PEER REVIEWED FINAL REPORT

LCI SUMMARY FOR SIX TUNA PACKAGING SYSTEMS

Prepared for

THE PLASTICS DIVISION OF
THE AMERICAN CHEMISTRY COUNCIL

by

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Table of Contents

Page

Table of Contents

Page

List of Tables

Page

List of Figures

Page

LCI SUMMARY FOR SIX TUNA PACKAGING SYSTEMS

The American Chemistry Council 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 (2007 Packaging Efficiency Study)**, on which to perform life cycle inventory (LCI) case studies. Primary packaging for tuna was chosen as one of these case studies. This summary evaluates the life cycle inventory results of the primary package for 100,000 ounces of tuna as sold in each packaging system.

LCI EXECUTIVE 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, total solid waste, and total greenhouse gas emissions results for the six tuna packaging systems is displayed in Table 1.

The total energy of the 12-ounce pouch is significantly lower than the other five tuna packaging systems. This is due to the lighter weight of the pouch, as well as the lower package-to-product weight ratio for the larger package size. The total energy of the 3-3-ounce steel cans in the paperboard sleeve is significantly higher than the other five tuna packaging systems. This is due to the higher weight of the small cans, which hold small amounts of tuna, as well as the extra paperboard sleeve. It is interesting to note that the total energies for the other four tuna packaging systems are grouped within a relatively tight range, all within 24 percent of each other.

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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, TOTAL SOLID WASTE, AND GREENHOUSE GASES FOR 100,000 OUNCES OF TUNA CONSUMED

	Total Energy	Total Solid Waste		Greenhouse Gases
	(MM Btu)	(lb)	(cu ft)	(lb of CO2 equivalents)
Tuna Packaging Systems				
12-oz. Steel Can (1)	22.7	1,333	44.0	4,292
12-oz. Pouch	9.30	346	10.5	977
6-oz. Steel Can (1)	24.1	1,413	46.6	4,551
3-oz. Pouch	25.2	936	28.4	2,647
3-3-oz. Steel Cans in Paperboard Sleeve (1)	43.2	2,562	83.6	7,518
2-2.8-oz. Plastic Cups in Paperboard Sleeve	28.2	1,106	37.8	1,702

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(1) End-of-life for the steel cans are modeled as 62% being recycled and 38% going to a landfill. The paper labels are assumed to be incinerated during steel recycling. Ash from the incineration of the labels is included in solid waste.
NOTE: The end-of-life for all other material is modeled as 80% going to a landfill and 20% combusted with energy recovery.

Source: Franklin Associates, a Division of ERG calculations using the Franklin Associates database and the U.S. LCI Database.

The total solid waste by weight and volume for the 12-ounce pouch are significantly lower than all other tuna packaging systems. As the postconsumer solid waste dominates the three solid waste categories (see Table 5), the 12-ounce pouch, which weighs the least, produces the least amount of solid waste. Although the three steel can systems include a 62 percent recycling rate, this cannot compensate for the heavier system, nor the lack of availability of combustion as an end-of-life option to reduce the weight of the postconsumer material. The three steel can systems produce the three greatest amounts of solid waste by weight and volume.

This same trend can be seen in the greenhouse gases produced by each of the tuna packaging systems. The heavy weight of the steel combined with the carbon dioxide from the fuel precombustion and combustion during the production of steel makes the amount of carbon dioxide equivalents greater than the other systems. Again, the 12-ounce pouch, with its lighter weight and lower amounts of carbon dioxide from the fuel precombustion and production during the production of the plastics used in the pouch layers, produces the least amount of greenhouse gases.

LCI METHODOLOGY

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's scope and the 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.

In one case, the evaluation of greenhouse gas emissions, this study applies the LCI results to LCIA (life cycle impact assessment). 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 tuna packaging study is to explore the relationship between the weight and material composition of primary tuna packages and the associated life cycle profile of each tuna package. The report includes discussion of the results for the tuna packages, but does not make comparative assertions, i.e., recommendations on which packages are preferred from an environmental standpoint.

SYSTEMS STUDIED

Six tuna packaging systems are considered in this LCI case study. These packages include a 12-ounce and 6-ounce steel can, a 12-ounce and 6-ounce laminate pouch, 3 3-ounce steel cans in a paperboard sleeve, and 2 2.8-ounce plastic cups in a paperboard sleeve. The weights of the tuna packaging systems are shown in Table 2. This table displays all lids, labels, and sleeves included in each packaging system.

The weights of these packaging components have all come from the 2007 ULS report, **A Study of Packaging Efficiency as it Relates to Waste Prevention**. In this report, packaging weights were given for specific brands of each container type. 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. The age of the weight data is the 2006-2007 period. The weight data represents weights within the United States.

In order to express the results on an equivalent basis, a functional unit of equivalent consumer use (100,000 ounces of tuna consumed) was chosen for this analysis.

Table 2

WEIGHTS FOR TUNA PACKAGING
(Basis: 100,000 OUNCES OF TUNA CONSUMED)

	Weight per unit		Weight per functional unit	
	(oz)	**(g)**	**(lb)**	**(kg)**
Tuna Packaging Systems				
12oz. Can				
Steel Can	2.09	59.2	1,088	493
Paper Label	0.07	1.9	34.9	15.8
12oz. Pouch (1)				
PET/Foil/Nylon/PP Pouch	0.40	11.2	206	93.3
6oz. Can				
Steel Can	1.11	31.4	1,154	523
Paper Label	0.04	1.0	36.7	16.7
3oz. Pouch (1)				
PET/Foil/Nylon/PP Pouch	0.27	7.6	558	253
3 -3oz. Cans in Paperboard Sleeve				
Steel Cans	0.89	25.2	1,854	841
Paper Label	0.02	0.6	44.1	20.0
Coated paperboard Sleeve	0.40	11.4	279	127
2-2.8 oz. Plastic Cups in Paperboard Sleeve				
PP Cups	0.28	7.8	614	279
PET/Foil Lid (2)	0.03	0.9	70.9	32.1
Coated paperboard Sleeve	0.38	10.7	421	191

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(1) The weight percentages of these layers have been estimated as 40% PET, 15% aluminum foil, 5% nylon, and 40% PP. The nylon layer has been included as PET.
(2) The weight percentages of these layers have been estimated as 90% PET and 10% aluminum foil.

Source: Franklin Associates, a Division of ERG

SCOPE AND BOUNDARIES

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

1. Production of the packaging materials (all steps from extraction of raw materials through the steps that precede packaging manufacture).
2. Manufacture of the primary packaging systems from their component materials.
3. Postconsumer disposal and recycling of the packaging systems.

The secondary packaging, transport to filling, filling, storage, distribution, and consumer activities are outside the scope and boundaries of the analysis. If these were included, the differences in the systems for these stages may affect the conclusions 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 packages studied. No composting has been considered in this analysis. The steel cans used as tuna containers are commonly recycled, and so their end-of-life scenario includes a recycling rate.[2]

Figures 1 through 4 define the materials and end-of-life included within the systems. Although considered in this study, these figures do not include the steps in the production of each material used in the packaging 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 six tuna packaging systems 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.
- Some of the aluminum production processes do not occur in the United States. The production steps for aluminum (which originates from bauxite mined in Australia) were modeled with the electricity grids specific to the geographies of bauxite mining, alumina refining, and aluminum smelting.

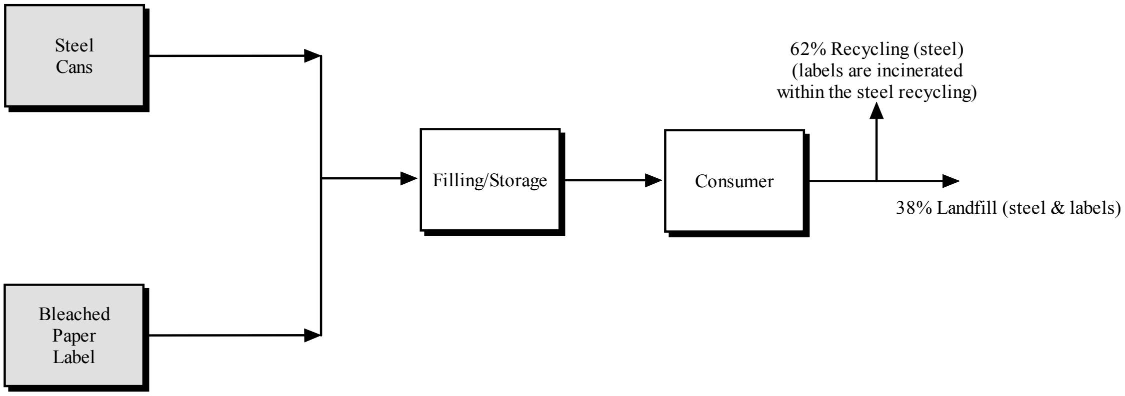

Figure 1. Flow diagram for the production of the 6-ounce and 12-ounce steel can systems.
Flow diagrams for the production of the materials in shaded boxes are shown in Appendix B.

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[2] **Life Cycle Inventory Data for Steel Products.** International Iron and Steel Institute. November, 2005.

