PEER REVIEWED FINAL REPORT

LCI SUMMARY FOR FOUR HALF-GALLON MILK CONTAINERS

Prepared for

THE PLASTICS DIVISION OF
THE AMERICAN CHEMISTRY COUNCIL

by

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September, 2008

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LCI SUMMARY FOR FOUR HALF-GALLON MILK CONTAINERS

The ACC Plastics Division chose the primary packaging of three common consumer products from the 2007 report[1], **A Study of Packaging Efficiency as it Relates to Waste Prevention**, on which to perform life cycle inventory (LCI) case studies. Primary packaging for milk was chosen as one of these case studies. This summary evaluates the life cycle inventory results of the primary package for 10,000 half-gallon milk containers as sold in each packaging system.

LCI RESULTS SUMMARY

Based on the uncertainty in the data used for energy, solid waste, and emissions modeling, differences between systems are not considered meaningful unless the percent difference between systems is greater than the following:

- 10 percent for energy and postconsumer solid waste
- 25 percent for industrial solid wastes and for emissions data.

Percent difference between systems is defined as the difference between energy totals divided by the average of the two system totals. The minimum percent difference criteria were developed based on the experience and professional judgment of the analysts and are supported by sample statistical calculations (see Appendix C).

The complete LCI results include energy consumption, solid waste generation, and environmental emissions to air and water. A summary of the total energy, postconsumer solid waste, and total greenhouse gas emissions results for the four milk containers is displayed in Table 1.

The refillable glass bottle requires the least amount of total energy due to its 90 percent reuse rate. The total energy for the gable top carton is not considered significantly different than the total energy for the HDPE bottle system. The PLA milk containers require significantly more energy than the competing milk containers. It should be noted that if the energy of material resource for corn were not included in the PLA bottle system, the total energy would be 48.7 million Btu. However, this total is still significantly higher than the total energy of all other systems.

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[1] **A Study of Packaging Efficiency as it Relates to Waste Prevention.** Prepared by the editors of the ULS Report. Feb. 2007.

Table 1

TOTAL ENERGY, POSTCONSUMER SOLID WASTE, AND GREENHOUSE GASES FOR THE USE OF 10,000 HALF-GALLON MILK CONTAINERS

	Total Energy	Postconsumer Solid Waste		Greenhouse Gases
	(MM Btu)	(lb)	(cu ft)	(lb of CO2 equivalents)
Half-gallon milk container systems				
PLA Bottle (1)	67.2	1,061	80.7	5,968
Gable Top Carton (1)	42.8	1,248	46.5	4,411
Refillable Glass Bottle (2)	32.0	3,733	42.2	5,398
HDPE Bottle (3)	40.0	763	58.0	3,336

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(1) End-of-life for this system is modeled with 80% going to a landfill and 20% combusted at a WTE facility.

(2) End-of-life for this system is modeled with a 90% reuse rate (8 trips) with 15% recovered for recycling, 68% going to a landfill, and 17% combusted at a WTE facility. However, the energy recovery is only available for the cap/seal.

(3) End-of-life for this system is modeled with 29% recovered for recycling, 57% going to a landfill, and 14% combusted at a WTE facility.

Source: Franklin Associates, a Division of ERG calculations using original data from LCI/LCA by NatureWorks, LLC and Franklin Associates.

The postconsumer solid waste by weight is highest for the glass milk container system. This is due to the weight of the glass. Although recycling and reuse of the glass is taken into account, the weight of the glass makes the disposed amount more than 3 times heavier than any of the other systems. It should be noted that although the glass system does produce a greater amount of solid waste by weight, the crushed glass itself is inert within a landfill. Because the glass has a high density, the volume of the postconsumer solid waste for the glass system is actually lower than the other milk container systems with the exception of the gable top carton, from which it is not significantly different. The landfill density of paperboard cartons is higher than the plastic bottles as the paperboard can easily be crushed flat. The same landfill density is used for the PLA and HDPE bottles, as they are considered rigid plastics containers, which does not compact completely in a landfill. However, the HDPE bottle includes recycling which subtracts from the amount being disposed in a landfill.

The HDPE bottle system produces the least amount of greenhouse gases. Although the PLA bottle produces the highest amount of carbon dioxide equivalents, the difference between it and the refillable glass bottle are not considered significant. The carbon dioxide equivalents for the glass system have been reduced due to its reuse rate. In the PLA bottle and gable top carton systems, the carbon dioxide released from combustion of biomass are not included in the greenhouse gas amounts in Table 1.

LCI METHODOLOGY

The same methodology utilized in the report, Life Cycle Inventory of Five Products Produced from PLA and Petroleum-Based Resins, is also used in this analysis.

The methodology used for goal and scope definition and inventory analysis in this study is consistent with the methodology for Life Cycle Inventory (LCI) as described by the ISO 14040 and 14044 Standard documents. 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 scope and boundaries established. This LCI is a cradle-to-grave analysis, covering steps from raw material extraction through container disposal. 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 the product. It can also pinpoint areas (e.g., material composition or processes) where changes would be most beneficial in terms of reduced energy use or environmental emissions.

This study is limited to an LCI, with the exception of greenhouse gas emissions, which are expressed in terms of global warming potential impact. Global warming potentials (GWP) are used to normalize various greenhouse gas emissions to the basis of carbon dioxide equivalents. The use of global warming potentials is a standard LCIA practice.

Appendix A contains details of the methodology used in this case study.

GOAL

The goal of the milk container study is to explore the relationship between the weight and material composition of primary milk containers and the associated life cycle profile of each milk container. The report includes discussion of the results for the milk container systems, but does not make comparative assertions, i.e., recommendations on which containers are preferred from an environmental standpoint.

SYSTEMS STUDIED

Four one-half gallon milk container systems are considered in this LCI case study. These containers include a PLA bottle, an HDPE bottle, a refillable glass bottle, and a gable top carton. Flow diagrams of the processes used to produce the container materials (PLA, HDPE, glass, paperboard, and LDPE) are shown in Appendix B. The weights of the milk container systems are shown in Table 2. This table displays all seals, caps, and spouts included in each container system.

In order to express the results on an equivalent basis, a functional unit of equivalent consumer use (10,000 containers, as all containers contain equivalent milk amounts) was chosen for this analysis.

Table 2

WEIGHTS FOR HALF-GALLON MILK CONTAINER SYSTEMS
(Basis: 10,000 milk container uses)

	Weight per unit		Weight per functional unit	
	(oz)	(g)	(lb)	(kg)
Half-Gallon Milk Container Systems				
PLA Bottle				
Bottle	2.53	71.6	1,578	716
HDPE Cap/seal	0.10	2.9	64	29
Gable Top Carton				
Carton	2.42	68.5	1,510	685
HDPE Cap/spout	0.06	1.8	40	18
Glass Bottle				
Bottle (1)	32.14	911.1	4,291	1,946
LDPE Cap/seal	0.19	5.3	117	53
HDPE Bottle				
Bottle	1.66	47.2	1,041	472
HDPE Cap/seal	0.10	2.9	64	29

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(1) The glass bottle is assumed to be reused 8 times before it is either landfilled or recycled. The recovery rate for the reuse of the glass bottle is 90 percent and the breakage rate is 1 percent. This reuse decreases the number of bottles needed for the basis.

Source: Franklin Associates, a Division of ERG

SCOPE AND BOUNDARIES

This analysis includes the following three steps for each container system:

1. Production of the container materials (all steps from extraction of raw materials through the steps that precede container manufacture).
2. Manufacture of the container systems from their component materials.
3. Transport of package to filling (where necessary) and from filling to retail.
4. Postconsumer disposal, reuse, and recycling of the container systems.

The secondary packaging, filling, storage, and consumer activities are outside the scope and boundaries of the analysis. The ink production and printing process is assumed to be negligible compared to the material production of each system.

The end-of-life scenarios used in this analysis reflect the current recycling rates of the containers studied. No composting has been considered in this analysis. HDPE and glass milk containers are more commonly recycled, and so their end-of-life scenario includes a recycling rate.[2] The glass milk container also includes eight reuses before it is either recycled or disposed. The PLA containers do not have a recycling infrastructure currently set up; therefore no recycling has been considered in this analysis. Gable top cartons are recycled at a rate of approximately 1 percent[2]; therefore no recycling has been considered in this analysis.

The analysis includes greenhouse gas emissions from waste-to-energy combustion, but does not estimate greenhouse gas emissions that may result from decomposition of landfilled containers. Glass and the plastic resins are inert in a landfill, and there are large uncertainties about the degree of decomposition that may occur for gable top cartons that are coated on both sides.

Figures 1 through 4 define the materials and end-of-life included within the four systems. These figures do not include the steps for the production of each material used in the container systems. The flow diagrams for each material used in this analysis are shown in Appendix B.

LIMITATIONS AND ASSUMPTIONS

Key assumptions of the LCI of milk containers are as follows:

- The majority of processes included in this LCI occur in the United States and thus the fuel profile of the average U.S. electricity grid is used to represent the electricity requirements for these processes. This is also true of the PLA LCI performed by NatureWorks using Ian Boustead's software; U.S. fuel profiles were used.
- Caps are included in this analysis. The cap/spout is also included for the gable top carton. The labels and/or printing for each of the containers are considered negligible by weight and results compared to the containers themselves and are not included in the analysis.
- No secondary packaging, filling, retail storage, or consumer use is included in this analysis as these are outside the scope and boundaries of the analysis.
- Polyethylene terephthalate (PET) as a bottle material was not included in this analysis, as no ½ gallon PET milk containers were found within the Kansas City market. PET was found in the pint and gallon sizes of milk, but these are outside the scope of this analysis.

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[2] Municipal Solid Waste in the United States, Facts and Figure 2005. U.S. Environmental Protection Agency. Office of Solid Waste, October, 2006. EPA-530-R-06-011. Found at http://www.epa.gov/epaoswer/non-hw/muncpl/pubs/mswchar05.pdf.

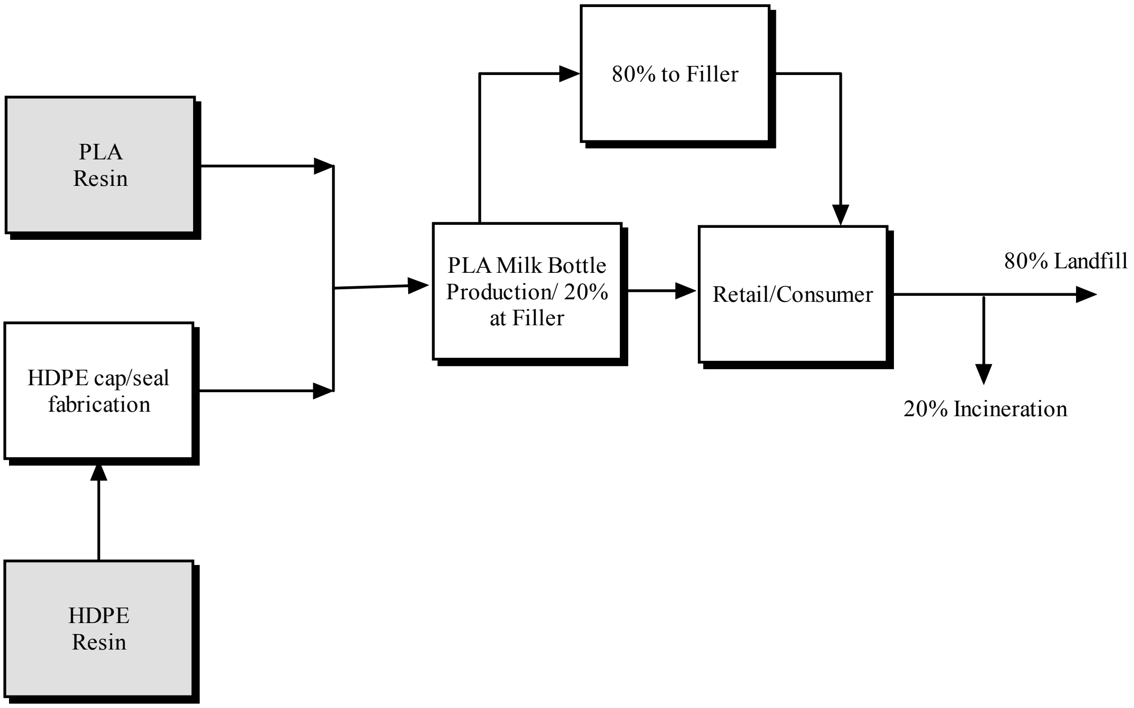


Figure 1. Flow diagram for the production of the one-half gallon PLA milk container system.
Flow diagrams for the production of the materials in shaded boxes are shown in Appendix B.
The data for filling, storage, retail, and consumer use are not included in this analysis.
It is assumed that 20 percent of the PLA bottle production is done at the filler.

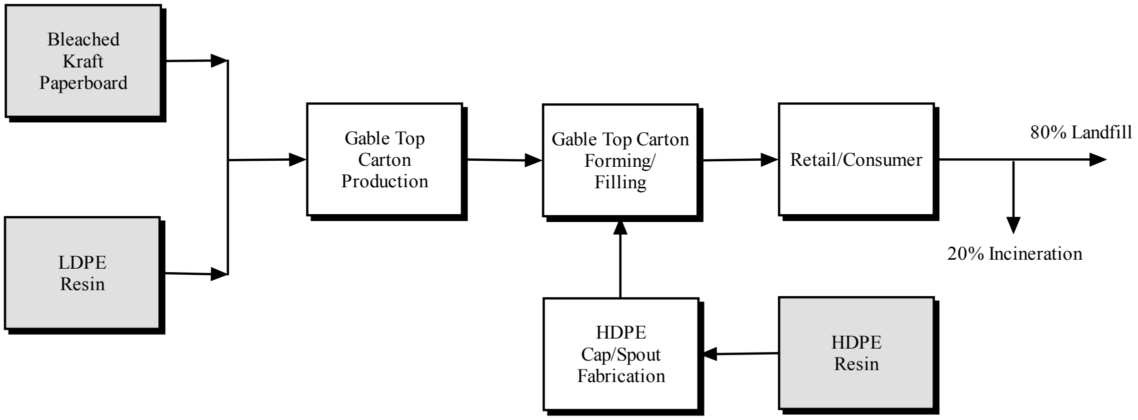


Figure 2. Flow diagram for the production of the one-half gallon gable top carton system.
Flow diagrams for the production of the materials in shaded boxes are shown in Appendix B.
The data for filling, storage, retail, and consumer use are not included in this analysis.
Gable top cartons are recycled at a rate of approximately 1 percent; therefore no recycling has been considered in this analysis.

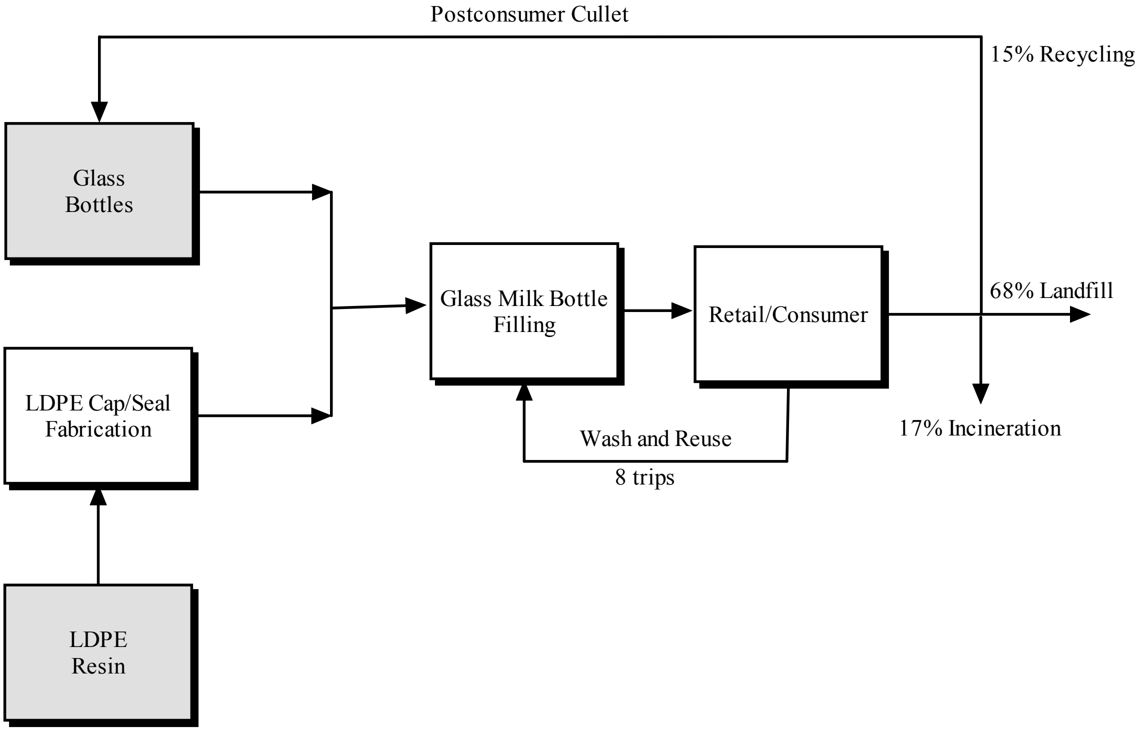


Figure 3. Flow diagram for the production of the one-half gallon glass milk container system. Flow diagrams for the production of the materials in shaded boxes are shown in Appendix B. The data for filling, storage, retail, and consumer use are not included in this analysis. This analysis assumes that the return rate for the glass milk bottles is 90 percent; the reuse rate is 8 times; and the breakage rate is 1 percent.

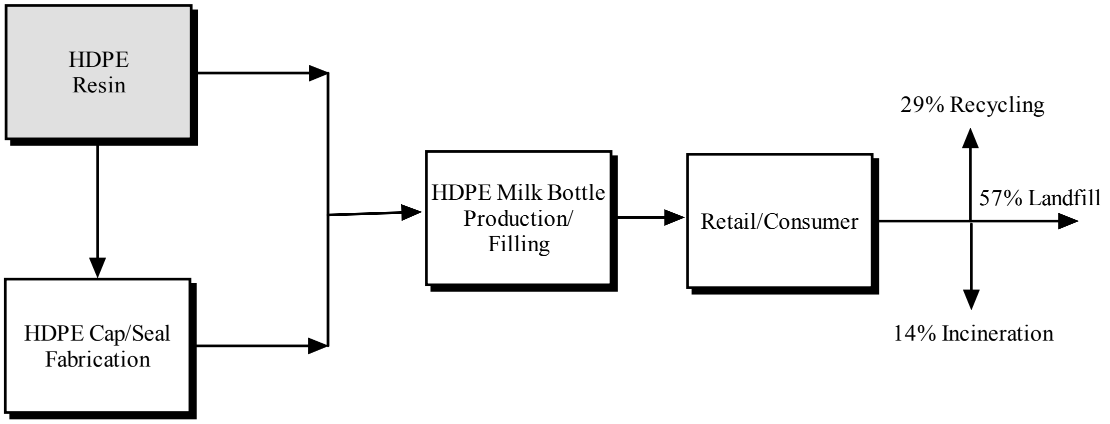


Figure 4. Flow diagram for the production of the one-half gallon HDPE milk container system. Flow diagrams for the production of the materials in shaded boxes are shown in Appendix B. The data for filling, storage, retail, and consumer use are not included in this analysis.

