1.48	0.16	0.15	0.16	3.05	2.74
Pesticides	0	0	0	0.093	0.084	0	0	0	0.17	0.15
Dissolved Organics	4.75	4.75	6.56	0	0	9.40	9.40	13.0	0	0
Total Volatile Solids	6.57	6.57	6.57	0	0	20.4	20.4	20.4	0	0
Chlorides	22.4	21.9	26.2	26.1	23.5	55.3	54.4	62.9	49.6	44.7
Cadmium	0.020	0.019	0.023	0.026	0.023	0.047	0.046	0.055	0.049	0.044
Organic Carbon	0.39	0.39	0.54	0	0	0.78	0.78	1.08	0	0
Sulfates	18.2	17.8	21.4	27.8	25.1	44.8	44.0	51.1	52.5	47.3
Sodium	3.29	3.29	3.29	0.026	0.023	10.2	10.2	10.2	0.047	0.043
Calcium	0.0037	0.0036	0.0042	0.014	0.012	0.0098	0.0097	0.011	0.026	0.023
Manganese	0.38	0.38	0.43	3.28	2.95	1.02	1.01	1.12	6.06	5.45
Nitrates	0.0016	0.0016	0.0018	0.074	0.067	0.0043	0.0042	0.0047	0.14	0.12
Boron	0.51	0.50	0.57	3.82	3.44	1.35	1.33	1.47	7.08	6.37
Other Organics	0.94	0.91	1.05	2.35	2.11	2.44	2.38	2.64	4.42	3.98
Chromates	4.8E-04	4.5E-04	5.1E-04	8.4E-04	7.6E-04	0.0012	0.0011	0.0013	0.0017	0.0015

For both systems, the dominant waterborne emissions by weight (but not necessarily dominant in environmental impact) are dissolved solids, suspended solids, biochemical oxygen demand, chemical oxygen demand, chlorides, sulfates, and oil. Emissions of dissolved solids, chlorides, and sulfates are roughly comparable in magnitude for average scenario RPCs and DRCs, but DRCs have higher emissions of BOD, COD, suspended solids, and oil. Essentially all the emissions of BOD and COD are process emissions associated with the steps in the production of linerboard and medium for corrugated boxes. Linerboard and medium production process emissions also account for 82 percent of emissions of suspended solids and 57 percent of oil emissions. Linerboard and medium production process fuel-related emissions account for the remaining suspended solid emissions and 40 percent of oil emissions.

OBSERVATIONS AND CONCLUSIONS

A number of observations and conclusions can be made based on the results of the analysis of RPCs and DRCs in a variety of produce applications:

- The more lifetime uses that can be achieved for an RPC, the lower the environmental burdens for container production that are allocated to each use of the container. Thus, the success of a reusable container system depends on keeping RPCs in circulation for repeated reuse and recycling. Containers lost from the system end up in the municipal solid waste stream rather than being recycled back into more RPCs, and new containers must be produced to replace the lost containers. This increases solid waste disposal burdens as well as environmental burdens for container production.
- Maximum reductions in container production burdens and disposal burdens are achieved by multiple uses of a container without remanufacturing (i.e., RPC reuse compared to DRC recycling). Although paperboard recycling reduces container disposal as well as the need for virgin pulp production, the environmental burdens for paperboard repulping and remanufacture are greater than burdens for RPC backhauling and washing in most applications and scenarios.
- Total solid waste for RPCs is much lower than for corresponding DRCs in all produce applications and scenarios. This is due to several key factors:
    - The burdens for production of RPCs are allocated over a large number of useful lives,
    - RPCs that remain in the closed-loop pooling systems are recycled when they are removed from service, keeping the material out of the solid waste stream indefinitely, and
    - Losses of RPCs from the closed-loop system are small, minimizing the amount of container solid waste to be managed.
- In almost every produce application studied, the benefits of the closed-loop RPC pooling operation more than offset the benefits of lighter container weight and a high recycling rate for corrugated containers. As a result, total energy requirements for RPCs are lower compared to corresponding DRCs in all average use scenarios and in all but two conservative scenarios evaluating the effects of lower reuse rates and higher loss rates for RPCs compared to lightweighted DRCs.
- GHG results generally track closely with fossil fuel consumption, since that is the source of the majority of GHG emissions. In the average scenarios, GHG are lower for RPCs compared to corresponding DRCs for all applications except two. In the conservative scenario comparisons, RPCs had lower GHG in half the comparisons, and half were inconclusive. DRCs have higher GHG emissions associated with process fuel, due to the quantity of single-trip containers that must be manufactured to make the produce shipments. RPCs have higher transportation-related GHG, due to their heavier weights and backhauling requirements.

CHAPTER 3

CONSIDERATIONS FOR INTERPRETATION OF DATA AND RESULTS

INTRODUCTION

An important issue with LCI results is whether two numbers are really different from one another. For example, if one product has a total system requirement of 100 energy units, is it really different from another product system that requires 110 energy units? If the error or variability in the data is sufficiently large, it cannot be concluded that the two numbers are actually different.