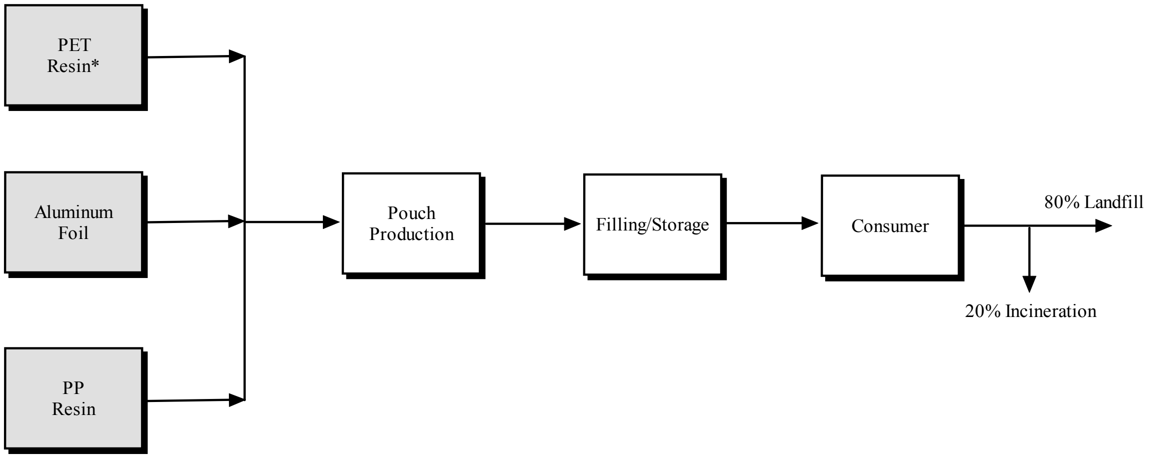

Figure 2. Flow diagram for the production of the 3-ounce and 12-ounce pouch systems.
Flow diagrams for the production of the materials in shaded boxes are shown in Appendix B.
* The PET resin weight includes the weight of the nylon 6 barrier layer.

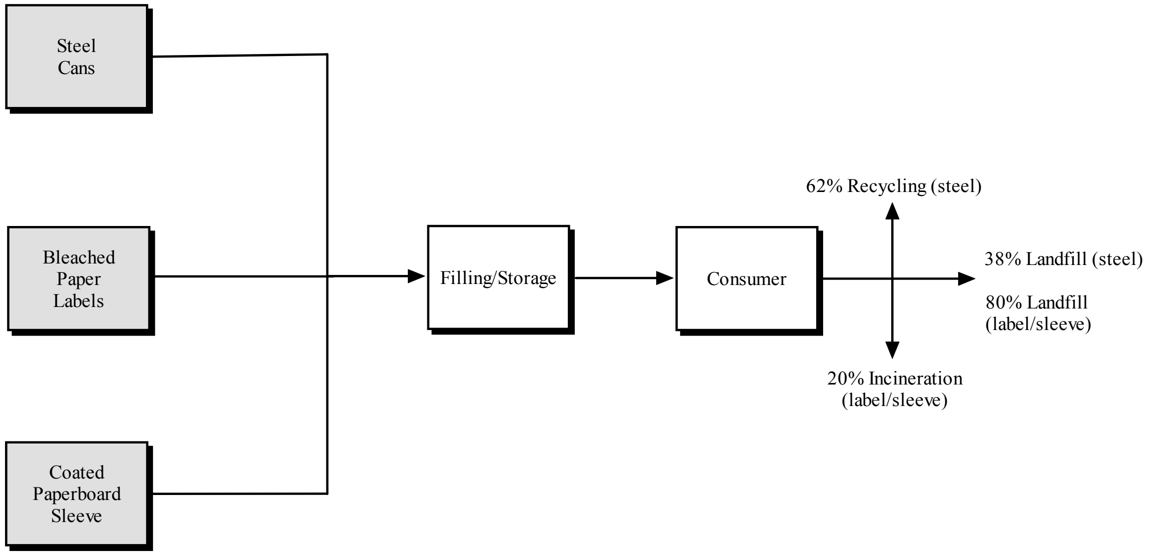

Figure 3. Flow diagram for the production of the 3/3-ounce cans in a paperboard sleeve system.
Flow diagrams for the production of the materials in shaded boxes are shown in Appendix B.

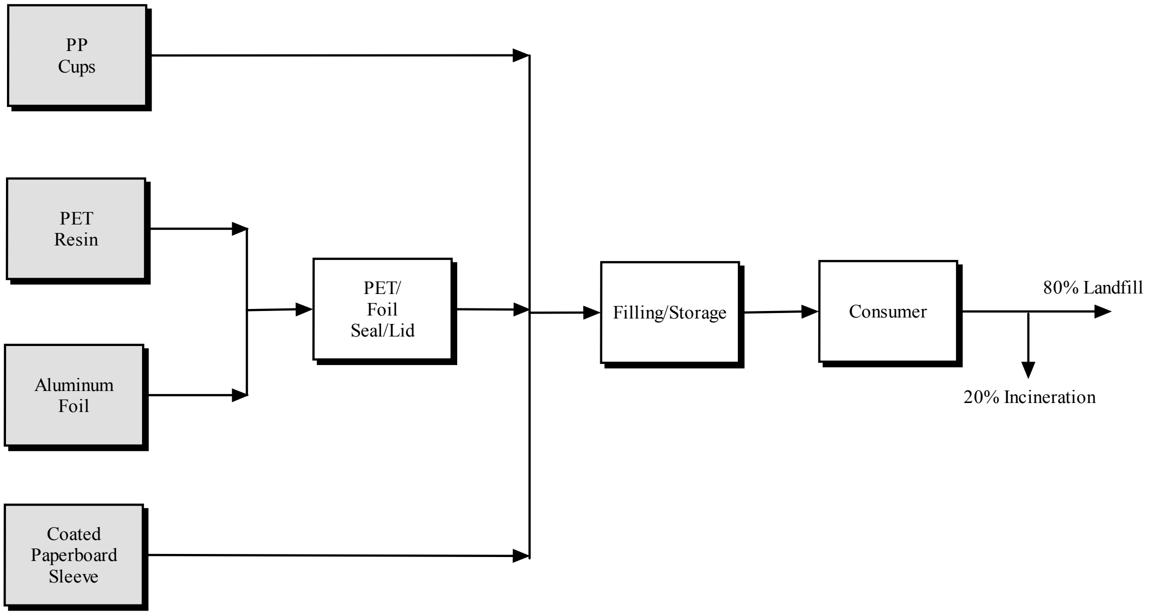

Figure 4. Flow diagram for the production of the 2/2.8-ounce plastic cups in a paperboard system. Flow diagrams for the production of the materials in shaded boxes are shown in Appendix B.

- Where possible, the complete primary packaging of the tuna was considered, including materials used for labels. The printing ink, as well as the printing process, for each of the labels/containers are considered negligible by weight and results compared to the packaging itself and are not included in the analysis.
- No secondary packaging, transportation to filling, filling, distribution, retail storage, or consumer use is included in this analysis as these are outside the scope and boundaries of the analysis. The transport of materials to the filler and of filled tuna containers from the filling step may affect the results of this report. All three major tuna producers have filling plants outside of the contiguous U.S. (American Samoa and Puerto Rico); whereas two of the three major tuna plants have one plant in California as well. It is unknown whether all of the plants utilize each packaging type considered within this analysis. This has been considered in the Sensitivity Analysis section.
- The omission of some of the life cycle stages, as discussed in the previous point, may affect the conclusions of the analysis. For example, the 12-ounce packages of tuna may not be completely consumed in one setting. This may lead the consumer to refrigerate the remaining tuna, which would add energy and emissions to those systems.
- This analysis is representative of U.S. production. The tuna container LCI data comes from the Franklin Associates database and the U.S. LCI Database using various sources including primary (collected) data.

- The following assumptions were made for the 12-ounce and 6-ounce steel can systems:
    - The weights were taken from the listed weights in the **2007 Packaging Efficiency Study**.
    - All steel used for food cans is produced by the BOF (basic oxygen furnace) process. BOF technology has a steel scrap input of 20 to 35 percent; this analysis assumes that 35 percent of iron input for a BOF is from steel scrap; the balance of iron is from iron ore via pig iron production. The scrap that results from steel stamping is "prompt scrap", which is directly returned to the basic oxygen furnace. Since prompt scrap is post-industrial scrap that is directly returned to the preceding unit process, it is assumed that the scrap rate for steel can stamping is zero.
    - Tin or enamel coatings represent less than one percent by weight of steel food cans and are thus excluded from this analysis. Due to a lack of available data, the VOCs (volatile organic compounds) that may be released from the application of tin or enamel are not included.
    - The paper label manufacture does not include a loss rate as the paper can be sent to repulping.
- The following assumptions were made for the 12-ounce and 3-ounce pouch systems:
    - The weights were taken from the listed weights in the **2007 Packaging Efficiency Study**.
    - The Foil/LDPE pouch actually includes four layers—polyethylene terephthalate (PET), aluminum foil, nylon 6, and polypropylene (PP). The weight percentages of these layers were unavailable and so estimated by Franklin Associates to be 40% PET, 15% Aluminum foil, 5% nylon 6, and 40% PP. The weight of the nylon was included as PET due to unavailability of nylon data and limited research funds for this project.
    - A trim scrap rate of 5 percent was assumed during the fabrication of the pouches.
- The following assumptions were made for the three 3-ounce steel cans in the paperboard sleeve system:
    - The weights were taken from the listed weights in the **2007 Packaging Efficiency Study**.
    - The same assumptions shown in the steel can assumptions apply for these steel cans.
    - The paperboard sleeve is made of clay-coated unbleached kraft paperboard, which includes a postconsumer recycled content of 10 percent.
    - The paper label manufacture does not include a loss rate as the paper can be sent to repulping.

- The following assumptions were made for the two 2.8-ounce plastic cups in the paperboard sleeve system:
    - The weights were taken from the listed weights in the **2007 Packaging Efficiency Study**.
    - The plastic cups are produced from PP and include barrier layer(s); however, information about these layers is considered confidential by the manufacturer and so was not available.
    - The composite lids of these PP cups are made of layers of PET and aluminum foil. The weight percentages of these layers are estimated by Franklin Associates to be 90% PET and 10% aluminum foil.
    - The paperboard sleeve is made of clay-coated unbleached kraft paperboard, which includes a postconsumer recycled content of 10 percent.
    - A trim scrap rate of 5 percent was assumed during the fabrication of the composite lids.
    - A scrap rate of 1 percent was assumed during the thermoforming of the PP cups.
- 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 7, but these make up less than 1 percent of the total greenhouse gases in each system.
- When materials such as plastic or paper are combusted for waste-to-energy, carbon dioxide is released. The carbon dioxide released when paper is combusted is considered to be from a non-fossil source and so is not included as a greenhouse gas According to the U.S. EPA. Using the carbon content of each of the plastics in this analysis (PP—87.5% and PET—62.5%), the theoretical maximum carbon dioxide amount from incineration has been included as a separate item in the greenhouse gas results in this analysis.
- The HHV (higher heating value) for each of the package components in this study is listed below.