- This analysis is representative of U.S. production. The U.S. LCI Database is used for the HDPE and LDPE resins in this analysis. Only the fabrication process data for the plastic bottles comes from the PlasticsEurope database, which is European data. The U.S. fuel precombustion and combustion data are used with this European fabrication data. The glass bottle and gable top carton LCI data comes from the Franklin Associates database using various sources including primary (collected) data.
- For calculating the weight of filled milk containers during transport, the density of milk is 8.611 lb per gallon at a temperature of 10° C.
- Weights for the HDPE bottle, PLA bottle, gable top carton, and their caps/seals were taken from the report, **A Study of Packaging Efficiency as it Relates to Waste Prevention** prepared by the Editors of the ULS Report, February, 2007. (http://www.americanchemistry.com/plastics/doc.asp?CID=1593&DID=6072)
- Transportation from filling to retail for the PLA, HDPE, and gable top containers is estimated to be an average of 100 ton-miles per 1,000 pounds of product by truck.
- The following assumptions were made for the PLA bottle system:
    - The weights were taken from the listed weights in the **2007 Packaging Efficiency Study**.
    - Erwin Vink of NatureWorks provided a journal paper, at the time under peer review, that included the NatureWorks 2005 PLA data used in this report. Mr. Vink's LCA of PLA uses the same model as the PlasticsEurope database.
    - Only the 2005 PLA dataset from the NatureWorks journal paper was used in this analysis. The choice was made not to use the 2006 PLA data with wind energy credits, based on the fact that any manufacturer of resin/paperboard/glass could buy those same credits. However, the datasets used in this report are based on industry averages of many manufacturers versus the PLA data coming from just one company, NatureWorks.
    - Franklin Associates staff estimated the energy for the drying of PLA resin, a hygroscopic resin, from specifications found on ConAir's website for the dehumidifying dryer, CD1600. ConAir produces dryers for the resin industry. The kW provided on the specifications sheet represent maximum power expended for the dryer.
    - The Franklin Associates LCI models were used to calculate fuel production and delivery energy and emissions for drying, PLA resin transportation, and disposal steps. There may be small differences between the Franklin Associates model and the Boustead model used by NatureWorks.

    - Transportation from the PLA resin producer to the product fabrication are
        - 96 ton-miles per 1,000 pounds of product by combination truck, and
        - 96 ton-miles per 1,000 pounds of product by rail.
    - Franklin Associates staff estimated that 20 percent of PLA bottles for dairy are produced at the filler in the Midwest and West Coast. The remaining 80 percent of PLA bottles are assumed to be sent from a bottle producer in Michigan to three U.S. regions (NE, SE, and Rocky Mountain area). Transportation from the bottle producer to the dairy filler is modeled as 354 ton-miles by truck.
    - It is beyond the scope of this analysis to consider greenhouse gas implications of landcover changes associated with corn growing.
- The following assumptions were made for the gable top carton system:
    - The weights were taken from the listed weights in the **2007 Packaging Efficiency Study**.
    - The gable top cartons are produced from paperboard, LDPE and likely an EVOH layer; however, information about the amount of EVOH was not available and so the total resin weight was modeled as LDPE.
    - A converting scrap rate of 1 percent was assumed during the fabrication of the cartons and the fabrication of the spout and lid.
    - Gable top cartons are assumed to be formed at the filler. This is commonly done at large dairy plants, which service a 2-3 state region. The transportation distance estimated from a major gable top carton producer to large dairy plants is
        - 350 ton-miles per 1,000 pounds of product by combination truck.
- The following assumptions were made for the glass bottle system:
    - The weight of the glass bottle and its cap/seal is an average from the weighing of two glass bottles and their caps (different milk producers) by Franklin Associates staff. These bottle weights were taken from glass dairy bottles within the Kansas City area. Both local dairies purchased these bottles from the same glass bottle producer in Ontario, CA. The difference between these weights is less than 1 percent for each of the weights of the two bottles and two caps/seals.
    - Contact was made with both of the local milk producers (Shatto Milk Company and Green Hills Harvest) who provided input on return rate, reuse rate, and breakage rate. This analysis assumes that the return rate for the glass milk bottles is 90 percent; the reuse rate is 8 times; and the breakage rate is 1 percent. These estimates are meant to represent an average of all milk producers using glass bottles. Each individual milk producer may have higher or lower rates than those used in this analysis. A sensitivity analysis of other return and reuse rates is included in this report.

    - A converting scrap rate of 1 percent was assumed during the fabrication of the seal and lid.
    - Only milk containers sold through grocery and retail stores are considered in this analysis. Home delivery has not been included in this analysis. It is possible that higher trip rates could be accomplished with home delivery. This is also a possibility in other large market areas.
    - The average transport distance between the dairy using glass bottles and grocery/retail stores was estimated to be 80 miles. The backhaul of the empty glass containers uses 40 ton-miles per 1,000 pounds of containers.
    - Glass commonly contains a percentage of recycled content. In this analysis, the glass milk bottles contain 35 percent cullet. Of this cullet, 80 percent is from postconsumer sources. This was verified with a major glass bottle producer.
- The following assumptions were made for the HDPE bottle system:
    - The weights were taken from the listed weights in the **2007 Packaging Efficiency Study**.
    - A converting scrap rate of 1 percent was assumed during the fabrication of the HDPE bottle and seal and lid.
    - HDPE milk containers are assumed to be blow molded at the filler. This is commonly done at large dairy plants, which service a 2-3 state region. HDPE resin is commonly produced in the Texas/Louisiana area. The distance was estimated using an average distance from the Houston area to an estimated midpoint of the eastern, western, and midwest U.S. The transportation distance estimated from HDPE resin producer to the large dairy plants is
        - 321 ton-miles by combination truck, and
        - 321 ton-miles by rail.
- The higher heating values used for the resins analyzed in this chapter are PLA—8,170 Btu/lb, HDPE/LDPE—19,965 Btu/lb, paperboard—7,261 Btu/lb, and glass—0 Btu/lb.
- When materials such as plastic or paper are combusted for waste-to-energy, carbon dioxide is released. The carbon dioxide released when paper or PLA is combusted is considered to be biogenic and so is not included as a greenhouse gas consistent with U.S. EPA methodology. Using the carbon content of each of the plastics in this analysis (PE—85.7%), the theoretical maximum carbon dioxide amount from incineration has been included as a separate item in the greenhouse gas results in this analysis.
- The global warming potentials used in this study were developed in 2001 by the Intergovernmental Panel on Climate Change (IPCC). The 100 year GWP used are as follows: fossil carbon dioxide—1, methane—25, and nitrous oxide—298. Other greenhouse gases are included in the emissions list shown in Table 6, but these make up less than 1 percent of the total greenhouse gases in each system and have not been included in Table 7.

- Currently, it is estimated that about 80 percent of discarded municipal solid waste (MSW) in the U.S. that is not diverted for reuse, recycling, or composting is landfilled, and the remaining 20 percent is burned in waste-to-energy facilities. Therefore, combustion of 20 percent of the postconsumer materials that are discarded and not reused, recycled, or composted is included in this study. In the LCI energy results, an energy credit for waste-to-energy combustion of 20 percent of disposed system components is assigned to each system.
- The analysis includes greenhouse gas emissions from waste-to-energy combustion, but does not estimate greenhouse gas emissions that may result from decomposition of landfilled containers.

COMPLETE LCI RESULTS

Tables 3 through 7 display the complete LCI results for this analysis. The energy results are shown in Table 3; the solid waste results are shown in Table 4; the comprehensive atmospheric emissions in Table 5, the greenhouse gas emissions in Table 6, and waterborne emissions in Table 7.

Energy

Franklin Associates commonly uses three energy reporting categories—process energy, fuel-related energy, and energy of material resource. These energy categories are shown in Table 3 for each of the milk container systems. The definitions of energy categories used in the Franklin Associates model and the energy categories used in the Boustead model are not identical in boundaries. The Boustead model categories, energy content of delivered fuel and fuel production and delivered energy, have been summed into the Franklin Associates' process energy category. It was not possible to allocate the transport energy part of the fuel production and delivered energy. This small amount of energy is included in the process energy category and does not affect the results of this analysis.

The combustion energy credit, which is the credit for the recovered energy from combustion of the final product in an incinerator, is shown separately in Table 3; however, the recovered energy from processes within the production of the materials are already included in the process energy.

Total and Net Energy. From Table 3, assuming current end-of-life scenarios, the PLA bottle system requires the most total energy to produce. The refillable glass bottle system requires the least amount of total energy. This is due to the reuse of the bottle 8 times over its life. The total energy for the HDPE bottle and gable top carton systems have a 7 percent difference, and therefore the total energy for these milk containers is not considered significantly different. The total energy for the HDPE bottle system is considered significantly less than the PLA bottle system.

The combustion energy credit is given for the energy collected at a waste-to-energy facility using a national average of 20 percent of the postconsumer waste. As glass does not combust, only the cap/seal of the glass system accounts for the credit given, which is approximately 1 percent of the system's total energy. The combustion energy credit for the HDPE bottle system decreases the total energy by almost 10 percent, with the remaining systems decreasing by 5 percent or less of their total energy amounts. This larger credit for HDPE is due to its higher heating value being greater than that of the PLA and paperboard.

Table 3

Energy by Category for Half-Gallon Milk Containers
(MM Btu per 10,000 half-gallon milk container uses)

	Energy Category					
	Process	Transport	Energy of Material Resource	Total	Combustion Energy Credit (4)	Net Energy
Half-gallon milk container systems						
PLA Bottle System (1)	45.4	3.24	18.5	67.2	2.83	64.3
Gable Top Carton System (1)	36.0	2.12	4.66	42.8	2.25	40.5
Glass Bottle System (2)	21.1	8.14	2.79	32.0	0.47	31.6
HDPE Bottle System (3)	15.8	1.73	22.4	40.0	3.81	36.1

	Energy Category (percent)				
	Process	Transport	Energy of Material Resource	Total	Combustion Energy Credit (4)
Half-gallon milk container systems					
PLA Bottle System (1)	68%	5%	28%	100%	4%
Gable Top Carton System (1)	84%	5%	11%	100%	5%
Glass Bottle System (2)	66%	25%	9%	100%	1%
HDPE Bottle System (3)	40%	4%	56%	100%	10%

(1) End-of-life for this system is modeled with 80% going to a landfill and 20% combusted with energy recovery.

(2) End-of-life for this system is modeled with 15% recovered for recycling, 68% going to a landfill, and 17% combusted with energy recovery.

(3) End-of-life for this system is modeled with 29% recovered for recycling, 57% going to a landfill, and 14% combusted with energy recovery.

(4) The combustion energy credit includes a credit for the recovered energy from combustion of the final product at an incinerator. Any recovered energy from the material production processes are subtracted out of the total.

Source: Franklin Associates, a Division of ERG calculations using original data from LCI/LCA by NatureWorks, LLC, the Franklin Associates database, and the U.S. LCI Database.

The conclusions for the net energy of the PLA and glass systems are identical to those of the total energy. The only conclusion that differs is the net energy for the HDPE bottle system can be considered significantly less than the net energy of the gable top carton system.

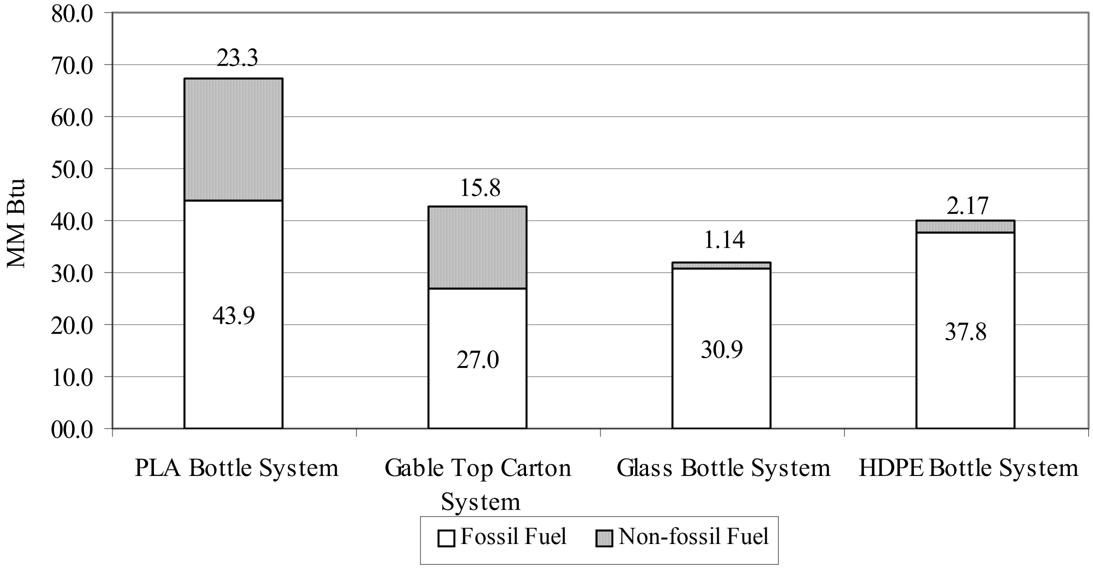
Energy of Material Resource. The energy of material resource (or feedstock energy) comprises more than half of the total energy in the HDPE bottle system. The energy of material resource shown for the gable top carton and glass systems are from the cap/seal production and the LDPE coating used on the carton. The energy of material resource category makes up 28 percent of the total energy for PLA. The PLA resin has been given feedstock energy in the NatureWorks report—most of this feedstock energy represents the corn used as raw material. It is true that the use of corn as a fuel (ethanol) has been increasing over the past few years. Franklin Associates does not commonly assign a fuel-energy equivalent to combustible biomass materials, such as corn, that are not major fuel sources in this country. However, the corn feedstock energy was included to follow NatureWorks' basic approach and methodology.

Process and Transportation Energy. Process energy comprises more than half of the total energy for the PLA bottle, gable top carton, and glass bottle systems. The transport energy is 4 to 5 percent for the HDPE bottle, PLA bottle and gable top carton systems. The glass bottle system transport energy is 25 percent of its total energy. This is due in part to the heavier bottle weights, as well as the additional transport needed to reuse the bottles.

Energy by Fuel Type. As shown in Figure 5, over 95 percent of the total energy required for the HDPE and glass milk container systems comes from fossil fuels. In the glass bottle system, almost all of the energy from fossil fuel is combusted during the production of the glass and the cap/seal. In the HDPE bottle system, over 55 percent of the energy from fossil fuel is feedstock energy, much of which is never combusted during the bottle's life. The remaining non-fossil energy for these two systems comes from the production of electricity.

Energy from fossil fuels is utilized for 63-65 percent of the total energy for the PLA and gable top milk containers. The remaining non-fossil energy for the gable top carton comes from the use of wood wastes to produce energy within the paper mill. For the PLA bottle, this non-fossil energy is mostly the feedstock energy for PLA, but does include a small amount from the use of biomass wastes to produce grid electricity.

Figure 5. Energy by Fuel Type for 10,000 Half-Gallon Milk Containers



Solid Waste

Solid waste, shown in Table 4, is categorized into empirical categories as shown in the Boustead model used by NatureWorks. Also included in the solid waste table are the common Franklin Associates solid waste categories—process, fuel-related, and postconsumer wastes, which are the wastes discarded by the end users of the product. Due to the differences in solid waste categories, no industrial (process + fuel-related) solid waste comparisons have been made between the PLA bottle system and other systems. Only postconsumer solid waste comparisons were made for all of the milk container systems. Postconsumer solid waste amounts are shown by both weight and volume.

No solid waste data were provided in Erwin Vink's journal paper for the PLA (2005) resin. The solid waste data shown for the PLA resin in Table 4 are estimated from the PLA (2006) dataset.

Table 4

Solid Wastes for Half-Gallon Milk Containers
(lb per 10,000 half-gallon milk container uses)

	PLA Bottle System (1) (2)	Gable Top Carton System (2)	Glass Bottle System (3)	HDPE Bottle System (4)
Solid Waste Categories				
Plastics	1.58	0	0	0
Unspecified refuse	1.77	0	0	0
Mineral waste	29.1	0	0	0
Slags & ash	41.5	0	0	0
Mixed industrial	3.67	0	0	0
Regulated chemicals	7.20	0	0	0
Unregulated chemicals	1.90	0	0	0
Construction waste	0.0032	0	0	0
Inert chemical	0.0016	0	0	0
Waste to recycling	0.0016	0	0	0
Waste returned to mine	58.6	0	0	0
Tailings	15.4	0	0	0
Municipal solid waste	11.2	0	0	0
Process	2.07	240	207	46.9
Fuel-related	18.0	435	161	223
Postconsumer solid waste	1,061	1,248	3,733	763
Postconsumer solid waste by volume (cu ft)	80.7	46.5	42.2	58.0

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(1) No solid waste data were provided in Mr. Vink's journal paper for the PLA(2005) resin. The data shown for the resin is estimated from the PLA(2006) dataset and does not include the solid waste reduction associated with the purchase of wind energy credits

(2) Disposal of postconsumer solid waste is modeled with 80% going to a landfill and 20% combusted with energy recovery.

(3) Disposal of postconsumer solid waste is modeled with 15% recovered for recycling, 68% going to a landfill, and 17% combusted with energy recovery. The glass bottle is assumed to be used 8 times before its end-of-life.

(4) Disposal of postconsumer solid waste is modeled with 29% recovered for recycling, 57% going to a landfill, and 14% combusted with energy recovery.

Source: Franklin Associates, a Division of ERG calculations using original data from LCI/LCA by NatureWorks, LLC, the Franklin Associates database, and the U.S. LCI Database.

Excluding the PLA bottle system due to differences in the source categories, the HDPE bottle system produces the least amount of process solid waste, while the gable top carton system produces the greatest amount. The fuel-related solid waste for the glass bottle system is significantly less than that of the HDPE bottle system; the gable top carton system produces the greatest amount of fuel-related solid waste.

The postconsumer solid waste is dependent on the end-of-life scenario chosen. The end-of-life scenarios used in this analysis reflect the current recycling and reuse rates of the containers studied. Based on the U.S. average combustion of mixed municipal solid waste, 20 percent of the disposed weight is combusted in waste-to-energy facilities and then subtracted out of the total postconsumer wastes. The weight of postconsumer wastes is directly related to the weight of a product. Therefore, heavier products produce more postconsumer solid wastes. For the half-gallon milk containers, the glass milk container is the heaviest and so produces the highest weight of postconsumer solid waste by far. This includes a reuse rate of 8 times and a recycling rate of 15 percent. The HDPE bottle system weighs the least and includes a 29 percent recycling rate, and so produces the least amount of postconsumer solid waste by weight.

Landfills fill up because of volume, not weight. While weight is the conventional measure of waste, landfill volume is more relevant to the environmental concerns of land use. The problem is the difficulty in deriving accurate landfill volume factors. There are a number of factors that contribute to the uncertainty of these results, including landfill moisture and landfill compaction. However, Franklin Associates has developed a set of landfill density factors for different materials based upon an extensive sampling by the University of Arizona[3]. While these factors are considered to be only estimates, their use helps add valuable perspective. Volume factors are estimated to be accurate to +/- 25%. This means that waste volume values must differ by at least 25 percent in order to be interpreted as a significant difference.