STATISTICAL CONSIDERATIONS

A statistical analysis that yields clear numerical answers would be ideal, but unfortunately LCI data are not amenable to this. The data are not (1) random samples from (2) large populations that result in (3) “normal curve” distributions. LCI data meet none of these requirements for statistical analysis. LCI data for a given sub-process (such as potato production, roundwood harvesting, or caustic soda manufacture, for example) are generally selected to be representative of a process or industry, and are typically calculated as an average of two to five data points. In statistical terminology, these are not random samples, but “judgment samples,” selected so as to reduce the possible errors incurred by limited sampling or limited population sizes. Formal statistics cannot be applied to judgment samples; however, a hypothetical data framework can be constructed to help assess in a general sense the reliability of LCI results.

The first step in this assessment is reporting standard deviation values from LCI data, calculated by:

$$s = \sqrt{\frac{\sum (x_1 - x_{mean})^2}{n-1}},$$

where x_i is a measured value in the data set and x_{mean} is the average of n values. An analysis of sub-process data from Franklin Associates, Ltd. files shows that, for a typical sub-process with two to five different companies supplying information, the standard deviation of the sample is about 30 percent of the sample average.

In a typical LCI study, the total energy of a product system consists of the sum of many sub-processes. For the moment, consider an example of adding only two numbers. If both numbers are independent of each other and are an average of measurements which have a sample standard deviation, s, of 30, the standard deviation of the sum is obtained by adding the variances of each term to form the sum of the variances, then taking the square root. Variances are calculated by squaring the standard deviation, s^2, so the sum of the variances is $30^2 + 30^2 = 900 + 900 = 1800$. The new standard deviation of the sum is the square root of the sum of the variances, or $\sqrt{1800} = 42.4$. In this example, suppose both average values are 100, with a sum of 200. If reported as a percent of the sum, the new standard deviation is 42.4/200 = 21.3% of the sum. Another way of obtaining this value is to use the formula $s_{\%} = \frac{s/x_{mean}}{\sqrt{n}}$, where the term $s_{\%}$ is defined as the standard deviation of n data points, expressed as a % of the average, where each entry has approximately the same standard deviation, s. For the example, then, $s_{\%} = \frac{30\%}{\sqrt{2}} = 21.3\%$.

Going back to a hypothetical LCI example, consider a common product system consisting of a sum of approximately 40 subsystems. First, a special hypothetical case is examined where *all of the values are approximately the same size, and all have a standard deviation of 30%*. The standard deviation in the result is $s_{\%} = \frac{30\%}{\sqrt{40}} = 4.7\%$. The act of summing reduces the standard deviation of the result with respect to the standard deviation of each entry because of the assumption that errors are randomly distributed, and by combining values there is some cancellation of total error because some data values in each component system are higher than the true values and some are lower.

The point of this analysis, however, is to compare two results, e.g., the energy totals for two different product systems, and decide if the difference between them is significant or not. To test a hypothetical data set it will be assumed that two product systems consist of a sum of 40 values, and that the standard deviation, $s_{\%}$, is 4.7% for each product system.

If there is statistical knowledge of the sample only, and not of the populations from which they were drawn, "t" statistics can be used to find if the two product totals are different or not. The expression selected is:
$\mu 1 - \mu 2 = x1 - x2 +/- t_{.025} s' \sqrt{\frac{1}{n1} + \frac{1}{n2}}$, where $\mu 1 - \mu 2$. is the difference in population means, x_1-x_2 is the difference in sample means, and s' is a pooled standard deviation of the two samples. For the hypothetical case, where it is assumed that the standard deviation of the two samples is the same, the pooled value is simply replaced with the standard deviation of the samples.

The goal is to find an expression that compares our sample means to "true," or population, means. A new quantity is defined:
$\Delta = (\mu 1 - \mu 2) - (x1 - x2)$, and the sample sizes are assumed to be the same (i.e., n_1=n_2).
The result is $\Delta = t_{.025} s' \sqrt{\frac{2}{n}}$, where Δ is the minimum difference corresponding to a 95%

confidence level, s' is the standard deviation of the sum of n values, and $t_{.025}$ is a t statistic for 95% confidence levels. The values for t are a function of n and are found in tables. This expression can be converted to percent notation by dividing both sides by the average of the sample means, which results in $\Delta\% = t_{.025} s'\% \sqrt{\frac{2}{n}}$, where $\Delta\%$ is now the percent difference corresponding to a 95% confidence level, and s'% is the standard deviation expressed as a percent of the average of the sample means. This formula can be simplified for the example calculation by remembering that $s'\% = \frac{s\%}{\sqrt{n}}$, where s% is the standard deviation of each energy entry for a product system. Now the equation becomes $\Delta\% = t_{.025} s\% \frac{\sqrt{2}}{n}$. For the example, t = 2.0, s = 30%, and n = 40, so that $\Delta\%$ = 2.1%. This means that if the two product system energy totals differ by more than 2.1%, there is a 95% confidence level that the difference is significant. That is, if 100 independent studies were conducted (in which new data samples were drawn from the same population and the study was conducted in the identical manner), then 95 of these studies would find the energy values for the two product systems to differ by more than 2.1%.