Steel Can	0 Btu/lb
Plastic Cup	19,910 Btu/lb
Laminate Pouch	14,610 Btu/lb
PE/Al foil Lid	10,246 Btu/lb
Paper Label	7,261 Btu/lb
Paperboard sleeve	6,624 Btu/lb

- 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 for all materials except the steel cans.

> The steel cans were modeled as 62 percent recycling and 38 percent landfilled. 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.

COMPLETE LCI RESULTS

Tables 3 through 9 display the complete LCI results for this analysis. The energy results are shown in Tables 3 and 4; the solid waste results are shown in Tables 5 and 6; the comprehensive atmospheric emissions in Table 7, the greenhouse gas emissions in Table 8, and waterborne emissions in Table 9.

Energy

Franklin Associates commonly uses three energy categories—process energy, fuel-related energy, and energy of material resource. These energy categories are shown in Table 3 for each of the tuna packaging systems. 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 resin materials is already included in the process energy for systems utilizing plastic as a material. The net energy is the total energy minus the combustion energy credit.

Total and Net Energy. From Table 3, the 12-ounce pouch system requires the lowest amount of total or net energy overall. The 12-ounce steel can system uses the next least energy amount, but requires more than double the energy needed by the 12-ounce pouch system. The 12-ounce steel can system total energy is not considered significantly lower than that of the 6-ounce steel can system; however, it is significantly lower than the 3-ounce pouch and 2-2.8-ounce plastic cups in the paperboard sleeve. The 6-ounce steel can system total energy is not considered significantly different from that of the 3-ounce pouch system; however, it is significantly lower than the 2-2.8-ounce plastic cups in the paperboard sleeve. The total energy for the 3-ounce pouch system is significantly lower than that of the 2-2.8-ounce plastic cups in the paperboard sleeve. Finally, the 3-3-ounce steel cans in the paperboard sleeve system requires the most energy. It requires more than 1.5 times the energy used by the plastic cup system.

For the 12-ounce pouch and 3-3-ounce steel cans in the paperboard sleeve systems, the conclusions for the net energy are identical to those of the total energy. However, the remaining systems (12-ounce steel can, 6-ounce steel can, 3-ounce pouch, and 2-2.8-ounce plastic cups in the paperboard sleeve) are all considered to have equivalent energy amounts after the combustion energy credit is given.

Energy of Material Resource. No system in this analysis is comprised completely of plastic, including the pouch, which has an aluminum foil layer. The energy of material resource (EMR) comprises more than half of the total energy in the plastic cup system only. The EMR for the two pouch systems makes up 42 percent of those systems' total energy. This percent is lower than half due to the aluminum foil and the lower amount of fuel feedstock used to produce PET (45 percent of the produce weight), as compared to PP. The steel can systems show a small amount of EMR from the paper and paperboard. This is from the production of fertilizer used for corn starch within the paper/paperboard.

Table 3

Energy by Category for Tuna Packaging Systems
(MM Btu per 100,000 Ounces of Tuna Consumed)

	Energy Category					
	Process	Transport	Energy of Material Resource	Total	Combustion Energy Credit (1)	Net Energy
12-oz. Steel Can						
Steel Can	20.8	0.88	0	21.7		
Paper Label	0.81	0.056	7.2E-04	0.87		
Waste Management	0.040	0.13	0	0.17		
Total Energy	21.6	1.07	7.2E-04	22.7	0	22.7
Total Percent	95%	5%	0%	100%		
12-oz. Pouch						
PET/Foil/Nylon/PP Pouch	5.03	0.28	3.92	9.23		
Waste Management	0.016	0.055	0	0.071		
Total Energy	5.05	0.34	3.92	9.30	0.60	8.70
Total Percent	54%	4%	42%	100%		
6-oz. Steel Can						
Steel Can	22.1	0.93	0	23.0		
Paper Label	0.86	0.059	7.6E-04	0.92		
Waste Management	0.042	0.14	0	0.18		
Total Energy	23.0	1.13	7.6E-04	24.1	0	24.1
Total Percent	95%	5%	0%	100%		
3-oz. Pouch						
PET/Foil/Nylon/PP Pouch	13.6	0.77	10.6	25.0		
Waste Management	0.044	0.15	0	0.19		
Total Energy	13.7	0.92	10.6	25.2	1.63	23.6
Total Percent	54%	4%	42%	100%		
3-3-oz. Steel Cans in Paperboard Sleeve						
Steel Cans	35.4	1.50	0	36.9		
Paper Labels	1.03	0.071	9.1E-04	1.10		
Coated paperboard Sleeve	4.49	0.27	0.12	4.87		
Waste Management	0.078	0.26	0	0.33		
Total Energy	41.0	2.09	0.12	43.2	0.37	42.9
Total Percent	95%	5%	0%	100%		
2-2.8-oz. Plastic Cups in Paperboard Sleeve						
PP Cups	2.21	0.76	14.5	17.5		
PET/Foil Lids	1.80	0.076	1.16	3.03		
Coated paperboard Sleeve	6.78	0.40	0.18	7.35		
Waste Management	0.071	0.25	0	0.32		
Total Energy	10.9	1.48	15.9	28.2	3.15	25.0
Total Percent	38%	5%	56%	100%		

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(1) 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 the Franklin Associates database and the U.S. LCI Database.

Process Energy. The process energy for all can systems makes up approximately 95 percent of the total energy. This is largely due to the high amount of heat needed to for the steel furnaces and can manufacture. The process energy of both pouch systems make up more than half of their total energy. The pouch system process energy is split evenly among the three material layers. Over 60 percent of the process energy for the plastic cup system is required by the paperboard sleeve.

Transportation Energy. The transportation energy for all systems is 4 to 5 percent of the total energy. However, as discussed in the Assumptions and Limitations section, the transport of materials to filling and filled containers to retail have not been included in this analysis. This omission may affect the results of this report. Each of the three major tuna producers have filling plants outside of the contiguous U.S. (American Samoa and Puerto Rico); whereas two of the three major tuna plants have one plant in California as well. It is unknown which plants utilize which packaging types within this analysis, and so no sensitivity analysis has been performed.

Energy Recovery. 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 steel does not combust readily, only the paperboard sleeves of the steel cans in the paperboard sleeve system accounts for the credit given, which is less than 1 percent of the system's total energy. The paper labels on the steel cans are likely incinerated during the steel recycling or landfilled with the steel can. The combustion energy credit for the plastic cups system decreases the total energy by over 10 percent, with the two pouch systems decreasing by approximately 6 percent of their total energy amounts. This larger credit for plastic cup system is due to its overall higher heating value being greater than that of the pouches.

Energy Profile. The total energy requirements for each system can also be categorized by the fuels from which the energy is derived. Energy sources include fossil fuels (natural gas, petroleum, and coal) and non-fossil fuels. Non-fossil fuels include nuclear energy, hydroelectric energy, and energy produced from wood wastes at pulp and paper mills. Table 4 displays the total energy by fuel source for the six tuna packaging systems.

Fossil fuels make up more than 80 percent of the total fuels used for all systems in the tuna packaging systems. In the systems with plastics, this is due to the use of fossil fuels both for material feedstock and fuel (process and transportation energy). In the systems with steel, this is largely due to the use of these fuels in the steel furnaces and steel sheet production. Higher percentages of hydropower and nuclear energy sources are shown for the systems including steel and larger amounts of aluminum foil. This is due to the need for higher electricity amounts to produce those metals. Wood as a fuel source shows up as 9 percent of the total energy for the steel cans within the paperboard sleeve and 17 percent of the total energy for the plastic cups within the paperboard sleeve.

Table 4

Energy Profile for Tuna Packaging Systems
(Million Btu per 100,000 Ounces of Tuna Consumed)