Although the glass system does produce a greater amount of solid waste by weight, the crushed glass itself is inert within a landfill. Because the glass has a very high density, the volume of the postconsumer solid waste for the glass system is actually lower than the other container systems. However, the postconsumer solid waste by volume for the glass and gable top systems cannot be considered significantly different. The PLA bottle system has the highest postconsumer solid waste by volume. The landfill density of paperboard cartons is higher than the plastic bottles as the paperboard can easily be crushed flat. The landfill density of the two plastic bottles is the same. However, the HDPE bottle includes recycling which subtracts from the amount being disposed in a landfill.

Environmental Emissions

Atmospheric and waterborne emissions for each system include emissions from processes and those associated with the combustion of fuels. Table 5 presents atmospheric emissions emitted, and Table 7 shows waterborne emissions released for the use of 10,000 milk containers. Table 6 gives a greenhouse gas summary for each of the systems analyzed.

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. No firm conclusions can be made from the various atmospheric or waterborne emissions that result from the product systems. The atmospheric and waterborne emissions shown here represent systems totals and are not separated by life cycle stage or process and fuel-related emissions.

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[3] **Estimates of the Volume of MSW and Selected Components in Trash Cans and Landfills**. Franklin Associates, Ltd., Prairie Village, KS and The Garbage Project, Tucson, Arizona. February, 1990.

Table 5

Atmospheric Emissions of Half-Gallon Milk Containers
(lb per 10,000 half-gallon milk container uses)

	PLA Bottle System	Gable Top Carton System	Glass Bottle System	HDPE Bottle System
Atmospheric Emissions				
dust (PM10)	16.0	8.45	0.46	0.28
CO	17.8	18.3	16.6	6.74
CO2	4,997	3,998	5,013	2,787
SOX as SO2	24.0	32.2	25.9	39.9
H2S	0.0016	0	0	0
mercaptan	5.5E-06	0.081	0.0068	3.1E-05
NOX as NO2	29.1	23.2	26.5	8.14
NH3	0.0104	0.12	0.012	0.0079
Cl2	2.6E-04	0.028	2.2E-05	9.9E-05
HCl	0.81	0.68	0.23	0.39
F2	1.6E-07	0	0	0
HF	0.035	0.12	0.028	0.048
hydrocarbons not specified elsewhere	3.40	3.92	1.25	1.24
aldehyde (-CHO)	0.0054	0.21	0.024	0.016
organics	0.12	0.14	0.0070	0.015
Pb+compounds as Pb	2.5E-05	0.0017	2.2E-04	1.5E-04
Hg+compounds as Hg	5.0E-06	4.1E-04	6.3E-05	3.0E-05
metals not specified elsewhere	0.0014	0.62	5.2E-04	2.6E-04
H2SO4	2.1E-05	0	0	0
N2O	0.59	0.42	0.11	0.061
H2	0.48	2.2E-04	1.3E-04	0.0010
dichloroethane (DCE) C2H4Cl2	3.2E-07	9.9E-06	1.3E-06	6.2E-09
vinyl chloride monomer (VCM)	5.2E-06	0	0	0
CFC/HCFC/HFC not specified elsewhere	6.4E-05	1.6E-04	1.2E-04	6.5E-05
organo-chlorine not specified elsewhere	0.016	5.8E-09	3.5E-09	2.8E-08
CH4	31.8	11.5	14.1	21.2
aromatic HC not specified elsewhere	0.0016	0.0015	3.6E-05	3.5E-05
polycyclic hydrocarbons (PAH)	1.0E-06	9.1E-06	4.0E-06	6.6E-06
NMVOC	0.69	0.60	1.45	1.15
methylene chloride CH2Cl2	2.1E-05	0.0044	1.5E-04	1.2E-04
Cu+compounds as Cu	7.4E-07	1.3E-06	1.0E-04	7.4E-07
As+compounds as As	2.3E-05	5.1E-04	9.9E-05	1.4E-04
Cd+compounds as Cd	4.3E-06	1.1E-04	3.4E-05	2.7E-05
Zn+compounds as Zn	3.5E-06	8.7E-07	4.9E-06	4.9E-07
Cr+compounds as Cr	1.6E-05	4.3E-04	8.1E-05	9.8E-05
Se+compounds as Se	6.7E-05	6.4E-04	0.017	4.2E-04
Ni+compounds as Ni	9.4E-05	0.0026	0.0010	4.9E-04
Sb+compounds as Sb	1.4E-06	1.2E-04	3.7E-06	5.8E-06

Table 5 (cont'd)

Atmospheric Emissions of Half-Gallon Milk Containers
(lb per 10,000 half-gallon milk container uses)

	PLA Bottle System	Gable Top Carton System	Glass Bottle System	HDPE Bottle System
Atmospheric Emissions				
dioxin/furan as Teq	4.0E-09	2.4E-05	2.2E-08	1.2E-08
benzene C6H6	0.0045	0.11	0.064	0.037
toluene C7H8	0.0068	0.039	0.093	0.056
xylenes C8H10	4.0E-03	0.023	0.054	0.033
ethylbenzene C8H10	5.2E-04	0.0030	0.0072	0.0043
styrene	6.1E-10	6.2E-06	7.9E-07	3.9E-09
propylene	3.2E-04	8.6E-04	1.5E-04	2.7E-04
Fe+compounds as Fe	3.6E-06	0	0	0
Co+compounds as Co	1.1E-05	2.8E-04	8.5E-05	6.0E-05
V+compounds as V	1.9E-05	0	0	0
Al+compounds as Al	-0.0065	0	0	0
B+compounds as B	8.1E-06	0	0	0
Manganese	3.2E-05	0.023	1.6E-04	1.8E-04
Molybdenum	1.6E-07	0	0	0
Corn dust	0.12	0	0	0
Tin	7.9E-07	0	0	0
Titanium	1.6E-07	0	0	0
Barium	5.5E-04	0	0	0
Beryllium	1.2E-06	2.5E-05	8.1E-06	7.3E-06
Bromine	6.6E-06	0	0	0
Cyanide (unspecified)	1.5E-06	6.2E-04	7.9E-05	3.9E-07
Fluoride (unspecified)	4.6E-06	0.011	0.0014	2.7E-05
Helium	6.0E-04	0	0	0
VOC (volatile organic compou	3.9E-04	0	0	0
Dust (PM 2.5)	0.024	0	0	0
Dust (unspecified)	0.30	3.73	57.4	1.18
Ethanol	0.72	0	0	0
Lactic acid	0.0014	0	0	0
Particles (< 2.5 um)	-0.033	0	0	0
Particles (> 10 um)	-0.40	0	0	0
Particles (<10 and > 2.5 um)	-0.36	0	0	0

Source: Franklin Associates, a Division of ERG calculations using original data from LCI/LCA by NatureWorks, LLC, the Franklin Associates database, and the U.S. LCI Database.

Due to the use of two different models, Franklin Associates modified its list of emissions to match the Boustead model list to the extent possible. In Tables 5 and 7, there are emissions where only the PLA system shows values. For those emissions, it may be true that only the PLA system produces those emissions (e.g. lactic acid in Table 5) or it is possible that the Boustead model's fuel pollutants contain emissions not included in the Franklin Associates model (e.g. dissolved chlorine in Table 7).

The atmospheric emissions shown for the PLA bottle system in Table 5 and the waterborne emissions for the PLA bottle system shown in Table 7 are, in a few cases, magnitudes apart from the other systems. As two different models were used, there are bound to be differences in the results. Some of the reasons for this are differences in methodology, data sources, and actual differences in the emissions from diverse processes.

This analysis is not an LCIA (life cycle impact assessment) and thus the impacts of various environmental emissions are not evaluated. However, due to the scientifically accepted relationship between greenhouse gases and global warming, it is reasonable to develop conclusions based on the quantity of greenhouse gases generated by a system. Greenhouse gas emissions are expressed as carbon dioxide equivalents, which use global warming potentials developed by the International Panel on Climate Change (IPCC) to normalize the various greenhouse gases to an equivalent weight of carbon dioxide. The 100-year time horizon Global Warming Potentials for GHG was used for this analysis.

In Table 6, the HDPE bottle system produces the least amount of carbon dioxide equivalents. More than 90 percent of the carbon dioxide equivalents comes from fuel-related emissions. Even though 95 percent of the HDPE system's total energy is from fossil fuels, the energy of material resource amount produces no carbon dioxide equivalents as the fuels are never combusted. The PLA and glass bottle systems are not considered significantly different and produce the greatest amount of carbon dioxide equivalents. In the case of the glass bottle system, this is mostly from fuel-related carbon dioxide due to the heavy weight of the container and the use of fossil fuels. The carbon dioxide equivalent amounts for the glass bottle and gable top carton systems are less than 25 percent different and so are not considered significantly different. The carbon dioxide equivalent amount for the PLA bottle system is considered greater than that of the gable top carton system.

Table 6

Greenhouse Gas Summary for Half-Gallon Milk Containers
(lb carbon dioxide equivalents per 10,000 half-gallon milk container uses)

	PLA Bottle System	Gable Top Carton System	Glass Bottle System	HDPE Bottle System
Fossil carbon dioxide (CO_2)	4,997	3,998	5,013	2,787
Nitrous oxide (N_2O)	177	125	33.1	18.3
Methane (CH_4)	795	288	352	531
Total	5,968	4,411	5,398	3,336
Carbon Dioxide from incineration (1)	40	25	73	600
Total including CO_2 from incineration	6,009	4,436	5,471	3,936

Note: The 100 year global warming potentials used in this table are as follows: fossil carbon dioxide--1, nitrous oxide--298, and methane--25.
(1) The carbon dioxide shown here is the theoretical maximum fossil carbon dioxide from incineration of the petrochemical-based plastics within the systems.

Source: Franklin Associates, a Division of ERG calculations using original data from LCI/LCA by NatureWorks, LLC, the Franklin Associates database, and the U.S. LCI Database.

Table 7

Waterborne Emissions of Half-Gallon Milk Containers
(lb per 10,000 half-gallon milk container uses)

	PLA Bottle System	Gable Top Carton System	Glass Bottle System	HDPE Bottle System
Waterborne Wastes				
COD	9.51	7.91	1.11	1.94
BOD	1.80	31.5	0.63	1.14
Pb+compounds as Pb	4.2E-04	0.0014	0.0022	0.0025
Fe+compounds as Fe	0.132	0.37	0.56	0.57
Na+compounds as Na	10.6	34.1	53.9	69.3
acid as H+	0.0027	0.0046	0.0091	0.0046
NO3-	1.91	3.0E-04	2.6E-04	4.9E-04
Hg+compounds as Hg	5.6E-07	5.4E-04	2.7E-06	2.5E-06
metals not specified elsewhere	3.09	18.0	42.8	25.8
ammonium compounds as NH4+	0.0026	1.2E-04	1.0E-04	2.0E-04
Cl-	24.3	85.5	170	75.6
CN-	8.6E-07	4.5E-07	3.8E-07	4.9E-07
F-	0.0066	2.0E-03	0.0017	3.2E-03
S+sulphides as S	2.4E-05	7.5E-05	1.0E-04	7.0E-05
dissolved organics (non-hydrocarbon)	8.5E-04	0	0	0
suspended solids	6.78	11.6	9.93	7.34
detergent/oil	0.020	0.073	0.11	0.14
hydrocarbons not specified elsewhere	0.0026	4.7E-04	9.4E-04	0.0013
organo-chlorine not specified elsewhere	3.2E-06	1.3E-07	2.1E-07	2.7E-07
dissolved chlorine	2.8E-06	0	0	0
phenols	4.6E-04	0.0016	0.0025	0.0032
dissolved solids not specified elsewhere	41.1	279	236	303
P+compounds as P	0.019	0	0	0
other nitrogen as N	0.13	0	0	0
other organics not specified elsewhere	0.0028	0.0085	0.014	0.016
SO4--	0.34	0.44	0.55	0.82
vinyl chloride monomer (VCM)	1.6E-07	0	0	0
K+compounds as K	0.0019	0	0	0
Ca+compounds as Ca	3.16	10.8	17.0	21.9
Mg+compounds as Mg	0.58	2.10	3.32	4.28
Cr+compounds as Cr	0.0014	0.0046	0.0069	0.0063
ClO3--	1.0E-04	0	0	0
BrO3--	4.7E-07	0	0	0

Table 7 (cont'd)

Waterborne Emissions of Half-Gallon Milk Containers
(lb per 10,000 half-gallon milk container uses)

	PLA Bottle System	Gable Top Carton System	Glass Bottle System	HDPE Bottle System
Waterborne Wastes				
TOC	2.48	0.0061	0.014	0.0093
AOX	3.2E-07	0.082	0	0
Al+compounds as Al	0.040	0.13	0.23	0.071
Zn+compounds as Zn	0.0012	0.0065	0.0059	0.0057
Cu+compounds as Cu	2.1E-04	7.2E-04	0.0011	0.0012
Ni+compounds as Ni	2.1E-04	7.3E-04	0.0011	0.0013
CO3--	4.1E-04	0	0	0
As+compounds as As	2.3E-04	8.2E-04	0.0013	0.0016
Cd+compounds as Cd	3.4E-05	1.2E-04	1.9E-04	2.3E-04
Mn+compounds as Mn	0.0016	0.0089	0.0079	0.011
Ag+compounds as Ag	0.0019	0.0070	0.011	0.014
Ba+compounds Ba	0.70	2.28	3.45	3.23
Sr+compounds as Sr	0.050	0.18	0.29	0.37
V+compounds as V	2.5E-05	9.1E-05	1.4E-04	1.8E-04
benzene	0.0015	0.0056	0.0089	0.011
dioxin/furan as Teq	2.2E-07	7.9E-07	1.1E-06	2.9E-06
Mo+compounds as Mo	2.1E-05	7.7E-05	1.2E-04	1.6E-04
Ca++	0.39	0	0	0
PO4(-3)	3.8E-04	0	0	0
Chromium +III	1.2E-05	0	0	0
Chromium +IV	7.9E-07	0	0	0
Heavy metals unspecified	0.49	2.09	3.47	5.84
Selenium	1.7E-05	6.2E-05	6.6E-05	9.6E-05
Titanium	4.8E-04	0.0015	0.0023	0.0021
Chlorine dissolved	7.9E-06	0	0	0
Fluorine	1.9E-06	0	0	0
Neutral salts	4.0E-05	0	0	0
halogenated organics	7.4E-04	5.5E-06	8.3E-06	7.8E-06

Source: Franklin Associates, a Division of ERG calculations using original data from LCI/LCA by NatureWorks, LLC, the Franklin Associates database, and the U.S. LCI Database.

SENSITIVITY ANALYSIS

Within the scope and boundaries of this analysis, there are a number of variables within this case study. These include the weights of the glass bottles, the reuse rate of the glass bottles, inclusion of EMR for the corn in PLA, and use of percent difference when comparing the PLA system with the others.

Glass Bottle Weights

The weight of the glass bottle is an average from the weighing of two glass bottles (different milk producers) by Franklin Associates staff. These bottle weights were taken from glass dairy bottles within the Kansas City area. Both local dairies purchased these bottles from the same glass bottle producer in Ontario, CA. Although the difference between these bottle weights is less than 1 percent, it is possible that dairies in other U.S. areas are using lighter or heavier glass bottles for their milk.

Due to this possibility, a sensitivity analysis has been performed on the weights of the glass bottles. A 10 percent increase and decrease in the glass bottle weight have been considered in this analysis. The following figures show the results from the main analysis using the report glass bottle weight, as well as the results for the increased and decreased weights. Figures 6, 7, and 8 show the total energy, postconsumer (PC) solid waste by volume and the greenhouse gases for 10,000 half-gallon milk containers.

Figure 6. Total Energy for Milk Containers with a 10 Percent Difference in the Glass Bottle Weight
(MM Btu per 10,000 half-gallon milk containers)

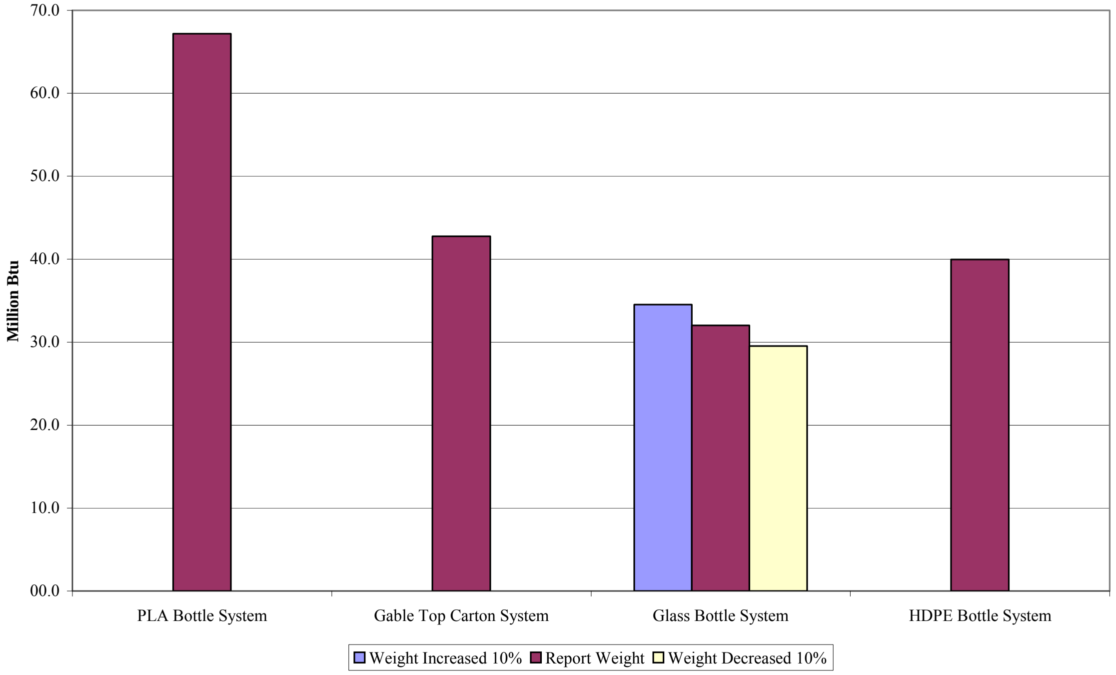


Figure 6 shows the total energy range for the refillable glass bottle system with a 10 percent increase and decrease in bottle weight. Although the total energies of the glass bottle and HDPE bottle systems are closer with an increased glass bottle weight, none of the report conclusions change.

It was decided that no sensitivity analysis was needed for the ranges for the postconsumer solid waste by weight since the glass bottle system results in the report were 3 times higher than all other systems.

Figure 7 shows the PC solid waste by volume range for the refillable glass bottle system with a 10 percent increase and decrease in bottle weight. In the report, the PC solid waste volumes of the gable top and glass systems were considered equivalent; however, when the glass weight is decreased by 10 percent, the PC solid waste volume of the glass bottle system is considered significantly less than that of the gable top carton system.

Figure 8 shows the total carbon dioxide equivalents range for the refillable glass bottle system with a 10 percent increase and decrease in bottle weight. In the report, the total carbon dioxide equivalents of the PLA and glass systems were not considered significantly different. This is still true if the glass weight is increased or decreased. If the glass weight is decreased, the carbon dioxide equivalents for the glass bottle is not considered significantly different from the gable top carton systems.

Glass Bottle Reuse Rate

This analysis assumes that the return rate for the glass milk bottles is 90 percent, and the reuse rate is 8 times. These estimates are meant to represent an average of all milk producers using glass bottles. Each individual milk producer may have higher or lower rates than those used in this analysis. A sensitivity analysis has been performed using 11.9 reuse trips, which is equivalent to a return rate of 95 percent, by the glass bottle. Figures 9, 10, and 11 show the total energy, total solid waste by weight and the greenhouse gases for 10,000 half-gallon milk containers.