The previous discussion applies only to a hypothetical and highly idealized framework to which statistical mathematics apply. LCI data differ from this in some important ways. One is that the 40 or so numbers that are added together for a final energy value of a product system are of widely varying size and have different variances. The importance of this is that large numbers contribute more to the total variance of the result. For example, if 20 energy units and 2,000 energy units are added, the sum is 2,020 energy units. If the standard deviation of the smaller value is 30% (or 6 units), the variance is 6^2 = 36. If the standard deviation of the larger number is 10% (or 200), the variance is 200^2 = 40,000. The total variance of the sum is 36 + 40,000 = 40,036, leading to a standard deviation in the sum of $\frac{\sqrt{(40036)}}{2020}$ = 9.9%. Clearly, the variance in the result is much more greatly influenced by larger numbers. In a set of LCI energy data, standard deviations may range from 10% to 60%. If a large number has a large percentage standard deviation, then the sum will also be more uncertain. If the variance of the large number is small, the answer will be more certain. To offset the potential problem of a large variance, Franklin Associates goes to great lengths to increase the reliability of the larger numbers, but there may simply be inherent variability in some numbers which is beyond the researchers' control.

If only a few numbers contribute most of the total energy in a system, the value of $\Delta\%$ goes up. This can be illustrated by going back to the formula for $\Delta\%$ and calculating examples for n = 5 and 10. From statistical tables, the values for $t_{.025}$ are 2.78 for n = 5, and 2.26 for n = 10. Referring back to the hypothetical two-product data set with s% = 30% *for each entry*, the corresponding values for $\Delta\%$ are 24% for n = 5 and 9.6% for n = 10. Thus, if only 5 numbers out of 40 contribute most of the energy, the percent *difference* in the two product system energy values must increase to 24% to achieve the 95% confidence level that the two values are different. The minimum difference decreases to 9.6% if there are 10 major contributors out of the 40 energy numbers in a product system.

CONCLUSIONS

The discussion above highlights the importance of sample size, and of the variability of the sample. However, once again it must be emphasized that the statistical analysis does not apply to LCI data. It only serves to illustrate the important issues. Valid standard deviations cannot be calculated because of the failure of the data to meet the required statistical formula assumptions. Nevertheless, it is important to achieve a maximum sample size with minimum variability in the data. Franklin Associates examines the data, identifies the large values contributing to a sum, then conducts more intensive analysis of those values. This has the effect of increasing the number of data points, and therefore decreasing the "standard deviation." Even though a calculated standard deviation of 30% may be typical for Franklin Associates' LCI data, the actual confidence level is much higher for the large values that control the variability of the data than for the small values. However, none of this can be quantified to the satisfaction of a statistician who draws conclusions based upon random sampling. In the case of LCI data, it comes down to a matter of professional judgment and experience. The increase in confidence level resulting from judgment and experience is not measurable.

It is the professional judgment of Franklin Associates, based upon over 25 years of experience in analyzing LCI data, that a 10% rule is a reasonable value for $\Delta\%$ for stating results of product system energy totals. That is, if the energy of one system is 10% different from another, it can be concluded that the difference is significant. It is clear that this convention is a matter of judgment. This is not claimed to be a highly accurate statement; however, the statistical arguments with hypothetical, but similar, data lend plausibility to this convention.

We also conclude that the weight of postconsumer solid waste data can be analyzed in a similar way. These data are at least as accurate as the energy data, perhaps with even less uncertainty in the results. Therefore, the 10% rule applies to postconsumer solid waste weight. However, we apply a 25% rule to the solid waste volume data because of greater potential variability in the volume conversion factors.

Air and water pollution and industrial solid waste data are not included in the 10% rule. Their variability is much higher. Data reported by similar plants may differ by a factor of two, or even a factor of ten or higher in some cases. Standard deviations may be as high as 150%, although 75% is typical. This translates to a hypothetical standard deviation in a final result of 12%, or a difference of at least 25% being required for a 95% confidence of two totals being different if 10 subsystems are major contributors to the final results. However, this rule applies only to single emission categories, and cannot be extended to general statements about environmental emissions resulting from a single product system. The interpretation of environmental emission data is further complicated by the fact that not all plants report the same emission categories, and that there is not an accepted method of evaluating the relative importance of various emissions.

It is the intent of this appendix to convey an explanation of Franklin Associates' 10% and 25% rules and establish their plausibility. **Franklin Associates' policy is to consider product system totals for energy and weight of postconsumer solid waste weight to be different if there is at least a 10% difference in the totals. Otherwise, the difference is considered to be insignificant. In the detailed tables of this report there are many specific pollutant categories that are variable between systems. For the air and waterborne emissions, industrial solid waste, and postconsumer solid waste volume, the 25% rule should be applied.** The formula used to calculate the difference between two systems is:

$$\%\ \text{Diff} = \left(\frac{x-y}{\frac{x+y}{2}} \right) \text{X } 100,$$

where x and y are the summed totals of energy or waste for two product systems. The denominator of this expression is the average of the two values.