	Nat. Gas	Petroleum	Coal	Hydropower	Nuclear	Wood	Other	Recovered	Total
12-oz. Steel Can									
Steel Can	9.34	0.97	8.44	1.43	0.64	0	0.19	0	21.0
Paper Label	0.10	0.13	0.24	0.0048	0.026	0.37	0.0049	5.1E-04	0.87
Waste management	0.088	0.48	0.20	0.0091	0.048	0	0.0094	0	0.83
Total Energy	**9.53**	**1.59**	**8.88**	**1.44**	**0.71**	**0.37**	**0.20**	**5.1E-04**	**22.7**
Total Percent	**42%**	**7%**	**39%**	**6%**	**3%**	**2%**	**1%**		**100%**
12-oz. Pouch									
PET/Foil/Nylon/PP Pouch	4.11	2.69	1.79	0.54	0.33	0	0.088	0.32	9.23
Waste Management	0.0034	0.066	0.0014	8.5E-05	4.6E-04	0	9.0E-05	0	0.071
Total Energy	**4.11**	**2.76**	**1.79**	**0.54**	**0.33**	**0**	**0.088**	**0.32**	**9.30**
Total Percent	**43%**	**29%**	**19%**	**6%**	**3%**	**0%**	**1%**		**100%**
6-oz. Steel Can									
Steel Can	9.90	1.03	8.95	1.51	0.68	0	0.20	0	22.3
Paper Label	0.11	0.14	0.25	0.0050	0.027	0.39	0.0052	5.3E-04	0.92
Waste Management	0.094	0.51	0.21	0.0096	0.051	0	0.010	0	0.89
Total Energy	**10.1**	**1.68**	**9.41**	**1.53**	**0.76**	**0.39**	**0.21**	**5.3E-04**	**24.1**
Total Percent	**42%**	**7%**	**39%**	**6%**	**3%**	**2%**	**1%**		**100%**
3-oz. Pouch									
PET/Foil/Nylon/PP Pouch	11.1	7.30	4.85	1.46	0.90	0	0.24	0.86	25.0
Waste Management	0.0093	0.18	0.0037	2.3E-04	0.0012	0	2.4E-04	0	0.19
Total Energy	**11.1**	**7.48**	**4.86**	**1.46**	**0.90**	**0**	**0.24**	**0.86**	**25.2**
Total Percent	**43%**	**29%**	**19%**	**6%**	**3%**	**0%**	**1%**		**100%**
3-3-oz. Steel Cans in Paperboard Sleeve									
Steel Cans	15.9	1.66	14.4	2.43	1.09	0	0.32	0	35.8
Paper Labels	0.13	0.16	0.30	0.0060	0.032	0.46	0.0062	6.4E-04	1.10
Coated paperboard Sleeve	0.92	0.41	0.18	0.0075	0.040	3.31	0.0077	0.0023	4.87
Waste Management	0.15	0.86	0.34	0.016	0.083	0	0.016	0	1.47
Total Energy	**17.1**	**3.10**	**15.2**	**2.46**	**1.25**	**3.77**	**0.35**	**0.0030**	**43.2**
Total Percent	**40%**	**7%**	**35%**	**6%**	**3%**	**9%**	**1%**		**100%**
2-2.8-oz. Plastic Cups in Paperboard Sleeve									
PP Cups	13.9	4.65	0.67	0.032	0.17	0	0.033	1.96	17.5
PET/Foil Lids	1.15	1.11	0.54	0.13	0.11	0	0.026	0.031	3.03
Coated paperboard Sleeve	1.39	0.62	0.27	0.011	0.061	4.99	0.012	0.0035	7.35
Waste Management	0.015	0.29	0.0061	3.8E-04	0.0020	0	4.0E-04	0	0.32
Total Energy	**16.5**	**6.67**	**1.49**	**0.17**	**0.34**	**4.99**	**0.071**	**1.99**	**28.2**
Total Percent	**55%**	**22%**	**5%**	**1%**	**1%**	**17%**	**0%**		**100%**

Source: Franklin Associates, a Division of ERG calculations using the Franklin Associates database and the U.S. LCI Database.

Recovered energy is energy (usually steam or electricity) produced as a coproduct to the system. The plastic cup system produces the highest amount of recovered energy (6 percent of the total system energy). This is due to coproduct energy production at the hydrocracker used to produce propylene or ethylene. The pouch systems recover approximately 3 percent of their total energy. The small amounts of recovered energy shown in the paper and paperboard in the steel can systems comes from the production of sulfuric acid.

Solid Waste

Solid waste is categorized into process wastes, fuel-related wastes, and postconsumer wastes. **Process wastes** are the solid wastes generated by the various processes throughout the life cycle of the container systems. **Fuel-related wastes** are the wastes from the production and combustion of fuels used for energy and transportation. Together, process wastes and fuel-related wastes are reported as **industrial solid waste**. **Postconsumer wastes** are the wastes discarded by the end users of the product.

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 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. All ash from combustion is included in the postconsumer solid waste weight and volume. The exception to this is the steel can, which is not sent to the waste-to-energy facilities. The weight of postconsumer wastes is directly related to the weight of a product. Therefore, heavier products produce more postconsumer solid wastes.

Table 5 shows the weight of total solid waste generated during the production of the six tuna packaging systems. The 12-ounce pouch produces the lowest amount of total solid waste. This is greatly due to the low weight of the packaging and high volume of product per package. The steel cans in the paperboard sleeve system produces the greatest amount of total solid waste. This is due to the weight of the three steel cans traced back to a combination of the postconsumer solid waste, as well as solid waste from processes and from fuel use.

As discussed previously, the postconsumer solid waste is greater for the heavier products and dependent on the end-of-life scenario chosen. The pouch systems are light-weight and so produce less postconsumer solid waste. The steel can systems are heavy in comparison, but do include credit for recycling. The steel cans themselves cannot be combusted for energy, and so the weight of all steel cans that are disposed to a landfill are shown as postconsumer solid waste. The postconsumer solid waste for the plastic cup system makes up 81 percent of its total solid waste. The plastic cup system itself is not a heavy system, and plastic produces very little solid waste during its production.

Table 5

Solid Wastes by Weight for Tuna Packaging Systems
(per 100,000 Ounces of Tuna Consumed)

	Solid Wastes by Weight Pounds per 100,000 Ounces of Tuna Consumed			
	Process	Fuel	Postconsumer	Total
12-oz Steel Can (1)				
Steel Can	359	193		551
Paper Label	5.63	11.1		16.7
Waste management	0	0.41	764	765
Total Solid Waste	364	204	764	1,333
Total Percent	27%	15%	57%	
12-oz. Pouch				
PET/Foil/Nylon/PP Pouch	115	59.9		175
Waste Management	0	0.17	171	171
Total Solid Waste	115	60.0	171	346
Total Percent	33%	17%	49%	
6-oz. Steel Can (1)				
Steel Can	381	204		585
Paper Label	5.92	11.7		17.6
Waste Management	0	0.44	810	811
Total Solid Waste	386	216	810	1,413
Total Percent	27%	15%	57%	
3-oz. Pouch				
PET/Foil/Nylon/PP Pouch	311	162		473
Waste Management	0	0.47	463	464
Total Solid Waste	311	163	463	936
Total Percent	33%	17%	49%	
3-3-oz. Steel Cans in Paperboard Sleeve (1)				
Steel Cans	611	328		940
Paper Labels	7.11	14.0		21.1
Coated paperboard Sleeve	35.6	40.0		75.6
Waste Management	0	0.81	1,525	1,526
Total Solid Waste	654	383	1,525	2,562
Total Percent	26%	15%	60%	
2-2.8-oz. Plastic Cups in Paperboard Sleeve				
PP Cups	20.7	27.6		48.2
PET/Foil Lids	30.1	18.7		48.8
Coated paperboard Sleeve	53.7	60.4		114
Waste Management	0	0.77	894	895
Total Solid Waste	105	107	894	1,106
Total Percent	9%	10%	81%	

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(1) End-of-life for the steel cans are modeled as 62% being recycled and 38% going to a landfill. The paper labels are assumed to be incinerated during steel recycling. Ash from the incineration of the labels is included in solid waste.
NOTE: The end-of-life for all other material is modeled as 80% going to a landfill and 20% combusted with energy recovery.

Source: Franklin Associates, a Division of ERG calculations using the Franklin Associates database and the U.S. LCI Database.

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. 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]. It should be noted that compaction rates and landfill moisture will vary by landfill, which may affect the volumes. While these factors are considered to be only estimates, their use helps add valuable perspective. 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. Table 6 displays the total solid waste by volume for the six tuna packaging systems.

The overall results for the total solid waste by weight and by volume are the same as the 12-ounce pouch produces the least amount and the steel cans in the paperboard sleeve produces the greatest amount of solid waste by volume. However, whereas the solid waste by weight for the 6-ounce steel can system was considered greater than that of the plastic cup in the paperboard sleeve system; the solid waste by volume for these two systems are not considered significantly different. In the same way, whereas the solid waste by weight for the 3-ounce pouch system was not considered different than the plastic cups in the paperboard sleeve system; the solid waste by volume for the plastic cups in the paperboard system is considered a greater amount than that of the 3-ounce pouch system.

Environmental Emissions

Atmospheric and waterborne emissions for each system include emissions from processes and those associated with the combustion of fuels. Table 7 presents atmospheric emissions results and Table 9 shows waterborne emissions for 100,000 ounces of tuna consumed. Table 8 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. The atmospheric or waterborne emissions results do not include emissions from the decomposition of the packaging within a landfill or from the waste-to-energy combustion.

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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 6

Solid Wastes by Volume for Tuna Packaging Systems
(per 100,000 Ounces of Tuna Consumed)

	Solid Wastes by Volume Cubic Feet per 100,000 Ounces of Tuna Consumed			
	Process	Fuel	Postconsumer	Total
12-oz Steel Can (1)				
Steel Can	7.18	3.85		11.0
Paper Label	0.11	0.22		0.33
Waste management	0	0.0083	32.6	32.6
Total Volume Solid Waste	7.29	4.08	32.6	44.0
Total Percent	17%	9%	74%	
12-oz. Pouch				
PET/Foil/Nylon/PP Pouch	2.29	1.20		3.49
Waste Management	0	0.0035	7.01	7.01
Total Volume Solid Waste	2.29	1.20	7.01	10.5
Total Percent	22%	11%	67%	
6-oz. Steel Can (1)				
Steel Can	7.61	4.09		11.7
Paper Label	0.12	0.23		0.35
Waste Management	0	0.0088	34.6	34.6
Total Volume Solid Waste	7.73	4.33	34.6	46.6
Total Percent	17%	9%	74%	
3-oz. Pouch				
PET/Foil/Nylon/PP Pouch	6.21	3.24		9.46
Waste Management	0	0.0094	19.0	19.0
Total Volume Solid Waste	6.21	3.25	19.0	28.4
Total Percent	22%	11%	67%	
3-3-oz. Steel Cans in Paperboard Sleeve (1)				
Steel Cans	12.2	6.56		18.8
Paper Labels	0.14	0.28		0.42
Coated paperboard Sleeve	0.71	0.80		1.51
Waste Management	0	0.016	62.8	62.8
Total Volume Solid Waste	13.1	7.66	62.8	83.6
Total Percent	16%	9%	75%	
2-2.8-oz. Plastic Cups in Paperboard Sleeve				
PP Cups	0.41	0.55		0.96
PET/Foil Lids	0.60	0.37		0.98
Coated paperboard Sleeve	1.07	1.21		2.28
Waste Management	0	0.015	33.5	33.5
Total Volume Solid Waste	2.09	2.15	33.5	37.8
Total Percent	6%	6%	89%	

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(1) End-of-life for the steel cans are modeled as 62% being recycled and 38% going to a landfill. The paper labels are assumed to be incinerated during steel recycling. Ash from the incineration of the labels is included in solid waste.
NOTE: The end-of-life for all other material is modeled as 80% going to a landfill and 20% combusted with energy recovery.