Figure 7. Postconsumer Solid Waste by Volume for Milk Containers with a 10 Percent Difference in the Glass Bottle Weight (Cubic Feet per 10,000 half-gallon milk containers)

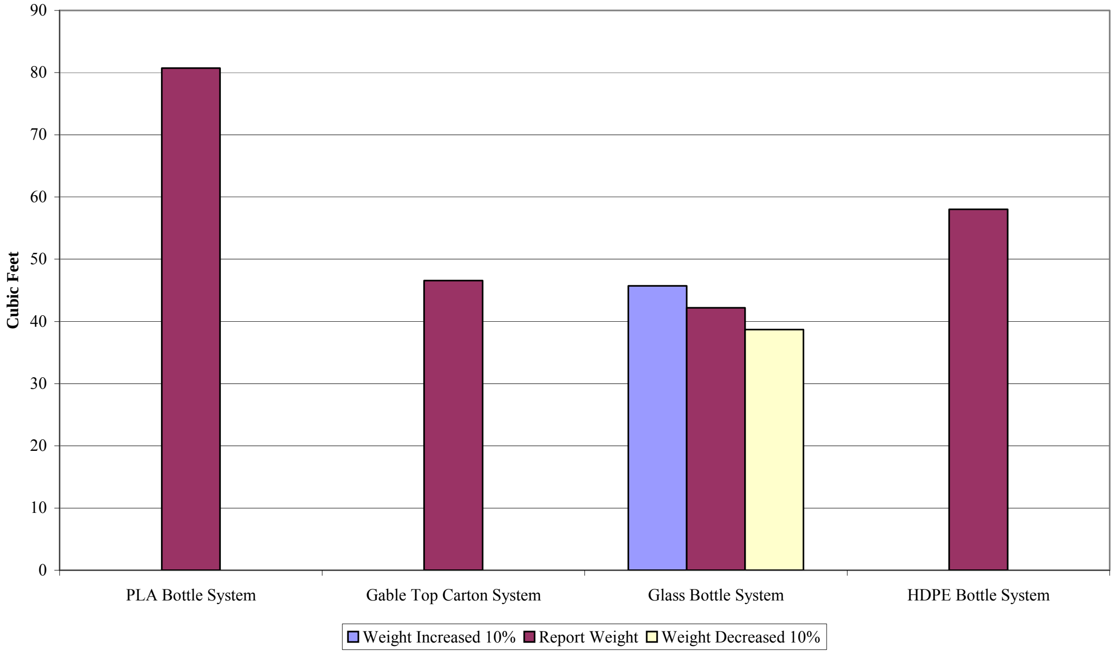


Figure 8. Total Carbon Dioxide Equivalents for Milk Containers with a 10 Percent Difference in the Glass Bottle Weight (Pounds of CO^2 equivalents per 10,000 half-gallon milk containers)

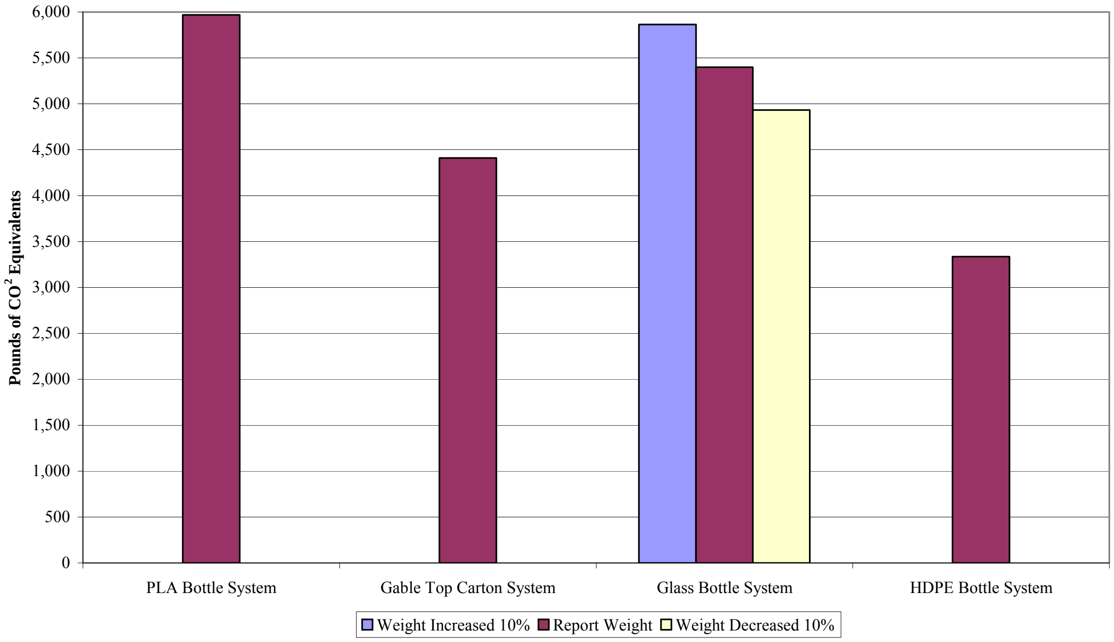


Figure 9. Total Energy for Milk Containers Using a 95 percent Reuse Rate with a Trip Rate of 11.9 for the Refillable Glass Bottles (MM Btu per 10,000 half-gallon milk containers)

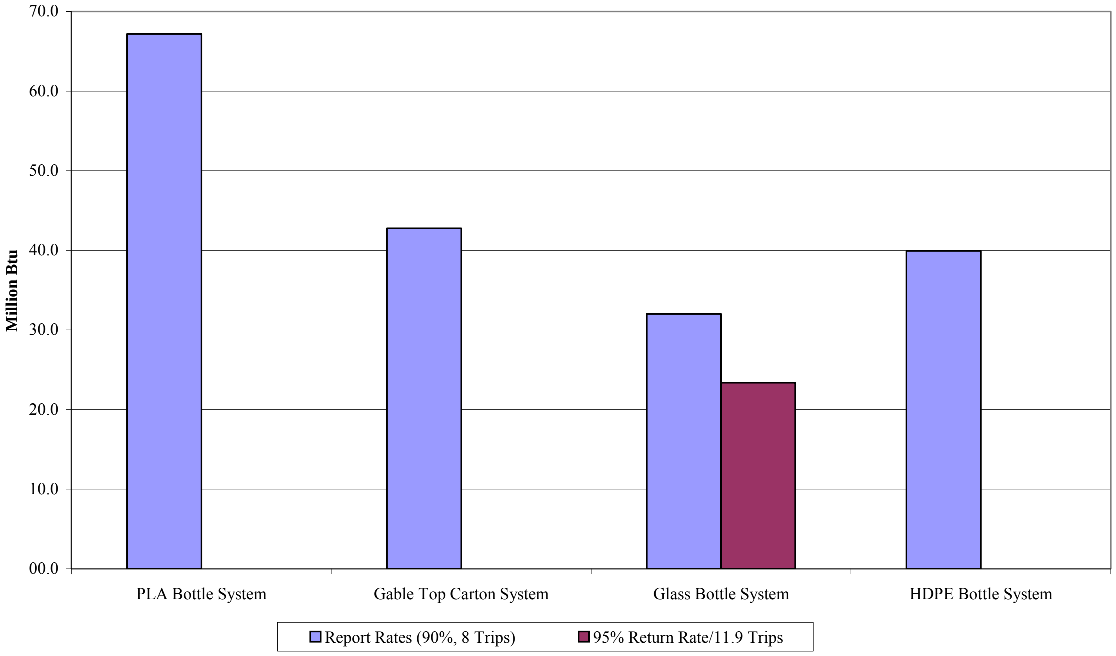


Figure 9 shows the total energy range for the refillable glass bottle system using a 95 percent reuse rate with a trip rate of 11.9. As the glass bottle system already required the least total energy, no conclusions change.

It was decided that no sensitivity analysis was needed for the ranges for the postconsumer solid waste by volume since the glass bottle system results in the report were already lower than all other systems.

Figure 10 shows the postconsumer solid waste by weight range for the refillable glass bottle system using a 95 percent reuse rate with a trip rate of 11.9. In the report, the glass bottle system produced the greatest PC solid waste weight. Although the weight of the PC solid waste is smaller, no conclusions change with a 95% reuse rate and 11.9 trip rate.

Figure 10. Postconsumer Solid Waste by Weight for Milk Containers
Using a 95 percent Reuse Rate with a Trip Rate of 11.9 for the Refillable Glass Bottles
(Pounds per 10,000 half-gallon milk containers)

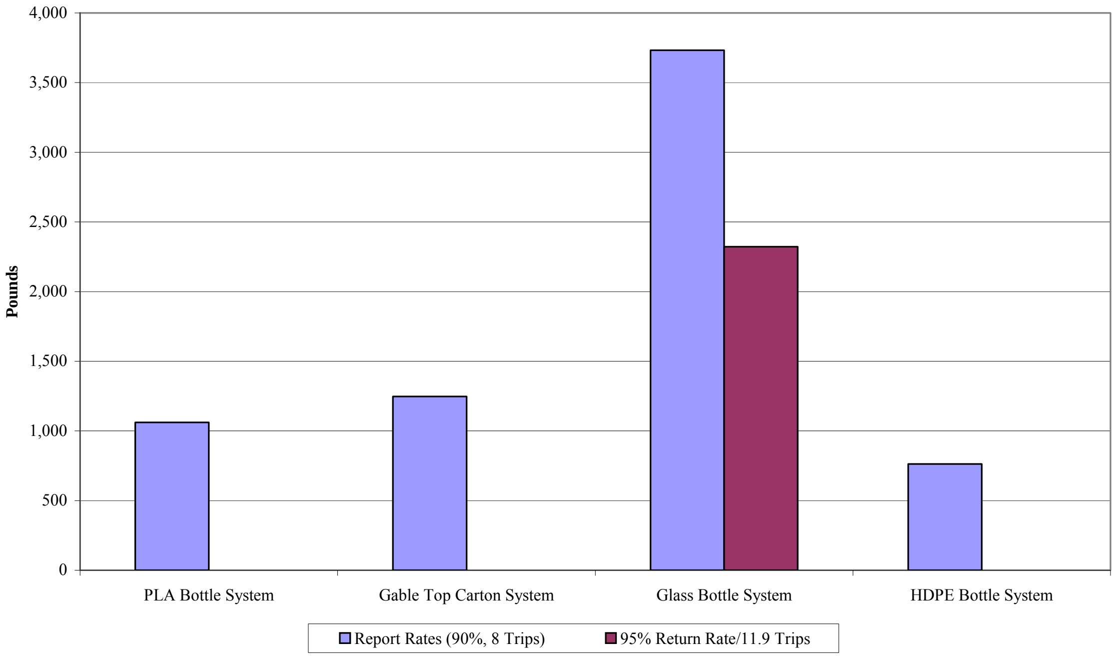
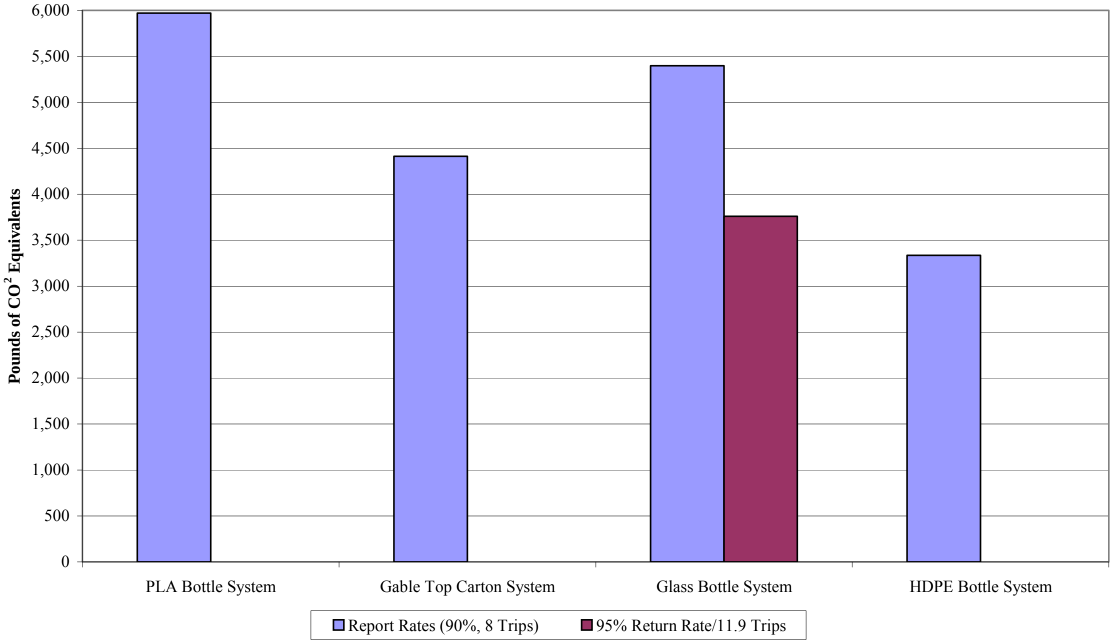


Figure 11 shows the total carbon dioxide equivalents range for the refillable glass bottle system using a 95 percent reuse rate with a trip rate of 11.9. In the report, the total CO2 equivalents of the glass bottle system were not considered significantly different than that of either the PLA bottle or gable top system. With a 95% reuse rate and 11.9 trip rate, the total CO2 equivalents of the glass bottle system are not considered significantly different than that of the gable top carton or HDPE bottle systems.

Figure 11. Total Carbon Dioxide Equivalents for Milk Containers
Using a 95 percent Reuse Rate with a Trip Rate of 11.9 for the Refillable Glass Bottles
(Pounds of CO^2 equivalents per 10,000 half-gallon milk containers)

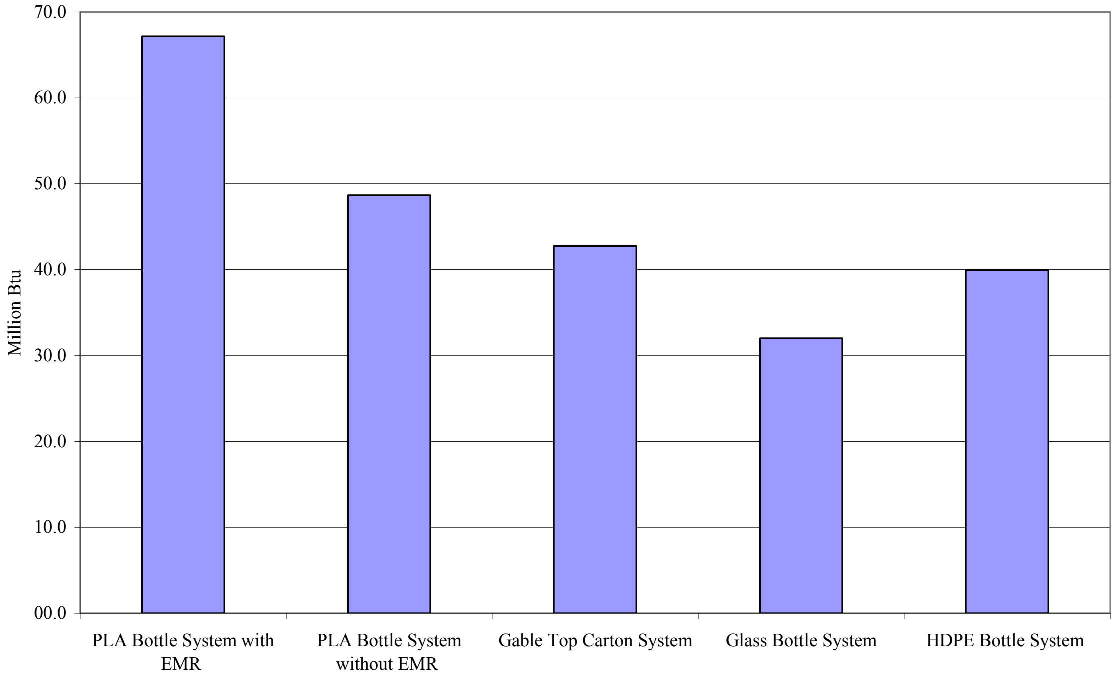


EMR for Corn in PLA Bottle

The inclusion or exclusion of corn feedstock energy is a methodology decision. As the U.S. government is now encouraging the use of corn as a fuel (ethanol), it can be argued that corn can be included as a feedstock energy. This is not a common practice for Franklin Associates; however, the corn feedstock energy was included to follow NatureWorks' basic approach and methodology. A sensitivity analysis has been performed on the total energy conclusions if energy of material resource (EMR) for the corn was excluded.

Figure 12 shows the total energy for 10,000 half-gallon milk containers. Without the energy of material resource, the total energy of the PLA system is 48.7 million Btu. The percent difference between the total energy of the PLA system without EMR and the gable top system is greater than 10 percent, and therefore the PLA system requires the greatest amount of total energy whether the EMR energy is included or not.

Figure 12. Total Energy for 10,000 Half-Gallon Milk Containers



Percent Difference Rule for PLA System Vs. Other Systems

The LCI dataset for the PLA resin was produced using the Boustead model, while all other systems in this analysis use the Franklin Associates model. In light of these differences, it is not clear whether the standard Franklin thresholds for significant differences (e.g., greater than a 10% difference in life cycle energy is significant) are appropriate without direct access to the Boustead model. However, we can compare the ACC Plastics LCI Database (using Franklin Associates' model) with the PlasticsEurope LCI Database (using Boustead's model). Although the raw data of these two databases are different, the results of the energy come to within 10 percent of each other in eight of the nine resins considered. In the comparison of the carbon dioxide equivalents for these two databases, the results for all resins are within 25 percent of each other. While performing these comparisons, it was noted that the largest differences were found when the methodology of the two databases differed. Besides the use of material resource energy for corn, no large methodological differences were found in the NatureWorks and Franklin Associates datasets.

The percent difference for the total energy, postconsumer solid wastes, and greenhouse gases for the PLA system and the other systems are shown in Table 8. The carbon dioxide equivalents of the PLA and glass bottle system are not considered significantly different within the report. The percent difference of the carbon dioxide equivalents for the gable top carton and PLA systems is 30 percent. This is the only percent difference in Table 8 that is close to the 25 percent boundary used for the emissions. If the gable top carton system is not considered significantly different from the

PLA system, then the PLA, glass, and gable top systems would be considered to produce the greatest amount of greenhouse gases, while the HDPE system would produce the least.

Table 8

Percent Differences for the PLA Milk Container System Versus the Remaining Milk Container Systems

	Gable Top Carton System	Glass Bottle System	HDPE Bottle System
Total Energy	44%	71%	51%
Postconsumer Solid Waste	54%	63%	33%
Total Greenhouse Gases	30%	10%	57%

Source: Franklin Associates, a Division of ERG

OVERVIEW OF FINDINGS

A life cycle inventory (LCI) is an environmental profile that expresses environmental burdens from the perspective of energy consumption, solid waste generation, atmospheric emissions, and waterborne emissions. This LCI evaluated four half-gallon milk containers on the basis of 10,000 container uses. The following is an overview of the findings with respect to energy consumption, postconsumer solid waste generation, and greenhouse gas emissions.

Energy Requirements

Energy is expended during all life cycle phases and includes the combustion of fuels for energy as well as the use of fossil fuels as raw materials (energy of material resource).