Source: Franklin Associates, a Division of ERG calculations using the Franklin Associates database and the U.S. LCI Database.

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 Intergovernmental 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 8, it is apparent that the 12-ounce pouch system produces the least amount of carbon dioxide equivalents. The steel cans in the paperboard sleeve system produces the greatest amount of carbon dioxide equivalents. This is mostly from fuel-related carbon dioxide due to the heavy weight of the system and the use of fossil fuels. In all the systems, the release of fossil carbon dioxide makes up 80 percent or more of the total carbon dioxide equivalents. Even though more than 90 percent of the plastics' total energy is from fossil fuels, the energy of material resource amount produces no carbon dioxide equivalents as the fuels are never combusted (except the 20 percent going to waste-to-energy).

Table 8 also provides theoretical maximums of carbon dioxide produced from all incineration of plastics in the systems. Although this adds some carbon dioxide to the two pouch systems and the plastic cup system, the conclusions are not different than if these amounts were not included.

Table 7

Atmospheric Emissions of Tuna Packaging Systems
(lb per 100,000 Ounces of Tuna Consumed)

	12-oz. Steel Can	12-oz. Pouch	6-oz. Steel Can	3-oz. Pouch	3-3-oz. Steel Cans in Paperboard Sleeve	2-2.8-oz. Plastic Cups in Paperboard Sleeve
Atmospheric Emissions						
Particulates (unspecified)	4.48	0.96	4.75	2.61	7.64	0.55
Particulates (PM2.5)	1.1E-07	2.9E-05	1.2E-07	8.0E-05	1.8E-05	1.1E-04
Particulates (PM10)	0.41	0.077	0.44	0.21	2.29	2.64
Nitrogen oxides	8.07	3.23	8.56	8.75	15.0	5.97
Hydrocarbons (unspecified)	2.03	0.93	2.15	2.51	3.47	1.28
VOC (unspecified)	0.55	0.21	0.58	0.57	0.99	0.76
TNMOC (unspecified)	0.034	0.018	0.036	0.048	0.070	0.034
Sulfur dioxide	19.6	4.91	20.7	13.3	34.3	8.11
Sulfur oxides	3.03	3.46	3.21	9.36	5.31	14.5
Carbon monoxide	20.5	5.00	21.8	13.6	37.4	10.1
Fossil carbon dioxide	4,009	871	4,251	2,360	7,004	1,345
Non-Fossil carbon dioxide	72.7	0.35	76.5	0.95	737	973
Aldehydes (Formaldehyde)	0.0028	3.8E-04	0.0030	0.0010	0.019	0.023
Aldehydes (Acetaldehyde)	3.9E-04	3.3E-05	4.2E-04	9.0E-05	0.0033	0.0043
Aldehydes (Propionaldehyde)	3.1E-06	9.0E-07	3.3E-06	2.4E-06	4.7E-06	1.2E-06
Aldehydes (unspecified)	0.0092	0.022	0.0097	0.060	0.014	0.027
Organics (unspecified)	0.0050	0.11	0.0052	0.30	0.0073	0.082
Ammonia	0.032	0.0053	0.034	0.014	0.14	0.14
Ammonium Chloride	2.1E-04	5.2E-05	2.3E-04	1.4E-04	3.7E-04	5.3E-05
Methane	10.5	4.02	11.2	10.9	18.7	13.2
Kerosene	3.8E-04	9.3E-05	4.0E-04	2.5E-04	6.6E-04	9.4E-05
Chorine	7.2E-04	6.0E-04	7.5E-04	0.0016	0.0042	0.0051
HCl	0.35	0.12	0.37	0.34	0.66	0.19
HF	0.044	0.033	0.047	0.090	0.075	0.016
Metals (unspecified)	0.016	1.3E-04	0.017	3.5E-04	0.16	0.21
Mercaptan	0.0018	5.1E-04	0.0019	0.0014	0.0027	6.7E-04
Antimony	8.1E-06	1.5E-06	8.5E-06	4.2E-06	3.9E-05	4.1E-05
Arsenic	1.3E-04	3.9E-05	1.4E-04	1.1E-04	3.0E-04	1.5E-04
Beryllium	7.2E-06	2.2E-06	7.7E-06	6.0E-06	1.6E-05	7.4E-06
Cadmium	2.9E-05	8.1E-06	3.1E-05	2.2E-05	6.4E-05	3.2E-05
Chromium (VI)	2.2E-05	6.7E-06	2.4E-05	1.8E-05	3.9E-05	5.9E-06
Chromium	1.0E-04	2.7E-05	1.1E-04	7.4E-05	2.5E-04	1.3E-04
Cobalt	5.0E-05	2.5E-05	5.3E-05	6.8E-05	1.1E-04	6.4E-05
Copper	1.3E-05	6.7E-07	1.4E-05	1.8E-06	2.2E-05	4.7E-07
Lead	1.9E-04	5.3E-05	2.0E-04	1.4E-04	4.7E-04	3.0E-04
Magnesium	0.0031	9.4E-04	0.0033	0.0025	0.0054	8.2E-04
Manganese	8.8E-04	5.4E-05	9.3E-04	1.5E-04	0.0065	0.0080
Mercury	3.9E-05	1.4E-05	4.1E-05	3.7E-05	7.8E-05	3.3E-05
Nickel	3.8E-04	2.6E-04	4.0E-04	7.0E-04	8.0E-04	5.3E-04
Selenium	3.8E-04	1.1E-04	4.0E-04	3.1E-04	6.6E-04	1.2E-04
Zinc	1.0E-04	5.3E-07	1.1E-04	1.4E-06	1.8E-04	9.3E-07
Acetophenone	1.2E-07	3.5E-08	1.3E-07	9.6E-08	1.8E-07	4.6E-08
acrolein	0.0016	3.5E-05	0.0017	9.6E-05	0.015	0.020
Nitrous oxide	0.068	0.018	0.072	0.049	0.16	0.096
Benzene	0.047	0.0097	0.050	0.026	0.097	0.045
Benzyl Chloride	5.7E-06	1.7E-06	6.0E-06	4.5E-06	8.6E-06	2.2E-06
Bis(2-ethylhexyl) Phthalate (DEHP)	6.0E-07	1.7E-07	6.3E-07	4.7E-07	9.0E-07	2.3E-07
1,3 Butadiene	3.8E-06	1.4E-06	4.0E-06	3.9E-06	8.0E-06	5.4E-06
2-Chloroacetophenone	5.7E-08	1.7E-08	6.0E-08	4.5E-08	8.6E-08	2.2E-08
Chlorobenzene	1.8E-07	5.2E-08	1.9E-07	1.4E-07	2.7E-07	6.8E-08
2,4-Dinitrotoluene	2.3E-09	6.6E-10	2.4E-09	1.8E-09	3.4E-09	8.7E-10
Ethyl Chloride	3.4E-07	9.9E-08	3.6E-07	2.7E-07	5.2E-07	1.3E-07
Ethylbenzene	0.0053	0.0011	0.0056	0.0030	0.0094	0.0028

Table 7 (cont'd)

Atmospheric Emissions of Tuna Packaging Systems
(lb per 100,000 Ounces of Tuna Consumed)