- Assuming current end-of-life scenarios, the PLA bottle system requires the most total energy to produce. The PLA bottle system does include energy of material resource for the corn used as a raw material. However, if the energy of material resource were not included in the PLA bottle system, the total energy would still be significantly greater than the other container systems’ total energy.
- The refillable glass bottle system requires the least amount of total energy. This is due to the reuse of the bottle 8 times over its life.

- The total energy for the HDPE bottle and gable top carton systems have a 7 percent difference, and therefore these milk containers are not considered significantly different.
- The net energy conclusions for the PLA and glass are identical to the total energy conclusions. The net energy amount for the HDPE bottle system is considered significantly less than that of the gable top carton system.
- The glass bottle system transport energy is 25 percent of its total energy. This is due in part to the heavier bottle weights, as well as the additional transport needed to reuse the bottles.

Postconsumer Solid Wastes

Solid waste can be measured in terms of weight and volume.

- When expressed on a *weight* basis, the postconsumer solid waste of the glass bottle system is more than 3 times higher than those of the other milk container systems. The HDPE bottle system weighs the least and includes a 29 percent recycling rate, and so produces the least amount of postconsumer solid waste by weight.
- When expressed on a *volume* basis, the postconsumer solid wastes of the PLA bottle system are the highest; while the postconsumer solid waste of the glass bottle system is the least. This is attributable to the high density of glass; a given weight of glass occupies significantly less volume than an equal weight of plastic or paperboard.
- Although the two plastic bottles have the same landfill density, the HDPE bottle system includes recycling, which subtracts from the amount being disposed in a landfill.

Greenhouse Gas Emissions

Greenhouse gas emissions are directly related to the combustion of fossil fuels, and thus an understanding of a system's fuel consumption profile allows an understanding of its greenhouse gas generation.

- The HDPE bottle system produces the least amount of carbon dioxide equivalents.
- The PLA and glass bottle systems are not considered significantly different and produce the greatest amount of carbon dioxide equivalents.

APPENDIX A

STUDY APPROACH AND METHODOLOGY

INTRODUCTION

The life cycle inventory presented in this study quantifies the total energy requirements, energy sources, atmospheric emissions, waterborne emissions, and solid waste resulting from the production and disposal of milk containers using polylactide (PLA) resin, glass, high-density polyethylene (HDPE), and gable top cartons. The methodology used for goal and scope definition and inventory analysis in this study is consistent with the methodology for Life Cycle Inventory (LCI) as described in the ISO 14040 and 14044 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 A-1 illustrates the general approach used in an LCI analysis.

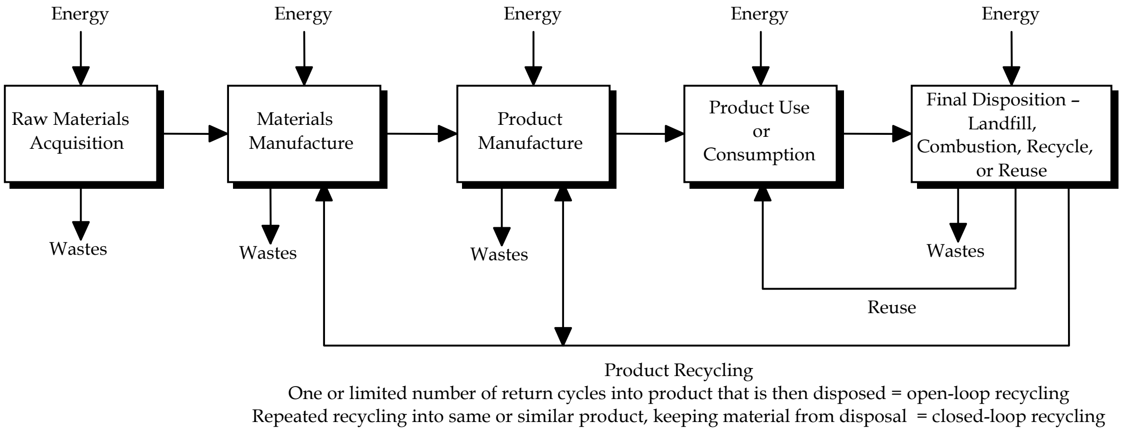


Figure A-1. General materials flow for “cradle-to-grave” analysis of a product

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.

GOAL OF THE STUDY

The goal of the milk container study is to explore the relationship between the weight and material composition of primary milk containers and the associated life cycle profile of each milk container. The report includes discussion of the results for the milk container systems, but does not make comparative assertions, i.e., recommendations on which containers are preferred from an environmental standpoint.

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 14044. 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.

In order to express the results on an equivalent basis, a functional unit of equivalent consumer use (10,000 containers, as all containers contain equivalent milk amounts) was chosen for this analysis.

System Boundaries

This cradle-to-grave LCI encompasses production of milk containers from raw material acquisition to end-of-life, rather than for a single manufacturing step or environmental emission. The boundaries of this LCI includes the following elements:

1. Production of the container materials (all steps from extraction of raw materials through the steps that precede container manufacture).
2. Manufacture of the container systems from their component materials.
3. Transport of package to filling (where necessary) and from filling to retail.
4. Postconsumer disposal, reuse, and recycling of the container systems.

Beginning with acquisition of initial raw materials from the earth, this study examines the sequence of processing steps for the production of the milk container systems. The secondary packaging, filling, storage, and consumer activities are outside the scope and boundaries of the analysis. The ink production and printing process is assumed to be negligible compared to the material production of each system.

The end-of-life scenarios used in this analysis reflect the current recycling rates of the containers studied. No composting has been considered in this analysis. HDPE and glass milk containers are commonly recycled, and so their end-of-life scenario includes a recycling rate.[4] The glass milk container also includes eight reuses before it is either recycled or disposed. The PLA containers do not have a recycling infrastructure currently set up; therefore no recycling has been considered in this analysis. Gable top cartons are recycled at a rate of approximately 1 percent[4]; therefore no recycling has been considered in this analysis.

LIFE CYCLE INVENTORY METHODOLOGY

Key elements of the LCI methodology include the study boundaries, resource inventory (raw materials and energy), and emissions inventory (atmospheric, waterborne, and solid waste). Although the PLA data used in this report originally comes from NatureWorks, LLC, all other processes are modeled and presented by Franklin Associates. Mr. Erwin Vink states in his journal paper that he uses Ian Boustead's LCI models and methodology. The Franklin Associates LCI methodology is described below.

Figure A-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.

For each process included in the study, resource requirements and environmental emissions are determined and expressed in terms of a standard unit of output. A standard unit of output is used as the basis for determining the total life cycle resource requirements and environmental emissions of a product.

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 pound, for each individual process included in the LCI. The purpose of the material balance is to determine the appropriate weight factors used in calculating the total energy requirements and environmental emissions associated with the materials used. Energy requirements and environmental emissions are determined for each process and expressed in terms of the standard unit of output.

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[4] Municipal Solid Waste in the United States, Facts and Figure 2005. U.S. Environmental Protection Agency. Office of Solid Waste, October, 2006. EPA-530-R-06-011. Found at http://www.epa.gov/epaoswer/non-hw/muncpl/pubs/mswchar05.pdf.

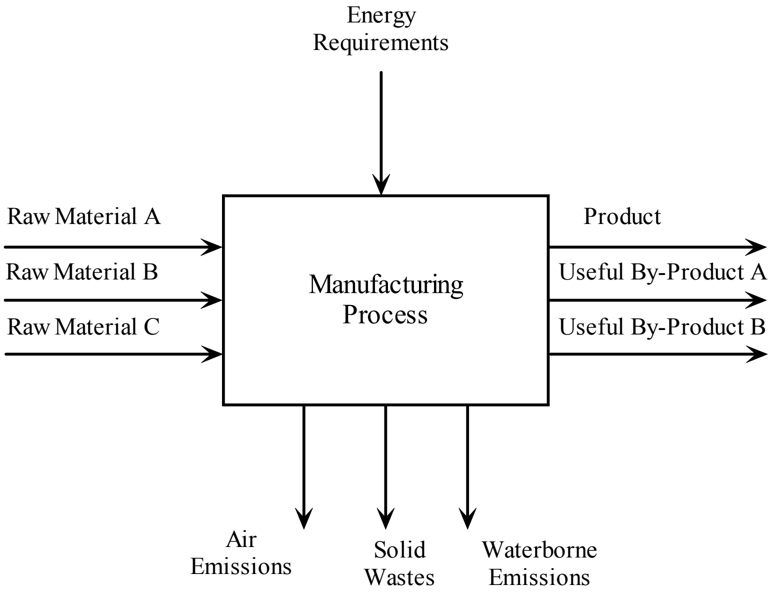

Figure A-2. "Black box" concept for developing LCI data

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 each product 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 process identified in the LCI 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. The fuel used to transport raw materials to each process is included as a part of the LCI energy requirements. Transportation energy requirements for each step in the life cycle 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 from their original units to an equivalent Btu value based on standard conversion factors.

The 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 labeled precombustion energy. For electricity, precombustion energy calculations include adjustments for the average efficiency of conversion of fuel to electricity.

The LCI methodology assigns a fuel-energy equivalent to raw materials that are derived from fossil fuels. Therefore, the total energy requirement for coal, natural gas, or petroleum-based materials includes the fuel-energy of the raw material (called energy of material resource or feedstock energy). In this study, this applies to the crude oil and natural gas used to produce the plastic resins. The NatureWorks LCI of PLA does give a feedstock energy value to the corn used as a raw material in PLA. Franklin Associates does not commonly assign a fuel-energy equivalent combustible materials, such as corn, that are not major fuel sources in this country.

Environmental Emissions

Environmental emissions are categorized as atmospheric emissions, waterborne wastes, and solid wastes and represent discharges into the environment after the effluents pass through existing emission control devices. Similar to energy, environmental emissions associated with processing fuels into usable forms (precombustion emissions) are also included in the inventory. When it is not possible to obtain actual industry emissions data, published emissions standards are used as the basis for determining environmental emissions.

The different categories of atmospheric and waterborne emissions are not totaled in this LCI because it is widely recognized that various substances emitted to the air and water differ greatly in their effect on the environment.

Atmospheric Emissions. These emissions include substances classified by regulatory agencies as pollutants, as well as selected nonregulated emissions such as carbon dioxide. For each process, atmospheric emissions associated with the combustion of fuel for process or transportation energy, as well as any emissions released from the process itself, are included in this LCI. Emissions are reported as grams of pollutant per the basis of each product. The amounts reported represent actual discharges into the atmosphere after the emissions pass through existing emission control devices. Some of the more commonly reported atmospheric emissions are: carbon dioxide, carbon monoxide, non-methane hydrocarbons, nitrogen oxides, particulates, and sulfur oxides.

Waterborne Wastes. As with atmospheric emissions, waterborne wastes include all substances classified as pollutants. Waterborne wastes are reported as grams of pollutant per the basis of each product. The values reported are the average quantity of pollutants still present in the wastewater stream after wastewater treatment and represent discharges into receiving waters. This includes both process-related and fuel-related waterborne wastes. Some of the most commonly reported waterborne wastes are: acid, ammonia, biochemical oxygen demand (BOD), chemical oxygen demand (COD), chromium, dissolved solids, iron, and suspended solids.

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, cornstalks returned to the field or forest residues left in the forest to decompose) are not reported as wastes.

DATA

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. Franklin Associates has developed a methodology for incorporating data quality and uncertainty into LCI calculations. Data quality and uncertainty are discussed in more detail at the end of this section.

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 diagrams. In this way, the flow diagram is revised to represent current industrial practices. Data suppliers are then contacted again to discuss the data, process technology, waste treatment, identify coproducts, and any assumptions necessary to understand the data and boundaries.

After each dataset has been completed and verified, the datasets for each process are aggregated 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. The provided process dataset and assumptions are then documented and returned with the aggregated data to each data supplier for their review.

At times, the scope or budget of an analysis do not allow for primary data collection. In this case, secondary data sources are used. These sources may be other LCI databases, government documents, or literature sources.

Confidentiality. Potential suppliers of data often consider the data requested in the worksheets proprietary. 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 unit 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 are 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.

Data Sources. Many of the process data sets 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. Data for the production of the plastics used in the milk containers were taken from the U.S. LCI Database, which includes plastics data from the ACC Plastics Division. Only the fabrication process data for the plastic bottles comes from the PlasticsEurope database, which is European data. The glass bottle and gable top carton LCI data comes from the Franklin Associates database using various sources including primary (collected) data.

Data for the production of the PLA resin were originally taken from Mr. Erwin Vink's draft journal article featuring LCI data as performed by NatureWorks in 2006. The drying data for the PLA resin were estimated from specification on the ConAir dehumidifying dryer, CD1600.

Fuel Data

When fuels are used for process or transportation energy, there are energy and emissions associated with the production and delivery of the fuels as well as the energy and emissions released when the fuels are burned. 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. For example, coal is crushed or pulverized and sometimes cleaned. Crude oil is refined to produce fuel oils, and "wet" natural gas is processed to produce natural gas liquids for fuel or feedstock.

To distinguish between environmental emissions from the combustion of fuels and emissions associated with the production of fuels, different terms are used to describe the different emissions. The combustion products of fuels are defined as "combustion data." Energy consumption and emissions that 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 model from which the energy requirements and environmental emissions for the production and combustion of process fuels are calculated.

Energy data are developed in the form of units of each primary fuel required per unit of each fuel type. For electricity production, federal government statistical records 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 U.S. federal government 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.

In 2003, Franklin Associates updated its fuels and energy database for inclusion in the U.S. LCI database. The U.S. LCI fuels and energy database is not used for the production of PLA resin. There are some differences between the Franklin Associates fuels database and the Boustead model, the fuel database used by NatureWorks. Electricity delivery losses are handled differently, as well as the different data sources.

Data Quality Goals for This Study

ISO standard 14044:2006 states that "Data quality requirements shall be specified to enable the goal and scope of the LCA to be met." Data quality requirements listed include time-related coverage, geographical coverage, technology coverage, and more.

All quality assurance procedures only apply to the Franklin Associates data. The data quality goal for this study is to use the best publicly available and most representative data for the materials used and processes performed in terms of time, geographic, and technology coverage.

In some cases, it was possible to achieve the intended data quality goals of the study in terms of current public data and geographic and technology coverage. The U.S. LCI database represents current U.S. plastics resin data. Mr. Vink's 2006 journal paper states that Boustead Consulting's model was used for the PLA LCI, using the MAPP U.S. regional grid for electricity.

All Franklin Associates' fuel data were reviewed and extensively updated in 2003 for the U.S. Electricity fuel sources and generation do meet all the data quality goals.

Data Accuracy

An important issue to consider when using LCI study results is the reliability of the data. In a complex study with literally thousands of numeric entries, 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.

A key question is whether the LCI profiles are accurate and study conclusions are correct. It is important that the environmental profiles accurately reflect the relative magnitude of energy requirements and other environmental burdens for the various materials analyzed.

The accuracy of an environmental profile depends on the accuracy of the numbers that are combined to arrive at that conclusion. Because of the many processes required to produce the products analyzed in this study, many numbers in the LCI are added together for a total numeric result. Each number by itself may contribute little to the total, so the accuracy of each number by itself has a small effect on the overall accuracy of the total. There is no widely accepted analytical method for assessing the accuracy of each number to any degree of confidence.

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. For example, changing the weight of an input to the fabrication of a product changes the amounts of the inputs to that process, and so on back to the quantities of raw materials.

In summary, for the particular data sources used and for the specific methodology described in this report, the results of this report are believed to be as accurate and reasonable as possible.

CRITICAL/PEER REVIEW

Critical review is specified in ISO standard 14040 as an optional component for LCI/LCA studies. The purpose is to verify that the study has met the requirements of the international standards for methodology, data and reporting. The review may be conducted by internal experts other than the persons performing the study, external experts, or by a review panel of interested parties.

Franklin Associates LCA staff has reviewed unit process data, models, and cradle-to-grave results internally. The study is also submitted to the client for critical review. A peer review by a three-person peer review panel was performed on this report as well.

METHODOLOGY ISSUES

There is general consensus among life cycle practitioners on the fundamental methodology for performing LCIs.[5] Franklin's methodology is consistent with the methodology outlined in the ISO standards. However, for some specific aspects of life cycle inventory, there is some minor variation in methodology used by experienced practitioners. The relevant areas for this report include the integration of results to Ian Boustead's energy and emissions categories, 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,

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[5] International Standards Organization. ISO 14040:2006 Environmental management—Life cycle assessment—Principles and framework, ISO 14044:2006, Environmental management – Life cycle assessment – Requirements and guidelines.

and the methodology used to allocate environmental burdens for postconsumer recycled content and end-of-life recovery of materials for recycling, and the methodology used to allocate environmental burdens for end-of-life recovery of materials for reuse. 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.

Integration of Results to Ian Boustead's Energy and Emissions Categories

Due to the fact that the PLA resin data used in this report comes from NatureWorks, which uses Ian Boustead's model, Franklin Associates used the energy, solid waste, and emissions categories as reported in the NatureWorks PLA Eco-Profile. These categories are described in the Methodology report for the PlasticsEurope database.

This eco-profile uses 4 categories to present energy requirements—energy content of delivered fuel, transport energy, feedstock energy, and fuel production and delivery energy. The following definitions are quotes from the Methodology report for the PlasticsEurope database. "*Energy content of delivered fuel* represents the energy that is received by the final operator who consumes energy. *Feedstock energy* represents the energy of the fuel bearing materials that are taken into the system but used as materials rather than fuels. *Transport energy* refers to the energy associated with fuels consumed directly by the transport operations as well as any energy associated with the production of non- fuel bearing materials, such as steel, that are taken into the transport process. *Fuel production and delivery energy* represents the energy that is used by the fuel producing industries in extracting the primary fuel from the earth, processing it and delivering it to the ultimate consumer."

Franklin Associates commonly uses 3 categories to present energy requirements—process energy, transportation energy, and energy of material resource. The "fuel production and delivery energy" used by Ian Boustead is usually contained within Franklin Associates' process and transportation energy categories. Franklin Associates considers this energy to be precombustion energy in our terms. In this analysis, Franklin Associates separated out the precombustion energy to be included as fuel production and delivery energy. Process energy is included in energy content of delivered fuel. Transportation energy is included in transport energy. Energy of material resource is included in feedstock energy.

Franklin Associates does not commonly include solid waste that is not actually *disposed* of in a type of landfill. The PLA Eco-Profiles uses an empirical system of reporting solid waste, which identifies the type of waste that is *generated.* This system includes some solid waste that Franklin Associates would not normally include as solid waste, such as waste to incinerator, waste returned to mine, and tailings. A category for postconsumer solid waste was also added to the solid waste categories list.

Franklin Associates used the PLA Eco-Profile list of atmospheric and waterborne emissions to limit the fuels emissions database available. The Franklin Associates fuels database has almost 200 emissions in it. To keep the fuel data sources comparable, Franklin Associates pared our fuels database to match the Boustead software fuels data list.

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"[6] or "partitioning"[7].

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 discussion among LCA researchers, and various methods of calculating this ratio are discussed in literature.[8,9,10,11,12]

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[6] 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.

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

[8] 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.

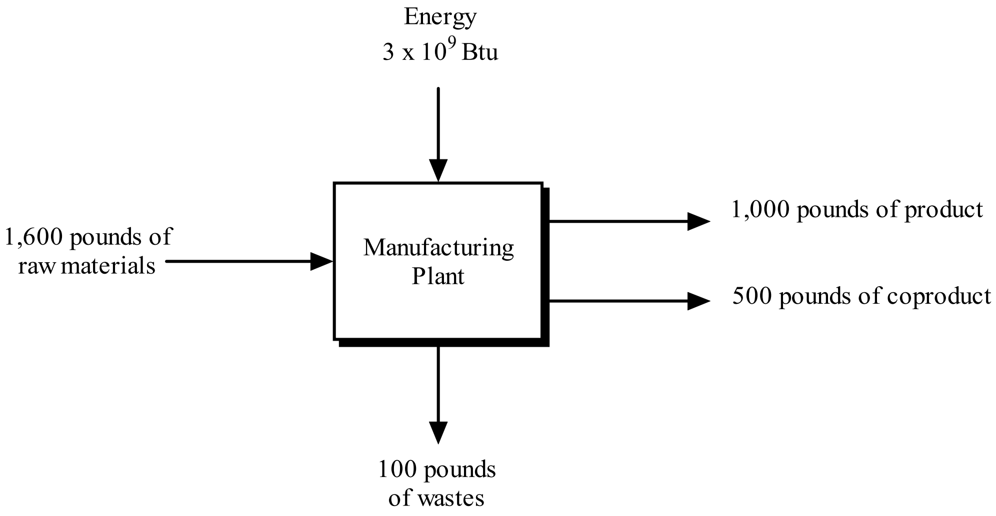
[9] Boustead, Ian. **Eco-balance Methodology for Commodity Thermoplastics.** A report for The Centre for Plastics in the Environment (PWMI). Brussels, Belgium. December, 1992.

[10] 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.

[11] **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.

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

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 A-3 illustrates the concept of coproduct allocation on a mass basis.



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

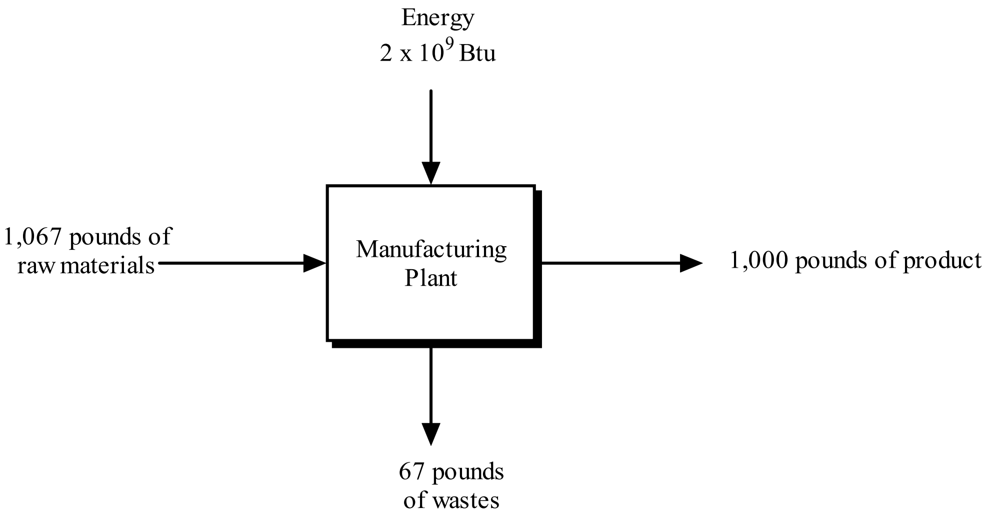


Figure A-3. Flow diagram illustrating coproduct mass allocation for a product.

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 A-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.

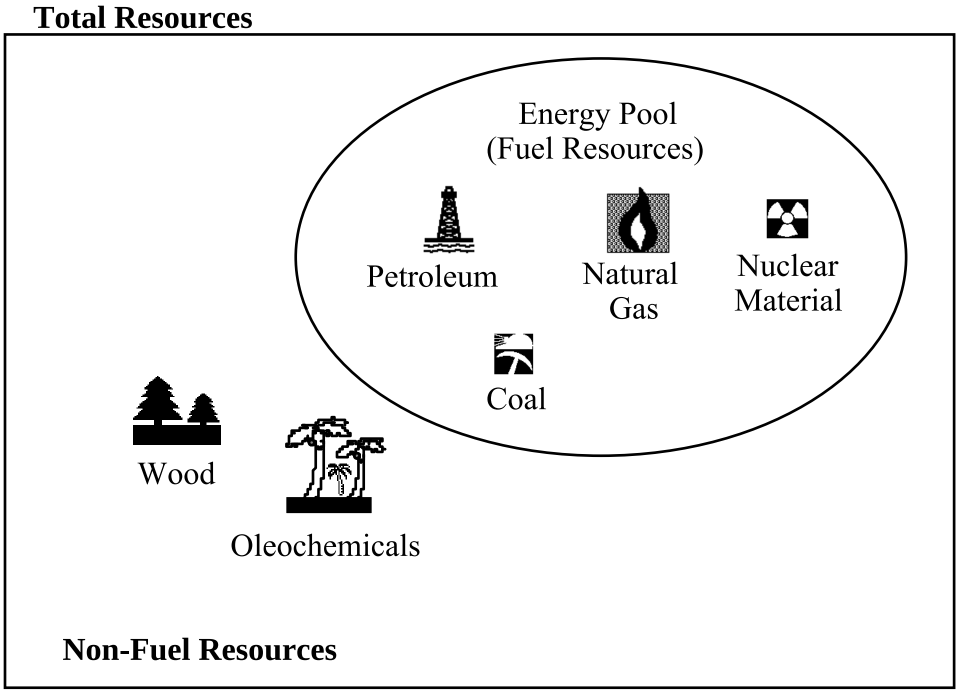


Figure A-4. Illustration of the Energy of Material Resource concept.

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.

The materials that 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. The use of corn to produce ethanol has increased in recent years. While it is estimated that approximately 14 percent of corn in the U.S. was grown specifically for fuel in 2006, the largest use of corn is still for food. 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.

NatureWorks has included an energy of material resource amount for the corn used in its PLA product. Franklin Associates has included this energy amount in the results; however, the conclusions of the energy results do not change if the energy of material resource for corn is excluded.

Recycling

Recycling is a means to reduce the environmental burdens for production of materials and to divert materials from the municipal solid waste stream at end of life. When recycling scenarios are included in LCI models, the environmental burdens are allocated among product systems based on the number of times a material is recycled as well as whether closed-loop or open-loop recycling occurs. This analysis allocates the burdens for virgin material production and end-of-life disposal 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. 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 and n is the number of times the material is recycled. Thus, (n+1) is the total number of useful lives of the material: initial use + recycled uses. For material that is recycled once, n=1; thus, the equation reduces to R/2, and half the recycling burdens are allocated to each useful life.

In this study, open-loop recycling was evaluated for the HDPE milk container at its average recycling rate of 29 percent. It was assumed that the HDPE in these containers are recycled only once.

The recycling of the glass milk containers is considered closed-loop recycling. As a material, glass can be recycled a large number of times before it becomes too brittle and eventually must be disposed. In closed-loop recycling, the number of recycling “loops” is assumed to be sufficiently large so as to make the virgin inputs and disposal negligible to the study. The average recycling rate for glass bottles in the U.S. is 15 percent.

Reuse

The modeling of the reusable glass bottle system in this analysis is based on a system operating at steady state. In order to initially establish a reusable container system, a supply of containers must be in place at various points throughout the system in order to ensure that a sufficient number of containers is circulating between the dairy, retail stores, and consumers' homes. In interpreting the results of this analysis, it is important to understand that the environmental burdens and costs associated with **establishing** the reusable bottle system are not included in this analysis. Once the system is established, however, each shipment of milk in reusable glass bottles is essentially withdrawing container **uses** from the established pool of containers. Thus, in this analysis the environmental burdens for the reusable glass bottle system are based on replacing the number of glass bottles "used up." This number is calculated based on the number of bottles of milk shipped, the percent of bottles that are returned by consumers for reuse, the lifetime trips for reused bottles, and the breakage rate.

This analysis assumes that 90% of reusable bottles are recovered and reused, with a 1% breakage rate during collection and washing, and 10% of the bottles are not returned by consumers. Bottles that are kept in circulation are assumed to be used 8 times during their life. Thus, the number of new bottles that must be added into the system each time a shipment of 10,000 bottles of milk goes out is: 1000 new bottles (to replace the 10% not returned) and 1/8 of a bottle for each of the 9000 returned bottles that are assumed to be reused 8 times during their life. The reused bottle number is scaled up by 1% to account for replacement of broken bottles.

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 energy.

It is recognized that the combustion of postconsumer products in waste-to-energy facilities produces atmospheric and waterborne emissions; however, these emissions are not included in this study. Allocating atmospheric and waterborne wastes from municipal combustion facilities to specific product systems is not feasible, due to the variety of materials present in combusted municipal solid waste. Theoretical carbon dioxide emissions from incinerated containers could be calculated based on their carbon content and assuming complete oxidation; however, this may not be an accurate representation of the results of mixed MSW combustion. Therefore, this analysis does not account for end-of-life carbon sequestration from landfilling materials, nor does it include greenhouse gas emissions from decomposition of materials in landfills or from combustion of postconsumer solid wastes in municipal mixed-waste incinerators.

Electricity Grid 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 U.S. average fuel consumption by electrical utilities is assumed in the Franklin Associates model.

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.

System Components Not Included

Unless otherwise stated in the PlasticsEurope methodology paper, the following components of each system are not included in this LCI study:

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. The energy and emissions associated with such capital equipment generally, for 1,000 pounds of materials, become negligible when averaged over the millions of pounds of product manufactured over the useful lifetime of the capital equipment.

Space Conditioning. The fuels and power consumed to heat, cool, and light manufacturing establishments are omitted from the calculations in most cases. For manufacturing plants that carry out thermal processing or otherwise consume large amounts of energy, space conditioning energy is quite low compared to process energy. Energy consumed for space conditioning is usually less than one percent of the total energy consumption for the manufacturing process. This assumption has been checked in the past by Franklin Associates staff using confidential data from manufacturing plants.

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 by weight of the net process inputs, are not included in the assessment. Omitting miscellaneous materials and additives helps keep the scope of the study focused and manageable within budget and time constraints. Additives such as plasticizers, stabilizers, etc. added to resins to adapt them for specific product applications were not included.

APPENDIX B

FLOW DIAGRAMS OF MATERIALS USED IN THIS ANALYSIS

This Appendix documents the materials and processes used to produce each major material used in this one-half gallon milk container system analysis. The flow diagrams are shown as cradle-to-gate (material). The flow diagrams included are shown in Figures B-1 through B-5 as listed below.

- PLA resin
- Bleached kraft paperboard
- Glass
- HDPE resin
- LDPE resin

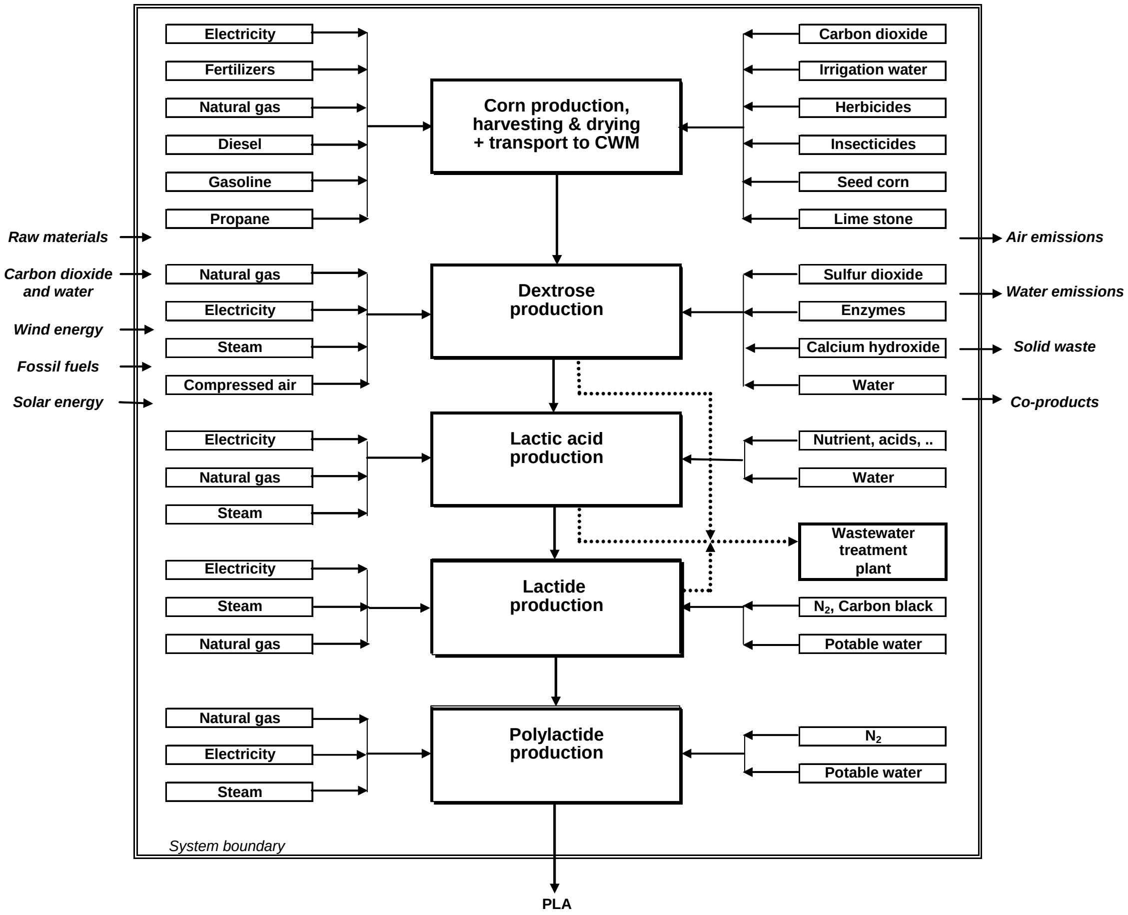


Figure B-1. Simplified flow diagram and system boundary for the NatureWorks PLA resin production system. This flow diagram was taken from the report, **Life Cycle Inventory of Five Products Produced from Polylactide (PLA) and Petroleum-Based Resins,** prepared by Franklin Associates for Athena Institute International. The original flow diagram comes from the 2006 draft journal paper provided by Mr. Erwin Vink of NatureWorks, LLC.

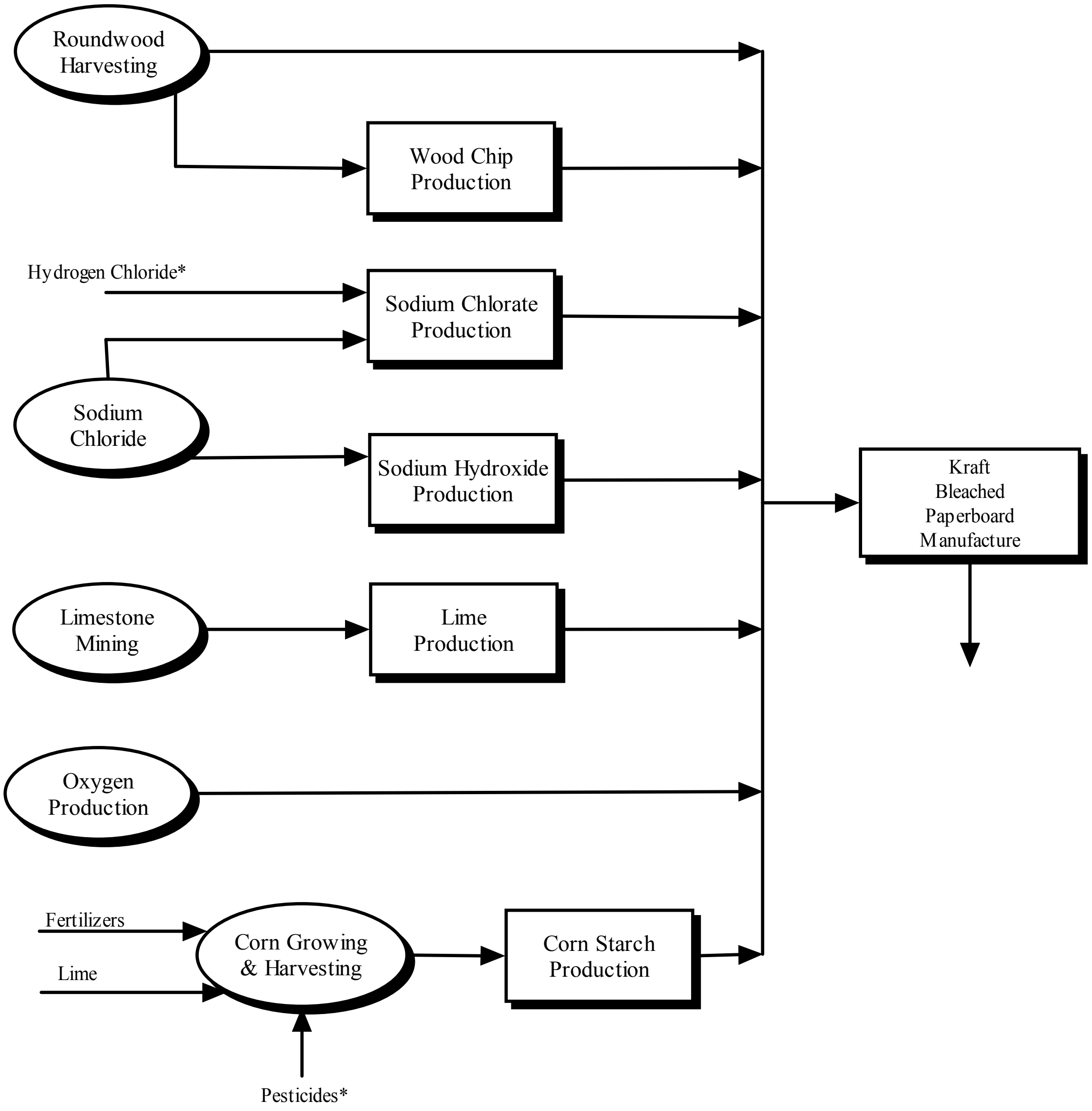


Figure B-2. Flow diagram for the manufacture of kraft bleached paperboard.
* These materials are considered negligible in the model.