	12-oz. Steel Can	12-oz. Pouch	6-oz. Steel Can	3-oz. Pouch	3-3-oz. Steel Cans in Paperboard Sleeve	2-2.8-oz. Plastic Cups in Paperboard Sleeve
Atmospheric Emissions						
Ethylene Dibromide	9.8E-09	2.8E-09	1.0E-08	7.7E-09	1.5E-08	3.7E-09
Ethylene Dichloride	3.3E-07	9.4E-08	3.4E-07	2.6E-07	4.9E-07	1.2E-07
Hexane	5.5E-07	1.6E-07	5.8E-07	4.3E-07	8.2E-07	2.1E-07
Isophorone	4.7E-06	1.4E-06	5.0E-06	3.7E-06	7.1E-06	1.8E-06
Methyl Bromide	1.3E-06	3.8E-07	1.4E-06	1.0E-06	2.0E-06	4.9E-07
Methyl Chloride	4.3E-06	1.3E-06	4.6E-06	3.4E-06	6.5E-06	1.6E-06
Methyl Ethyl Ketone	3.2E-06	9.2E-07	3.4E-06	2.5E-06	4.8E-06	1.2E-06
Methyl Hydrazine	1.4E-06	4.0E-07	1.5E-06	1.1E-06	2.1E-06	5.3E-07
Methyl Methacrylate	1.6E-07	4.7E-08	1.7E-07	1.3E-07	2.5E-07	6.2E-08
Methyl Tert Butyl Ether (MTBE)	2.9E-07	8.3E-08	3.0E-07	2.2E-07	4.3E-07	1.1E-07
Naphthalene	4.6E-05	4.6E-06	4.8E-05	1.2E-05	3.8E-04	4.9E-04
Propylene	2.5E-04	9.5E-05	2.7E-04	2.6E-04	5.3E-04	3.6E-04
Styrene	2.0E-07	5.9E-08	2.2E-07	1.6E-07	3.1E-07	7.7E-08
Toluene	0.068	0.014	0.072	0.039	0.12	0.036
Trichloroethane	1.7E-07	5.2E-08	1.8E-07	1.4E-07	2.6E-07	7.1E-08
Vinyl Acetate	6.2E-08	1.8E-08	6.5E-08	4.9E-08	9.3E-08	2.3E-08
Xylenes	0.040	0.012	0.042	0.034	0.071	0.024
Bromoform	3.2E-07	9.2E-08	3.4E-07	2.5E-07	4.8E-07	1.2E-07
Chloroform	4.8E-07	1.4E-07	5.1E-07	3.8E-07	7.2E-07	1.8E-07
Carbon Disulfide	1.1E-06	3.1E-07	1.1E-06	8.3E-07	1.6E-06	4.0E-07
Dimethyl Sulfate	3.9E-07	1.1E-07	4.1E-07	3.1E-07	5.9E-07	1.5E-07
Cumene	4.3E-08	1.3E-08	4.6E-08	3.4E-08	6.5E-08	1.6E-08
Cyanide	2.0E-05	5.9E-06	2.2E-05	1.6E-05	3.1E-05	7.7E-06
Perchloroethylene	1.3E-05	3.9E-06	1.3E-05	1.1E-05	2.2E-05	3.5E-06
Methylene chloride	2.2E-04	4.3E-05	2.3E-04	1.2E-04	0.0013	0.0015
Carbon Tetrachloride	1.7E-05	8.2E-07	1.8E-05	2.2E-06	1.7E-04	2.3E-04
Phenols	4.1E-05	1.4E-05	4.3E-05	3.8E-05	2.3E-04	2.7E-04
Fluorides	3.8E-04	1.1E-04	4.0E-04	3.0E-04	5.8E-04	1.4E-04
Polyaromatic Hydrocarbons (PAH total)	2.2E-05	0.0051	2.4E-05	0.014	4.5E-05	0.0012
dioxins (unspecified)	6.2E-07	3.1E-09	6.6E-07	8.5E-09	6.3E-06	8.3E-06
Furans (unspecified)	1.3E-09	3.9E-10	1.3E-09	1.1E-09	2.2E-09	3.3E-10
CFC11	1.1E-08	1.6E-08	1.2E-08	4.2E-08	2.1E-08	4.3E-08
radionuclides (unspecified)	0.022	0.0053	0.023	0.014	0.037	0.0053
Sulfuric acid	0	6.5E-05	0	1.8E-04	0	1.5E-05
COS	0	0.036	0	0.098	0	0.0083
Hydrogen cyanide	0	0.0012	0	0.0033	0	2.8E-04
Trichloroethane	1.9E-11	8.4E-09	2.0E-11	2.3E-08	2.9E-10	2.6E-08
BTEX	1.8E-05	0.032	1.9E-05	0.086	7.2E-04	0.18
HCFC/HFCs	1.7E-07	0.0039	1.8E-07	0.011	4.6E-06	9.0E-04
Hydrogen	0	1.6E-04	0	4.3E-04	1.9E-06	0.0010
Methanol	0	1.4E-04	0	3.9E-04	0	1.0E-04
PFC (perfluorocarbons)	0	0.012	0	0.033	0	0.0028
Fluorine	3.5E-07	6.2E-04	3.7E-07	0.0017	5.0E-07	1.4E-04
Odorous Sulfur	0	0	0	0	0.059	0.088
Ethylene oxides	0	0.0025	0	0.0067	0	0.0017
Acetic acid	0	0.0050	0	0.013	0	0.0034
Bromine	0	0.0077	0	0.021	0	0.0053
Methyl Acetate	0	0.0039	0	0.011	0	0.0027

Source: Franklin Associates, a Division of ERG calculations using the Franklin Associates database and the U.S. LCI Database.

Table 8

Greenhouse Gas Summary for Tuna Packaging Systems
(lb carbon dioxide equivalents per 100,000 Ounces of Tuna Consumed)

	12-oz. Steel Can	12-oz. Pouch	6-oz. Steel Can	3-oz. Pouch	3-3-oz. Steel Cans in Paperboard Sleeve	2-2.8-oz. Plastic Cups in Paperboard Sleeve
Fossil Carbon Dioxide	4,008	871	4,251	2,360	7,004	1,345
Methane	263	100.4	279	272	467	329
Nitrous Oxide	20.3	5.38	21.5	14.6	47.5	28.7
Total	4,292	977	4,551	2,647	7,518	1,702
Carbon Dioxide from incineration (1)	0	94	0	255	0	415
Total including CO_2 from incineration	4,292	1,071	4,551	2,902	7,518	2,118

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 plastics within the systems.

Source: Franklin Associates, a Division of ERG calculations using the Franklin Associates database and the U.S. LCI Database.

Table 9

Waterborne Emissions of Tuna Packaging Systems
(lb per 100,000 Ounces of Tuna Consumed)

	12-oz. Steel Can	12-oz. Pouch	6-oz. Steel Can	3-oz. Pouch	3-3-oz. Steel Cans in Paperboard Sleeve	2-2.8-oz. Plastic Cups in Paperboard Sleeve
Waterborne Wastes						
Acid (unspecified)	0.0028	0.0078	0.0030	0.021	0.021	0.029
Acid (benzoic)	0.0024	0.0014	0.0026	0.0038	0.0043	0.0048
Acid (hexanoic)	5.0E-04	2.9E-04	5.3E-04	7.8E-04	9.0E-04	0.0010
Metals (unspecified)	31.4	6.62	33.3	17.9	56.1	16.6
Dissolved Solids	109	61.2	116	166	196	214
Suspended Solids	2.56	2.03	2.71	5.51	4.82	6.25
BOD	1.16	0.31	1.22	0.83	8.23	10.8
COD	0.79	0.54	0.83	1.46	1.33	1.49
Phenolic Compounds	0.0016	6.7E-04	0.0017	0.0018	0.0028	0.0023
Sulfur	0.0063	0.0016	0.0067	0.0043	0.011	0.0038
Sulfates	0.45	0.28	0.48	0.75	0.79	0.44
Sulfides	1.8E-05	2.5E-05	1.9E-05	6.9E-05	3.6E-05	7.2E-05
Oil	0.051	0.030	0.054	0.080	0.093	0.098
Sulfuric Acid	0	0	0	0	0	0
Hydrocarbons	4.8E-04	1.2E-04	5.1E-04	3.2E-04	8.6E-04	2.9E-04
Ammonia	0.044	0.032	0.047	0.087	0.076	0.078
Ammonium	1.7E-04	2.0E-04	1.8E-04	5.4E-04	2.9E-04	1.4E-04
Aluminum	0.070	0.023	0.074	0.063	0.13	0.052
Antimony	4.2E-05	3.9E-05	4.5E-05	1.1E-04	7.8E-05	1.1E-04
Arsenic	5.5E-04	3.3E-04	5.8E-04	9.0E-04	9.9E-04	0.0011
Barium	1.00	0.89	1.07	2.41	1.84	2.61
Beryllium	2.6E-05	1.7E-05	2.7E-05	4.5E-05	4.6E-05	5.5E-05
Cadmium	8.2E-05	4.9E-05	8.7E-05	1.3E-04	1.5E-04	1.7E-04
Chromium (unspecified)	0.0019	0.0024	0.0020	0.0065	0.0035	0.0056
Cobalt	5.3E-05	3.0E-05	5.6E-05	8.2E-05	9.5E-05	1.1E-04
Copper	4.3E-04	2.8E-04	4.6E-04	7.6E-04	7.8E-04	8.8E-04
Lead	8.6E-04	5.8E-04	9.1E-04	0.0016	0.0016	0.0019
Lithium	2.17	0.90	2.30	2.44	3.88	3.67
Magnesium	1.49	0.86	1.58	2.33	2.69	2.98
Manganese	0.0084	0.0025	0.0089	0.0069	0.015	0.0058
Mercury	1.4E-05	7.5E-07	1.5E-05	2.0E-06	1.9E-05	2.0E-06
Molybdenum	5.5E-05	3.1E-05	5.8E-05	8.5E-05	9.8E-05	1.1E-04
Nickel	4.5E-04	2.9E-04	4.8E-04	7.9E-04	8.2E-04	9.7E-04
Selenium	6.8E-05	2.2E-05	7.2E-05	6.0E-05	1.2E-04	3.7E-05
Silver	0.0050	0.0029	0.0053	0.0078	0.0090	0.010
Sodium	24.2	14.1	25.6	38.1	43.5	48.4
Strontium	0.13	0.075	0.14	0.20	0.23	0.26
Thallium	8.9E-06	8.2E-06	9.5E-06	2.2E-05	1.6E-05	2.4E-05
Tin	3.0E-04	2.1E-04	3.2E-04	5.7E-04	5.5E-04	6.8E-04
Titanium	6.5E-04	6.0E-04	6.9E-04	0.0016	0.0012	0.0017
Vanadium	6.4E-05	3.7E-05	6.8E-05	1.0E-04	1.2E-04	1.3E-04
Yttrium	1.6E-05	9.2E-06	1.7E-05	2.5E-05	2.9E-05	3.2E-05
Zinc	0.0019	0.0021	0.0020	0.0057	0.0034	0.0049
Chlorides (unspecified)	85.7	21.4	90.9	58.0	154	51.5
Chlorides (methyl chloride)	9.5E-08	2.4E-08	1.0E-07	6.5E-08	1.7E-07	5.7E-08
Calcium	7.63	4.40	8.09	11.9	13.7	15.3
Fluorine/Fluorides	0.0028	0.0027	0.0029	0.0072	0.0063	0.0035
Nitrates	4.2E-04	1.0E-04	4.5E-04	2.8E-04	7.3E-04	1.0E-04

Table 9 (cont'd)

Waterborne Emissions of Tuna Packaging Systems
(lb per 100,000 Ounces of Tuna Consumed)

	12-oz. Steel Can	12-oz. Pouch	6-oz. Steel Can	3-oz. Pouch	3-3-oz. Steel Cans in Paperboard	2-2.8-oz. Plastic Cups in Paperboard
Waterborne Wastes						
Nitrogen (ammonia)	0.049	3.7E-05	0.051	9.9E-05	0.069	0.010
Boron	0.0074	0.0043	0.0079	0.012	0.013	0.015
Organic Carbon	0.010	0.0065	0.011	0.018	0.018	0.0084
Cyanide	0.0012	2.3E-05	0.0012	6.1E-05	0.0020	5.5E-06
Hardness	23.5	13.6	24.9	36.7	42.3	47.0
Total Alkalinity	0.19	0.11	0.20	0.30	0.34	0.38
Surfactants	0.0023	0.0013	0.0024	0.0035	0.0042	0.0045
Acetone	2.4E-05	1.4E-05	2.5E-05	3.7E-05	4.3E-05	4.8E-05
Alkylated Benzenes	3.7E-05	1.2E-05	3.9E-05	3.4E-05	6.8E-05	2.8E-05
Alkylated Fluorenes	2.1E-06	7.2E-07	2.3E-06	1.9E-06	3.9E-06	1.6E-06
Alkylated Naphthalenes	6.1E-07	2.0E-07	6.4E-07	5.5E-07	1.1E-06	4.6E-07
Alkylated Phenanthrenes	2.5E-07	8.4E-08	2.7E-07	2.3E-07	4.6E-07	1.9E-07
Benzene	0.0040	0.0023	0.0042	0.0062	0.0072	0.0080
Cresols	1.4E-04	8.1E-05	1.5E-04	2.2E-04	2.5E-04	2.8E-04
Cymene	2.4E-07	1.4E-07	2.5E-07	3.7E-07	4.3E-07	4.7E-07
Dibenzofuran	4.5E-07	2.6E-07	4.8E-07	7.1E-07	8.1E-07	9.0E-07
Dibenzothiophene	3.7E-07	2.1E-07	3.9E-07	5.7E-07	6.6E-07	7.3E-07
2,4 dimethylphenol	6.6E-05	3.8E-05	7.0E-05	1.0E-04	1.2E-04	1.3E-04
Ethylbenzene	2.2E-04	1.3E-04	2.4E-04	3.5E-04	4.0E-04	4.5E-04
2-Hexanone	1.5E-05	8.9E-06	1.6E-05	2.4E-05	2.8E-05	3.1E-05
Methyl Ethyl Ketone (MEK)	1.9E-07	1.1E-07	2.0E-07	3.0E-07	3.4E-07	3.8E-07
1-methylfluorene	2.7E-07	1.6E-07	2.9E-07	4.2E-07	4.9E-07	5.4E-07
2-methyl naphthalene	3.8E-05	2.2E-05	4.0E-05	5.9E-05	6.8E-05	7.5E-05
4-methyl 2-pentanone	1.0E-05	5.8E-06	1.1E-05	1.6E-05	1.8E-05	2.0E-05
Naphthalene	4.3E-05	2.5E-05	4.6E-05	6.7E-05	7.8E-05	8.6E-05
Pentamethylbenzene	1.8E-07	1.0E-07	1.9E-07	2.8E-07	3.2E-07	3.6E-07
Phenanthrene	3.6E-07	2.6E-07	3.8E-07	7.0E-07	6.5E-07	8.2E-07
Toluene	0.0038	0.0022	0.0040	0.0059	0.0068	0.0076
Total Biphenyls	2.4E-06	2.2E-06	2.5E-06	6.0E-06	4.4E-06	6.4E-06
Total dibenzo-thiophenes	7.4E-09	6.9E-09	7.9E-09	1.9E-08	1.4E-08	2.0E-08
Xylenes	0.0020	0.0012	0.0021	0.0031	0.0036	0.0040
Radionuclides (unspecified)	3.0E-07	7.3E-08	3.2E-07	2.0E-07	5.2E-07	7.5E-08
Iron	0.0034	0.089	0.0036	0.24	0.0091	0.31
Chromium (hexavalent)	0	3.2E-06	0	8.7E-06	7.5E-08	9.8E-06
Aluminum	6.9E-05	0.040	7.3E-05	0.11	0.0017	0.13
Phosphates	0.012	5.0E-05	0.013	1.4E-04	0.017	0.0024
Phosphorus	0.0035	0	0.0037	0	0.0044	0
Bromide	2.1E-04	0.17	2.2E-04	0.45	0.0012	0.71
Lead 210	1.0E-16	8.1E-14	1.1E-16	2.2E-13	5.9E-16	3.5E-13
Methyl Chloride	3.9E-11	3.1E-08	4.1E-11	8.5E-08	2.3E-10	1.3E-07
Styrene	0	1.1E-08	0	2.9E-08	0	6.3E-08
Detergents	0	2.0E-05	0	5.5E-05	0	4.6E-06
Dissolved organics	0	0.0023	0	0.0063	0	5.3E-04
Other nitrogen	0	3.2E-07	0	8.8E-07	0	7.5E-08
Heavy metals	0	0.0011	0	0.0029	0	2.5E-04
Aldehydes	0	0.0025	0	0.0067	0	0.0017
Sodium dichromate	2.5E-07	0	2.6E-07	0	3.1E-07	0

Source: Franklin Associates, a Division of ERG calculations using the Franklin Associates database and the U.S. LCI Database.

SENSITIVITY ANALYSIS

Within the scope and boundaries of this analysis, the main variable of this case study is the weight of the tuna packaging. Using the ULS report, only one tuna manufacturer was cited for each package. Different tuna producers may use different package manufacturers which could have differing specification weights for their packages.

Due to this possibility, a sensitivity analysis has been performed on the weights of the main containers in the packaging systems. A 10 percent increase and decrease in the weights have been considered in this analysis. The following figures show the results from the main analysis using the ULS report weights, as well as the results for the increased and decreased weights. Figures 5, 6, and 7 show the total energy, total solid waste by weight and the greenhouse gases for 100,000 ounces of tuna consumed.

Overall, the results of this sensitivity analysis do not change the findings of the study.

Figure 5
Total Energy for Tuna Packaging
with a 10 Percent Difference in Package Weight
(Million Btu per 100,000 ounces of tuna consumed)

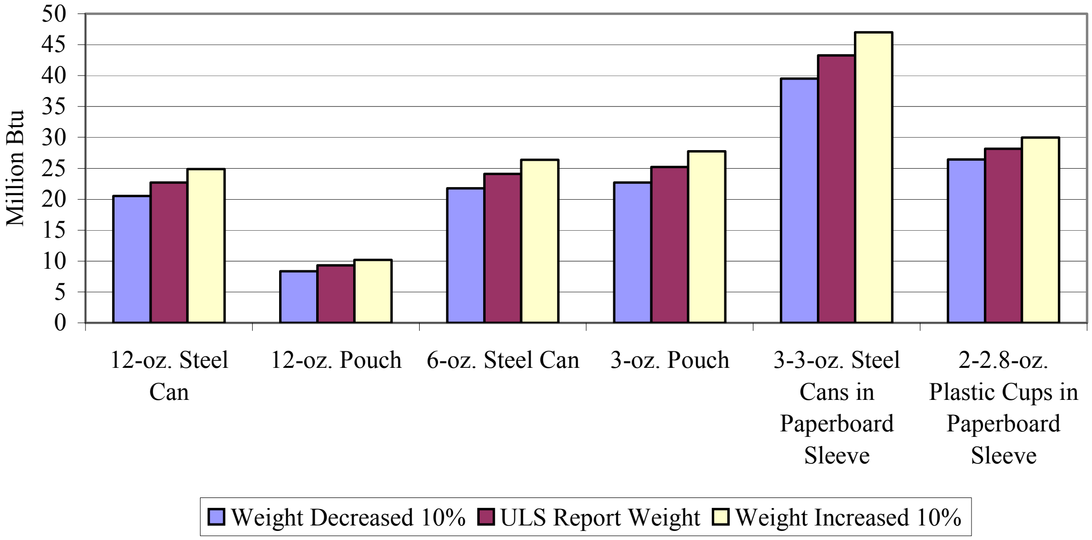


Figure 6
Total Solid Waste for Tuna Packaging
with a 10 Percent Difference in Package Weight
(Pounds per 100,000 ounces of tuna consumed)

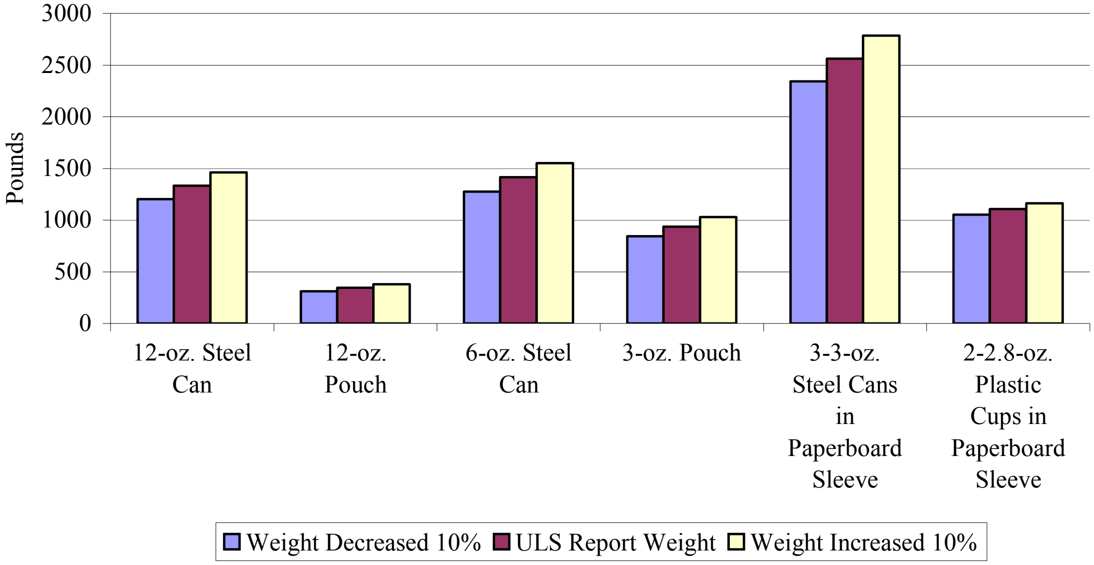
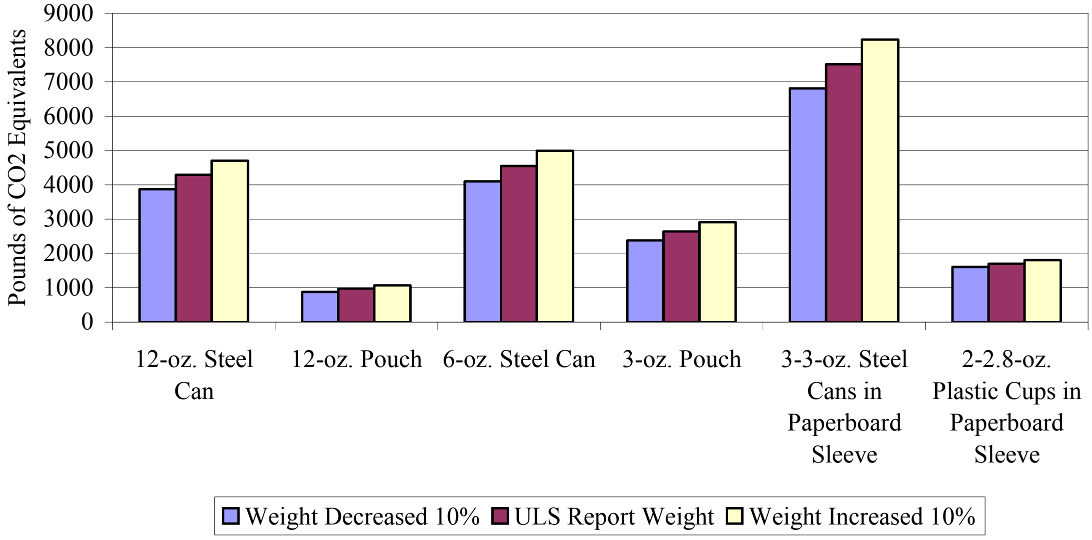