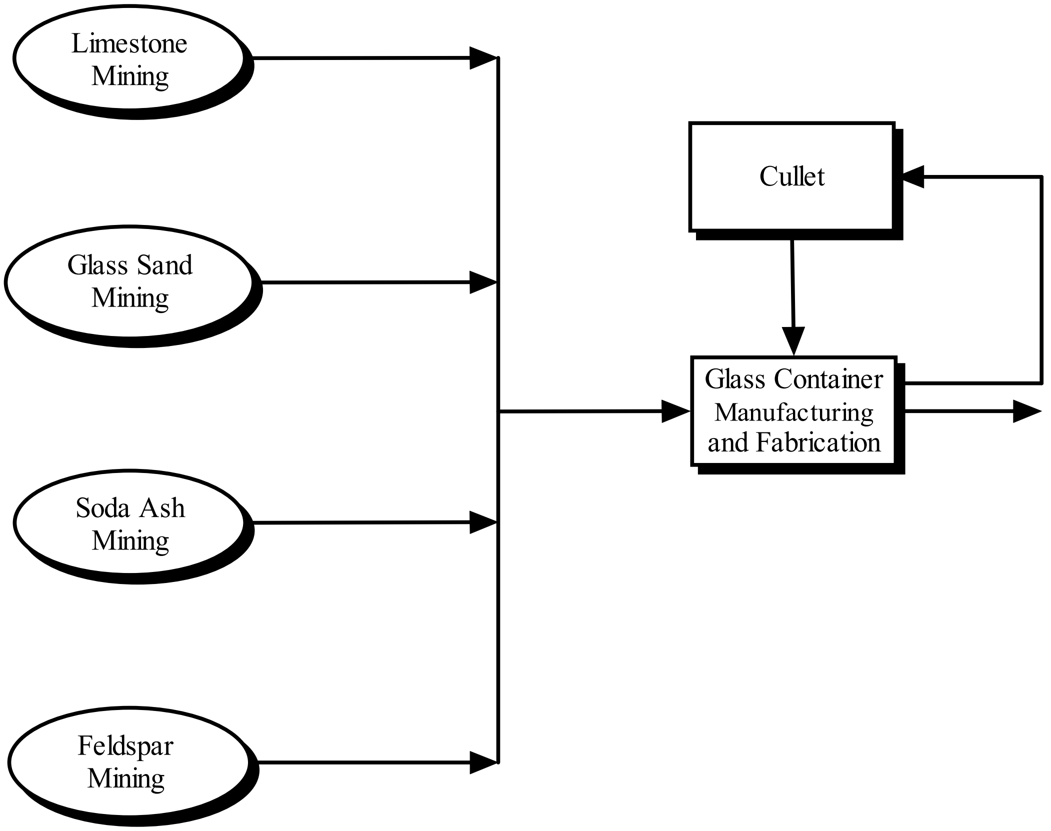


Figure B-3:Flow diagram for the manufacture of glass containers.

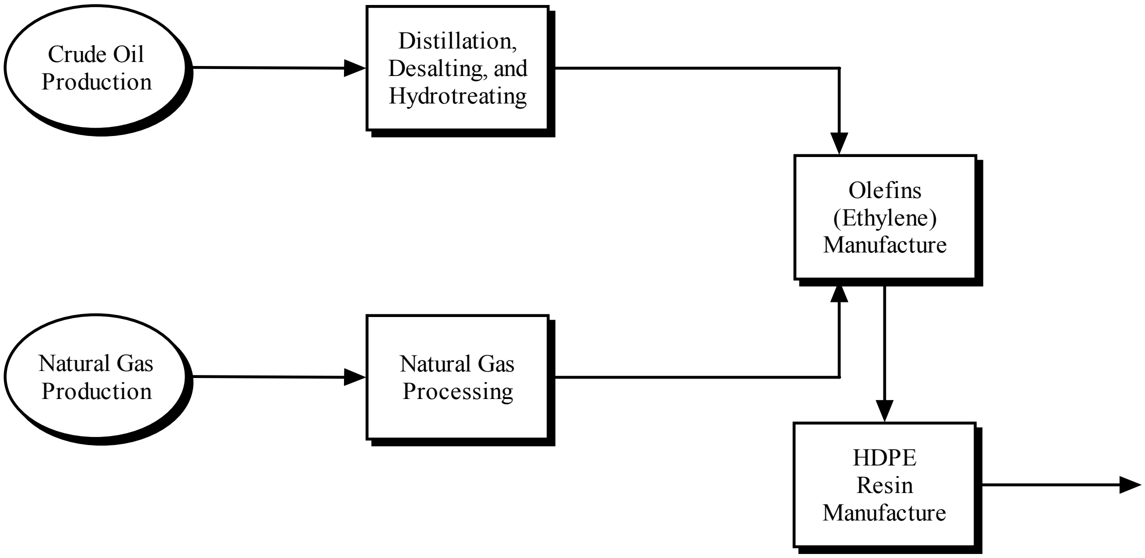


Figure B-4. Flow diagram for the manufacture of virgin high-density polyethylene (HDPE) resin.

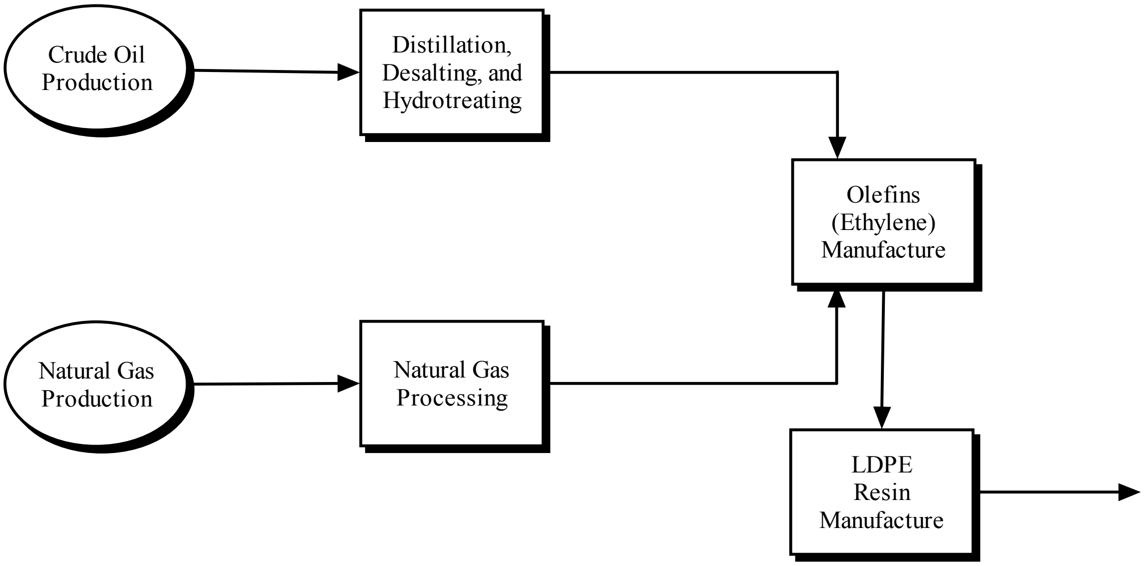


Figure B-5. Flow diagram for the manufacture of virgin low-density polyethylene (LDPE) resin.

APPENDIX C

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:

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

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 $\text{s'\%} = \frac{\text{s\%}}{\sqrt{\text{n}}}$, 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.

APPENDIX D

PEER REVIEW

The American Chemistry Council Plastics Division commissioned a peer review of the LCI of milk containers. The following comments were provided by a panel of three LCI experts. Franklin Associates' responses to these comments are shown in italics following the peer reviewers' comments.

PEER REVIEW

of

THREE LIFE CYCLE INVENTORY CASE STUDIES: MILK CONTAINERS, TUNA PACKAGING, and COFFEE PACKAGING

Prepared for

THE PLASTICS DIVISION of
THE AMERICAN CHEMISTRY COUNCIL
and
FRANKLIN ASSOCIATES, A Division of ERG

by

Dr. David Allen
University of Texas

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Private Consultant

July 23, 2008

SUMMARY

At the request of the American Chemistry Council (ACC) Plastics Division, a panel peer reviewed three life cycle inventory (LCI) case studies that were recently conducted by Franklin Associates, a Division of ERG. The studies were:

- "LCI Summary for Four Half-Gallon Milk Containers"—a PLA bottle, an HDPE bottle, a refillable glass bottle, and a gable-top paperboard carton.
- "LCI Summary for Six Tuna Packaging Systems"—a 12-oz. and a 6-oz. steel can, a 12-oz. and a 3-oz. PET/aluminum/nylon/PP laminate pouch, a multi-pack of three 3-oz. steel cans in a paperboard sleeve, and two 2.8-oz. PP plastic cups in a paperboard sleeve.
- "LCI Summary for Eight Coffee Packaging Systems"—a 15-oz. and a 26-oz. fiberboard/steel canister, an 11.5-oz. and 34.5-oz. steel can, an 11.5-oz. and 34.5-oz. HDPE canister, a 12-oz. bag and a 13-oz.brick of LLDPE/aluminum/PET laminate.

Since filling, storage, distribution, and consumer activities were assumed to be equivalent for all packages in each study, any secondary packaging other than that specified above was not included in the analyses. The reports examined the energy consumption, solid waste generation and emissions associated with each set of packaging.

In conformance with ISO 14044:2006 Section 6.3, the panel consisted of 3 external experts independent of the study. They work as private consultants and/or university professors and are familiar with LCI. Panel members were provided copies of the Executive Summaries and some appendices to review; detailed appendices were not included. They reviewed the studies against the following six criteria:

- Is the methodology consistent with ISO 14040/14041?
- Are the objectives, scope, and boundaries of the study clearly identified?
- Are the assumptions used clearly identified and reasonable?
- Are the sources of data clearly identified and representative?
- Is the report complete, consistent, and transparent?
- Are the conclusions appropriate based on the data and analysis?

Generally, the panel found the 3 LCI's to be well constructed, technically sound, and developed in accordance with ISO 14040 series documents. Although panel members did not replicate all of the calculations, they found that the analyses, in general, yielded results that seemed reasonable. The calculations, assumptions employed, and data analysis methods were, with minor exceptions, clearly and carefully described. The sources of data were generally well documented. Overall, the case studies met the high professional standards that life cycle assessment practitioners have come to expect from Franklin Associates.

While the peer reviewers did not question the calculations described in the reports, they did find some areas where additional explanations would be beneficial, and a few areas where the studies did not conform to ISO 14044 requirements. It should be noted that the panel was charged to review the studies against ISO 14040/14041. However, each report stated, “The methodology used…in this study is consistent with… ISO 14040 and 14044 Standard documents.” Therefore, the panel also reviewed the reports against the ISO 14044 Standard. Since the goals, scopes, and boundaries of all 3 studies were very similar, some of the panel’s findings were common to all 3 studies, while others were unique to a specific case study. Therefore, this report arranges the panel’s comments and findings accordingly.

Generic Findings

- One requirement of ISO 14044:2006 is the clear definition of the study goal. According to Section 4.2.2 that goal “shall…unambiguously” state “the intended application; the reasons for carrying out the study; the intended audience…whether the results are intended to be used in comparative assertions intended to be disclosed to the public.” The reports strongly imply that the case study goals are to make comparative assertions; however, this goal is not unambiguously stated.

  The goal for each case study will be unambiguously restated. The goal of the milk container study is to explore the relationship between the weight and material composition of primary milk containers and the associated life cycle profile of each milk container. The report includes discussion of the results for the milk containers, but does not make comparative assertions, i.e., recommendations on which packages are preferred from an environmental standpoint.

- Each LCI study explains, “Certain numbers do not stand alone, but rather affect several numbers in the system...Errors…that propagate throughout the system are more significant in steps that are closest to the end of the production sequence. For example, changing the weight of an input to the fabrication of a container changes the amounts…back to the quantities of raw materials.” The choice of container weights studied can significantly affect study results. Variation in container weight can occur for several reasons. (1) Normal statistical variation in a process can account for relatively small changes. (2) Different companies and even different regional plants within a single manufacturer can use slightly different processes which affect container weight to a greater degree. (3) In an effort to reduce cost, many companies lightweight their packages through use of new technologies. A container manufacturing plant’s age or where it is in its company’s cycle of overhaul/retrofit can significantly affect the weight of the packages it produces. An analyst needs to develop a sampling plan to collect data on a sufficiently large enough number of containers to account for such variation. No sampling plan details were provided in the reports; almost no sample sizes were included. The mention on page 7 of the Milk Container LCI of only 2 refillable glass bottles’ being weighed is of concern.

  For the study goal of exploring relationships between package weight and composition and associated environmental profiles, a representative weight and composition of each package was sufficient for this purpose. These case studies were based on the 2007 ULS report, **A Study of Packaging Efficiency as it Relates to**

Waste Prevention. *However, in some of the cases, some common packaging systems were not represented in the report. Where weights were available in the ULS study, they were used. When packaging systems were not represented, samples were collected and weighed. These samples were limited to those available within the Kansas City area.*

Further, ISO 14044:2006, Section 4.2.3.6 states, "Where a study is intended to be used in comparative assertions intended to be disclosed to the public, the data quality requirements stated…shall be addressed." These data quality requirements include: time-related coverage/age of data, geographical coverage, technology coverage, and representativeness (degree to which data set reflects true population of interest). These areas are not addressed in the report as to container weights.

The data quality requirements for container weights have been added to each case study in the Systems Studied section.

- ISO 14044:2006, Section 4.5.3.3 states, "When an LCA is intended to be used in comparative assertions intended to be disclosed to the public, the evaluation element shall include interpretive statements based on detailed sensitivity analyses." Sensitivity analyses of certain key factors, such as container weights, recycling rates, and refillable glass bottle trippage rates were not included in these reports.

  A Sensitivity Analysis section has been added to each case study.

- The most unusual assumption in all these LCI's is to ignore secondary packaging. It is not clear why this assumption was made, and it is possible that, for at least some of the systems examined, differences in secondary packaging will cause differences in the findings. This possibility is noted qualitatively on page 21 of the Tuna Packaging report. At a minimum, the studies should describe the rationale for making this assumption, and provide quantitative data on the magnitude of secondary packaging contributions in previous LCI's of food packaging systems. In addition, the studies should revisit the assumption regarding what constitutes a significant difference (e.g., 10% difference in total life cycle energy is, in the present reports, assumed to constitute a significant difference) given the added uncertainty of ignoring secondary packaging.

  The secondary packaging of these systems was outside the scope of these case studies. This has been stated in each case study. The ACC Plastics Division was interested in whether there is a correlation in the life cycle profile of the individual packages focusing on their weights and materials. Inclusion of the secondary packaging would obfuscate the answer to this question.

- Steel cans are included in both the Coffee and Tuna Packaging LCI's. Reports for both studies state, "The steel can…systems of this analysis are assumed to be recycled once…at their average recycling rate of 62 percent. The steel cans were also modeled with 33 percent closed-loop recycled content.…open-loop recycling was used because the steel will likely be used in an automotive or construction application, and therefore unavailable for recovery/recycling for a long period of time…the energy and emissions of virgin material…are divided evenly between the first and second product." If the cans are assumed to have 33% recycled content, why is some (if not all) of that content assumed to come from recycled cans? Assuming open loop recycling penalizes the steel package. At least a sensitivity analysis of this assumption should be included in the reports.

This comment pertains to the Coffee and Tuna Packaging LCIs only and is answered in the Peer Review Appendix of those case studies.

- A key assumption made in each report is that emissions of greenhouse gases from waste management cannot be reliably estimated, and are therefore not included in the analyses. The authors document their reasoning in making this assumption in Appendix A. While this reasoning is sound for methane releases from landfills, the reasoning behind ignoring the carbon dioxide emissions from waste combustion is not as clear. Is it because the authors assume that there may be segregation of the waste prior to combustion (e.g., energy recovery only from yard wastes)? Some additional clarification would be useful. Taking energy credits for post-consumer waste combustion with energy recovery, then not counting the greenhouse gas emissions from that activity is an inconsistent approach.

  We agree that carbon dioxide emissions should be estimated if energy recovery is also estimated, and we are currently developing models that will allow us to do so in future LCIs. These have been added in the assumptions and results in each case study.

- "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." Why isn't the carbon dioxide from methane combustion inventoried?

  Although we recognize that natural gas flaring may occur at onshore oil extraction sites, no data were available to quantify the amount of natural gas flared, and no emission factors were available for flaring operations. Further research in this area might improve the data quality.

- The labels on steel coffee and tuna packaging are assumed separated from the steel and disposed through the general 80% landfill/20% incineration waste stream. However, don't some, if not many, labels remain on the cans until they are melted for recycling? If so, don't the labels serve as fuel for the furnace? Also, since some consumers replace lids to containers before recycling them, some HDPE lids on steel coffee cans may reach the furnace as fuel for steel recycling.

  This comment pertains to the Coffee and Tuna Packaging LCIs only and is answered in the Peer Review Appendix of those case studies.

- The scope of each LCI should be clarified. The reports are not clear as to whether the scope includes the transportation of the empty packages from the manufacturer to the filling plants? A bullet on page 7 of the Coffee Packaging LCI appears to indicate this transportation step was not included. Differences in packaging system weight can influence transportation energy requirements of empty containers to fillers and shipment of filled containers to retailers. Weight differences in secondary packaging will have an additional impact on transportation energy.

  An assumption has been added to the Limitations and Assumptions section of each case study stating the transportation amounts used from the packaging plant to the filling plants, where applicable.

- In the Coffee and Tuna Packaging LCI's, a key assumption is one that has been made in previous Franklin Associates Life Cycle Inventories (LCI). "No fuel-energy equivalent (EMR) is assigned to combustible materials such as wood that are not major fuel sources in this country." This convention was recommended in the US EPA LCI Guidance Manual. It has been true, and continues to be true, that wood has not been a major component of the fuel supply system in the United States for many decades. However, growing initiatives in deriving fuel ethanol from cellulosic sources may change this situation and the authors should reconsider this assumption in future analyses. Making this assumption, while at the same time accounting for the EMR of corn used for the PLA resin in the Milk Container LCI, represents an inconsistency in approach that may influence the results.

  It is true that this is a methodology difference between Franklin Associates and NatureWorks. An energy table clearly identifies the EMR assigned to the plastic and PLA systems. A discussion has been added to the Results section of the milk container LCI about the differences in conclusions if EMR is not included for corn.

- "Based on the uncertainty in the data used for energy, solid waste, and emissions modeling, differences between systems are not considered meaningful unless the percent difference between systems is greater than the following 25 percent for industrial solid wastes and for emissions data." These values are based on the judgment of the analyst. Uncertainty ranges for air and water pollutant emissions data can be significantly higher.

  Many of the water and air pollutants that are shown in minute amounts are based on emission factors from the manufacture and combustion of fuels. In our experience, these would likely have a higher uncertainty range than even the 25 percent that we state. In addition, as we state in our Considerations for Interpretation of Data and Results appendix, "[Emissions] Data reported by similar plants may differ by a factor of two, or even a factor of ten or higher in some cases." Because of these uncertainties in many emissions categories, we typically limit our emissions analysis to greenhouse gases.

- The global warming potential (GWP) values used in this study were developed in 2001. Updated values have been reported in the IPPC's AR4.

The GWP values have been updated in each case study.

- A GWP value of 1700 was used for CFC's/HCFC's. There is a wide range of values for this class of greenhouse gases; how was the 1700 value determined?

  Due to the fact that this is an uncertain value and the results values for the CFCs/HCFCs and methylene chloride were less than 1 percent of the total greenhouse gas equivalent totals in all systems, these were removed from the GHG totals for each system. The 1700 value was a Franklin Associates estimate based on the major HCFCs and HFCs used in industry.

- One panel member does not support the recycling allocation method used, and would prefer use of the EPA LCI Guidance Manual (1993) allocation method 2. This method indicates that if the original product is recycled the solid waste burden for that product is reduced by the amount of waste diverted from the disposal phase. The product system that uses the recycled material picks up the burdens for processing of the secondary material but avoids virgin material production burdens. The panel member feels that burdens should be allocated equally to a material that has been down-cycled.

  It is noted that the peer review panel member recommends a different allocation method for recycling. However, the chosen methodology for recycling has been clearly described and is within the guidelines of the ISO Standards. Franklin Associates prefers to use a methodology that allocates virgin material production burdens and postconsumer disposal burdens among all the useful lives of the material. In this approach, each system using the material bears some share of the burdens for producing and disposing of the material. Each system shows reductions in both virgin material production burdens and postconsumer disposal burdens as a result of recycling. The more times the material is recovered and recycled, the lower the burdens assigned to each system using the material. This approach does require some assumptions about previous and future recovery and recycling of the material in order to determine the total number of useful lives used for the allocation calculations.

  The reviewer's preferred recycling methodology is easier from an accounting standpoint, as it draws distinct boundaries between each useful life of the material and focuses only on the current application; however, in this approach the first useful life is charged with all the virgin material production burdens and the last useful life is charged with all the disposal burdens, while interim systems using the material are not charged with production or disposal burdens, only collection and reprocessing burdens. This approach seems to unduly penalize the first and last systems.

- "Volume factors are estimated to be accurate to +/- 25 percent. This means that waste volume values must differ by at least 25 percent in order to be interpreted as a significant difference." There are many other factors that contribute to uncertainty in the solid waste results in addition to the uncertainty in the volume factors.

It is true that there are a number of factors that contribute to the uncertainty of the solid waste by volume results. A sentence has been added to stress this point in the Solid Waste section of the results.

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- Waterborne wastes include chromium. There are significant differences in toxicity between chromium (III) and chromium (VI).

  Chromium emissions are listed with "unspecified" in parentheses. This is because many data sources did not distinguish between chromium III and chromium IV. Where information was available, the two are reported separately. As noted by the reviewer, this distinction is important because of toxicity differences. However, toxicity differences are taken into account in the impact assessment phase of LCA. This analysis is limited to an LCI and does not include impact assessment.

- Material production burdens have the greatest influence on the results. Because detailed material production inventory data were not provided for this review, it is difficult to comment on the accuracy of the results.

  This is noted. The budget of these case studies did not allow for a detailed appendices. Where needed, I have added the sources for the data under the Assumptions/Limitations section, as well as the Data Sources section of the Methodology appendix.

Milk Container LCI

- The report states, "This analysis is being released to ensure the public that plastic packaging is a viable alternative for everyday consumer products". This is a biased goal statement. The study goal should be to investigate the environmental performance of plastic packaging; the study results will determine the environmental performance relative to the alternatives.

  The goal for the milk container LCI case study will be unambiguously restated. The goal of the study is to explore the relationship between the weight and material composition of primary packages and the associated life cycle profile of each package. The report includes discussion of the results for the packages within each case study application but does not make comparative assertions, i.e., recommendations on which packages are preferred from an environmental standpoint.

- Implicit in the report is the assumption that the 4 container systems chosen are representative of milk containers. It is not clear why the half-gallon size was chosen. Was it because of market share? Also, why were PET milk containers not also included in the analysis? The rationale for the selection of the four containers chosen should be provided.

  These case studies were based on the 2007 ULS report, **A Study of Packaging Efficiency as it Relates to Waste Prevention.** *In the case of the milk containers, the largest number of container types is given for the ½ gallon size in the 2007 ULS* *report. In the Kansas City area grocery stores, a ½ gallon glass bottle was available as well. No ½ gallon PET milk containers were found within the Kansas City market. PET was found in the pint and gallon sizes of milk, but these are outside the scope of this analysis.*

This reasoning will be included in the assumptions.

- Both implicit and explicit in the report is the assumption that comparisons can be made between container systems that were analyzed with the Franklin Associates database and container systems analyzed with the Boustead data. While these are both well established databases for performing life cycle inventories, there are significant differences. The report highlights the different ways in which emission and energy data are aggregated in the two databases, but in addition, the Boustead data is primarily European, while the Franklin Associates data are North American. In light of these differences, it is not clear whether the standard thresholds for significant differences (e.g., greater than a 10% difference in life cycle energy is significant) are still appropriate. The report would be improved if comparisons between the Franklin and Boustead databases, performed for the same product systems, were discussed.

  Though Boustead's database includes primarily European data, he does include U.S. fuels and electricity data. NatureWorks has used U.S. data for the main processes in producing PLA. This U.S. data includes their own plant data, as well as secondary data for corn growing. Other process chemicals were from EcoInvent, which contains primarily European data, but these would likely be a small part of the results. A sensitivity analysis has been added considering the possibility of a larger percent difference between the results of the PLA milk container and the other milk containers.

- On page 37 the report states, "This analysis assumes that 70% of reusable bottles are recovered and reused…and 30% of the bottles are not returned by consumers. Bottles that are kept in circulation are assumed to be used 8 times during their life. Thus, the number of new bottles that must be added into the system each time a shipment of 10,000 bottles of milk goes out is: 3000 new bottles (to replace the 30% not returned) and 1/8 of a bottle for each of the 7000 returned bottles that are assumed to be reused 8 times during their life." This discussion is very confusing. If 30% of the refillable bottles are not returned by consumers each time, less than 50% of the original bottles will still be in use after 2 trips (70% return X 70% return). A 30% loss rate doesn't result in an average 8 trips over a container's life; it results in an average life of about 2 trips. At this low trippage the refillable glass bottle would be heavily penalized in the study analyses.

  The panelist is correct that this trip and loss rate are not possible. This is an error, which has been corrected. A 90% reuse rate with 8 trips was specified by one of the dairies using refillable glass bottles. The other dairy contact had a much lower resuse rate, which seems to be an anomaly within the refillable glass dairy market. Within *the report, all references to the reuse and trip rates have been changed to 90% reuse and 8 trips. The results have also been changed for the refillable glass bottle throughout the report.*

- The report is not clear on whether the refillable glass bottles are sold through a store or through home delivery. Nor is it clear in what part of the world the glass bottles are being used. In traditionally refillable bottle markets, such as parts of Europe, trippages much higher than 8 would probably be achieved. Further, in home delivery situations higher trippages might also be achieved.

  Only milk containers sold through grocery and retail stores are considered in this analysis. This has been added to the assumptions. The market considered in the milk container study is the Kansas City area. However, most of the U.S. milk container market areas include some glass containers by small or medium size milk producers. This has also been added to the assumptions. It is possible that other market areas would have higher trip rates for glass milk containers; therefore, scenarios including higher trip rates and lower loss rates for the glass milk containers have been included in the added sensitivity analysis.

- The report should also specify that the glass bottle is a refillable container and give more detail on why 8 trips were selected for the bottle to be studied.

  A sentence will be added in the Systems Studied section specifying that the glass bottle is refillable. The trip number was selected after discussions with the two milk producers in the Kansas City market using glass containers. The added sensitivity analysis includes a scenario using 16 trips for reuse. A glass bottle producer claims that the ink on the bottle will last through 35 washes.

- "The PLA resin has been given feedstock energy in the NatureWorks report—most of this feedstock energy represents the corn used as raw material. It is true that the use of corn as a fuel (ethanol) has been increasing over the past few years. Franklin Associates does not commonly assign a fuel-energy equivalent to combustible biomass materials, such as corn, that are not major fuel sources in this country. However, the corn feedstock energy was included to follow NatureWorks' basic approach and methodology." The feedstock energy for the paperboard in the gable top container is not included in the inventory. This is inconsistent with the accounting for PLA. Also, non-fossil energy from the use of biomass wastes is included for paperboard production but the feedstock energy is not counted.

  The inclusion or exclusion of corn feedstock energy is a methodology decision. As the U.S. government is now encouraging the use of corn as a fuel (ethanol), it can be argued that corn can be included as a feedstock energy. According to an article[13] *in the Environmental Science and Technology Journal, in 2006, 14 percent of the U.S. corn crop was used as ethanol. This is not the case with wood used in paperboard; it*

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[13] Miller, Shelie A., **Amy E. Landis**, Thomas L. Theis (2007). "Environmental Tradeoffs of Biobased Production." *Environmental Science & Technology*, **41** (15) pp 5176-5182.

is not common in the U.S. for trees to be grown specifically for fuel. Energy of material resource is only given to materials used as a feedstock for a product that are commonly used as fuels in the U.S. energy pool. By using the material as a feedstock, the total energy pool is decreased. The added sensitivity analysis includes a comparison of the results if no corn feedstock energy is included in the PLA milk container results.

Separately, the biomass wastes used as fuel in the paper industry are counted as process energy. These biomass wastes are not a feedstock; they are combusted for energy in the paper industry.

- PLA product will not influence the carbon sequestered in landcovers and soils. Recent publications (Fargione, et al., Science, 319, 1235 (2008); Searchinger, et al., *Science*, 319, 1238 (2008)) have indicated that changes in landcovers, and the associated carbon sequestration associated with those landcovers, associated with corn-growing can be substantial. While it is likely beyond the scope of the present analysis to consider these greenhouse gas implications of the landcover changes associated with corn growing, the report should explicitly state that these processes are neglected.

  These issues are beyond the scope of the milk container LCI analysis; however, this issue will be added to the limitations section.

- The report assumes filling, storage, distribution, and consumer activities are equivalent for all containers. However, if the refillable glass bottles are sold through home delivery, these activities are not equivalent. Refrigerated distribution then point-of-sale, and transportation to distribution centers then retail stores don’t exist in home delivery. Conversely, pick-up and washing are unique to refillable glass bottles.

  Further, differences in shelf area requirements due to differences in non-refillable container size will impact refrigeration energy demand.

  Home delivery was not considered in this analysis. This has been added to the limitations section. The report has been edited to say, “The secondary packaging, filling, storage, and consumer activities are outside the scope and boundaries of the analysis.”

- Why were only 1% of gable top cartons assumed recycled? This number seems very low. Haven’t other studies assumed at least 5% of aseptic packages were recycled?

  According to the EPA MSW report, it is unlikely that more than 1 percent of the gable top cartons would be recycled. Five percent is a common recycling rate for aseptic packages; however, it is unknown whether gable top cartons are recycled with the aseptic packages. Also, the 5 percent may not represent the gable top cartons as well *as the aseptic packages. A footnote reference for the recycling rate of the gable top cartons is now included in the report.*

- There should be a scrap rate for packaging containers during manufacturing. Was this assumed to be zero? If so, it should be stated. Also, it does not appear that fabrication scrap losses are accounted for. This needs to be addressed.

  All scrap rates are now shown in the assumptions section for each container.

- The report states, "Transportation from the PLA resin producer to the product fabrication are
  - 96 ton-miles by combination truck, and
  - 96 ton-miles by rail."

  What are the weight(s) shipped and the distance(s)? Is there more than one supplier for the PLA?

  All transport assumptions will be restated to include the distance per weight shipped.

- "HDPE milk containers are assumed to be blow molded at the filler. This is commonly done at large dairy plants, which service a 2-3 state region. HDPE resin is commonly produced in the Texas/Louisiana area." Was the transportation requirement estimated for shipping resin from Texas to dairy plants across the country and then averaged?

  The transportation was estimated using an average distance from the Houston area to an estimated midpoint of the eastern U.S., the western U.S., and the U.S. Midwest. This will be included in the assumptions section.

- On-page 4, Figure 3 shows 17% of post consumer glass goes to incineration; at later stages of the report, it is made clear that there is only a very small energy credit given for this flow, and that the credit is due to combustion of the caps. If the glass is really being fed to incinerators, however, it may be that this should become an energy sink due to the inefficiencies associated with the glass being heated then cooled.

  The 17 percent of glass going to incineration was due to the estimated 20 percent of all mixed solid waste sent to waste-to-energy facilities in the U.S. Most likely the glass bottles would be broken and not separated for recycling. In this case, there would be energy inefficiencies due to the heating of the glass. The WTE credit calculations that Franklin Associates includes in our reports are calculated using the higher heating values of the materials incinerated. This is an estimated credit amount that when converting to electricity would take into account a number of inefficiencies in the waste stream (e.g. glass, aluminum, wet trash). However, these inefficiencies are not taken into account in our raw energy estimates.

- Page 5, bullet 2 states, in support of neglecting certain transportation stages in the life cycle, "the conclusions of this report do not change whether this transportation step is included or not". Is there a sensitivity analysis to support this claim?

  Due to changes in the reuse rate of the glass containers system and the results of a sensitivity, transport from filling to retail is now included in the report.

- Page 6, the first two bullets are very confusing. Who is ConAir, for example? Some context for this information should be provided.

  These bullets have been revised for clarification. ConAir produces dryers for the resin industry.

- Page 6, final bullet, has a non-current url. It is also not clear who the "Editors of the ULS Report" are. One reviewer was eventually able to find the document, but even in the primary document, it is not immediately clear who the Editors are.

  This url has been replaced with a current one. The reference has been clarified within the bullet.

- Page 11, the final paragraph makes reference to biomass wastes being used in the PLA process. Is this being counted as part of the process energy?

  The sentence on page 11 has been edited to say, "For the PLA bottle, not only does this non-fossil energy come from the use of biomass and renewable energy sources to produce electricity, but also this includes the feedstock energy for the PLA itself."

- Page 14, paragraph 1, a reference should be provided for the University of Arizona data.

  The reference has been added.

- In the Appendix, the sections dealing with quality assurance procedures only apply to the Franklin Associates data. This should be made clear.

  These statements have been added where necessary.

- Page 35, Figure A-4, should be adapted to properly convey how EMR for corn-based materials are handled in this analysis.

  A sentence has been added to the section on Energy of Material Resource to explain the differences between the two methodologies used.

- On page 11 the report states, "In the HDPE bottle system, almost 60 percent of the energy from fossil fuel is feedstock energy and so not combusted during the bottle's life cycle." However, a fraction of the bottles are incinerated.

This statement has been corrected.

- How are the consumer markets (retailers) and logistics defined?

  The retailers and consumer use are not included in the scope of this analysis. However, due to the reuse of the glass bottles, it has been made clear in the assumptions that the market considered in this analysis is grocery stores, not home delivery.

- "Only the 2005 PLA dataset from the NatureWorks journal paper was used in this analysis. The choice to not present the 2006 PLA data with credit given for wind energy credits taken was made based on the fact that any manufacturer of resin/paperboard/glass could buy those same credits. However, the datasets used in this report are based on industry averages of many manufacturers versus the PLA data coming from just one company, NatureWorks." Consider analyzing a wind energy scenario. Treatment of renewable energy credits is an unresolved issue in LCA. The argument that any company could buy the credits is weak. Any company could also install wind turbines but they don't.

  This is an ongoing discussion with LCA practitioners; there is no consensus on the issue at this time. Franklin Associates takes the stance that any company can buy or sell energy credits. As much of the data in the Franklin Associates database is average data from many companies, no energy credits are given to this data. This is an issue when comparing data from an industry average to data from a specific company. If the comparison is between resins (each from a specific plant), a case could be made for comparing both the total energy and the total energy after purchased credits. If a specific company would like to present these credits to the public, this is acceptable, as long as the actual inventory energy is shown before credits as well. The NatureWorks journal article, from which the PLA data was retrieved, did include both datasets (with and without energy credits).

- On page 11 the report states, "Glass does not combust readily." Glass is incombustible.

  This statement has been edited.

- For those unfamiliar with the PLA technology including a brief explanation at the beginning of the Executive Summary would be helpful.

  A directive sending those unfamiliar with PLA to the flow diagram in Appendix B has been included in the Systems Studied section of the report.

PEER REVIEW PANEL QUALIFICATIONS

The panel who performed the peer review of the report **Life Cycle Inventory of Container Systems for Tomatoes** consisted of the following members: Beth Quay, chair, Dr. David T. Allen, and Dr. Greg Keoleian. Their educational backgrounds and professional experience and qualifications are summarized below.

Beth H. Quay

Ms. Quay, formerly Director of Environmental Technical Affairs for The Coca-Cola Company in Atlanta, Georgia is an owner/manager of a family business, Antique & Surplus Auto Parts.

She is also an independent consultant to industry and has chaired five Life Cycle Inventory peer review teams. As chair of peer review teams she reviewed the draft LCI reports and appendices, developed a consensus report for the team, and represented the peer review team on issues raised during the peer review.

Ms. Quay’s LCA experience at The Coca-Cola Company included managing and coordinating LCAs of beverage packaging and delivery systems. She participated in the SETAC “Code of Practice” Workshop in Sesimbra, Portugal in 1993, where she chaired the team that developed Chapter 6, “Presentations and Communications.” She also served as a member of the U.S. EPA LCA Peer Review Groups on Impact Analysis and Data Quality and participated in the SETAC Workshop, “A Technical Framework for Life Cycle Assessment,” in Smuggler’s Notch, Vermont in 1990.

Ms. Quay’s background at The Coca-Cola Company also included management of environmental issues in company operations worldwide, including evaluation of environmental impacts of proposed packaging designs and development of recycling programs and comprehensive waste management solutions. She represented The Coca-Cola Company at environmental conferences and with industry environmental groups.

Ms. Quay has a Bachelor’s Degree in Industrial Engineering (Summa Cum Laude) from Georgia Institute of Technology and has done graduate work in Applied Statistics.

David T. Allen

Dr. David Allen is the Gertz Regents Professor of Chemical Engineering and the Director of the Center for Energy and Environmental Resources at the University of Texas at Austin. His research interests lie in air quality and pollution prevention. He is the author of six books and over 150 papers in these areas. The quality of his research has been recognized by the National Science Foundation (through the Presidential Young Investigator Award), the AT&T Foundation (through an Industrial Ecology Fellowship), the American Institute of Chemical Engineers (through the Cecil Award for contributions to environmental engineering), and the State of Texas (through the Governor’s

Environmental Excellence Award). Dr. Allen was a lead investigator in one of the largest and most successful air quality studies ever undertaken: the Texas Air Quality Study (www.utexas.edu/research/ceer/texaqs). His current research is focused on using the results from that study to provide a sound scientific basis for air quality management in Texas. In addition, Dr. Allen is actively involved in developing Green Engineering educational materials for the chemical engineering curriculum. His most recent effort is a textbook on design of chemical processes and products, jointly developed with the U.S. EPA.

Dr. Allen has extensive experience in LCA and has served on a number of peer review panels of LCIs. He has taught short courses on LCA for government agencies, private companies and in continuing education programs.

Dr. Allen received his B.S. degree in Chemical Engineering, with distinction, from Cornell University in 1979. His M.S. and Ph.D. degrees in Chemical Engineering were awarded by the California Institute of Technology in 1981 and 1983. He has held visiting faculty appointments at the California Institute of Technology, the University of California, Santa Barbara, and the Department of Energy.

Gregory A. Keoleian, PhD

Dr. Keoleian as Co-Director of the Center for Sustainable Systems is directly involved in the primary mission of the Center which is to organize and lead interdisciplinary research and education on the application of life cycle based models and sustainability metrics.

He has been involved in teaching and research at the University of Michigan for over 20 years, and has an impressive list of accomplishments in Life Cycle Inventory (LCI)/Life Cycle Assessment (LCA) and related fields. He has been principal investigator on 29 funded research projects totaling over $3 million since 1989. Nine of these projects involved LCI/LCA projects, and the balance are in related areas such as design for the environment, pollution prevention, and industrial ecology. In addition, Dr. Keoleian has authored or co-authored more than 100 articles and papers for professional journals, peer reviewed technical reports, technical papers, plus presentations at conferences and workshops. Finally, he has authored or co-authored books or chapters in books on the subject of Life Cycle Assessment, industrial ecology, and pollution prevention. In short, he has been a leader in the fields of LCA, pollution prevention, and industrial technology.

Dr. Keoleian has also been a peer reviewer for a number of LCI/LCA reports.

Dr. Keoleian has BS degrees in Chemical Engineering and Chemistry (1980), a MS degree in chemical engineering (1982), and a PhD in Chemical Engineering (1987) all from the University of Michigan.