Figure 7
Total Greenhouse Gases for Tuna Packaging
with a 10 Percent Difference in Package Weights
(Pounds of CO2 Equivalents per 100,000 ounces of tuna consumed)



OVERVIEW OF FINDINGS

A life cycle inventory (LCI) is an environmental profile that identifies and quantifies environmental burdens from the perspective of energy consumption, solid waste generation, atmospheric emissions, and waterborne emissions. This LCI evaluated six tuna packaging systems on the basis of 100,000 ounces of tuna consumed. The following is an overview of the findings with respect to energy consumption, 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).

- The total energy of the 12-ounce pouch is significantly lower than the other five tuna packaging systems, due to the lighter weight of the pouch, as well as the larger package size.
- The total energy of the 3-3-ounce steel cans in the paperboard sleeve is significantly higher than the other five tuna packaging systems, due to the higher weight of the small cans, which hold small amounts of tuna, as well as the extra paperboard sleeve.
- The net energy of the 12-ounce pouch is significantly lower than the other five tuna packaging systems. The net energy of the 3-3-ounce steel cans in the paperboard sleeve is significantly higher than the other five tuna packaging systems. However, the remaining systems (12-ounce steel can, 6-ounce steel can, 3-ounce pouch, and 2-2.8-ounce plastic cups in the paperboard sleeve) are all considered to have equivalent energy amounts after the combustion energy credit is given.
- Due to the close proximity of the total energy for the 12-ounce steel can, 6-ounce steel can, 3-ounce pouch, and 2-2.8-ounce plastic cups in the paperboard sleeve systems, it is possible that including transportation of the materials to the filling plants or the transportation of the filled containers to retail would change the results of this analysis for those systems. It is unlikely that the results of the 12-ounce pouch or steel cans in the paperboard sleeve would change significantly in terms of their ranking relative to other packaging systems.

Solid Wastes

Solid waste is generated during all life cycle phases and can be measured in terms of weight and volume.

- When expressed on a *weight* basis, the 12-ounce pouch produces the lowest amount of total solid waste. This is due to the low weight of the packaging and high volume of product per package. The steel cans in the paperboard sleeve system produces the greatest amount of total solid waste. This is due to the weight of the three steel cans traced back to a combination of the postconsumer solid waste, as well as solid waste from processes and from fuel use.
- When expressed on a *volume* basis, the results for the 12-ounce pouch and steel cans in the paperboard sleeve systems are the same. However, although the solid waste by weight for the 6-ounce steel can system was considered greater than that of the plastic cup in the paperboard sleeve system, the solid waste by volume for these two systems are not considered significantly different. In the same way, although the solid waste by weight for the 3-ounce pouch system was not considered different than the plastic cups in the paperboard sleeve system, the solid waste by volume for the plastic cups in the paperboard system is considered a greater amount than that of the 3-ounce pouch system.

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 12-ounce pouch system produces the least amount of carbon dioxide equivalents. Even though more than 90 percent of the plastics' total energy is from fossil fuels, the energy of material resource amount produces no carbon dioxide equivalents as the fuels are never combusted except for the 20 percent going to the waste-to-energy facility.
- The steel cans in the paperboard sleeve system produces the greatest amount of carbon dioxide equivalents. This is mostly from fuel-related carbon dioxide due to the heavy weight of the system and the use of fossil fuels.

APPENDIX A

STUDY APPROACH AND METHODOLOGY

INTRODUCTION

The life cycle inventory presented in this study quantifies the total energy requirements, energy sources, atmospheric pollutants, waterborne pollutants, and solid waste resulting from the production of tuna packaging systems. 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 scope and boundaries established. Figure A-1 illustrates the general approach used in an LCI analysis. 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 components or processes) where changes would be most beneficial in terms of reduced energy use or environmental emissions.

GOAL OF THE STUDY

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

Six tuna packaging systems are considered in this LCI case study. These packages include a 12-ounce and 6-ounce steel can, a 12-ounce and 6-ounce laminate pouch, 3 3-ounce steel cans in a paperboard sleeve, and 2 2.8-ounce plastic cups in a paperboard sleeve. All lids, labels, and sleeves are included in each packaging system.

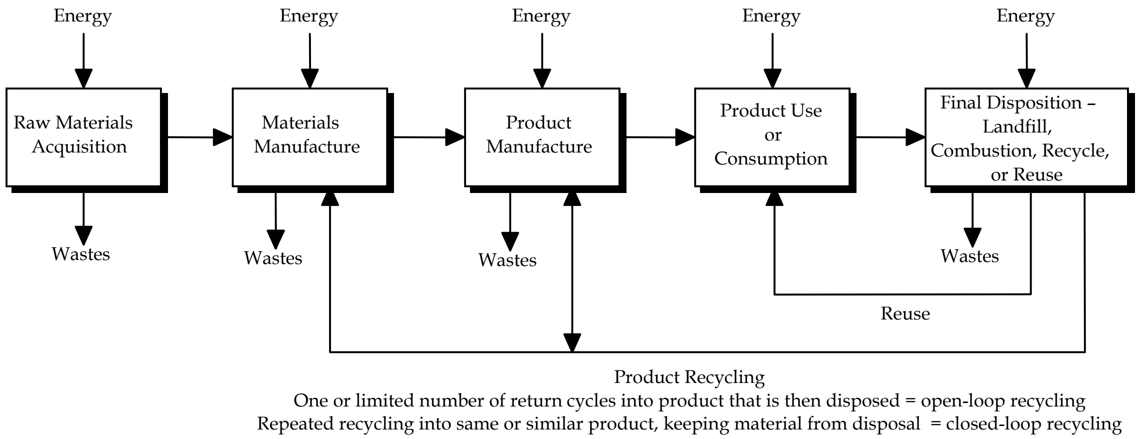


Figure A-1. General materials flow for "cradle-to-grave" analysis of a product

STUDY SCOPE

Functional Unit

In order to provide a basis for the reporting of LCI results, a 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 product. This common basis, or functional unit, is used to normalize the inputs and outputs of the LCI. A functional unit of 100,000 ounces of tuna consumed was chosen for this analysis.

System Boundaries

Beginning with acquisition of initial raw materials from the earth, this study examines the sequence of processing steps for the production of the tuna packaging systems. The secondary packaging, transportation to filling, filling, storage, distribution, and consumer steps are outside the scope and boundaries in this 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. The steel cans used as tuna containers are more commonly recycled, and so their end-of-life scenario includes a recycling rate.

Description of Data Categories

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

Figure 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.

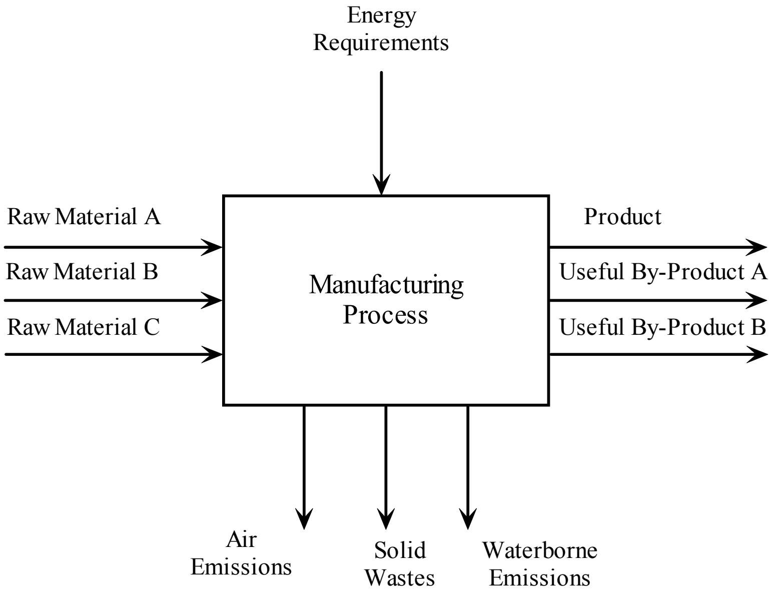


Figure A-2. "Black box" concept for developing LCI data

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

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

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

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

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

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

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

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

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

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

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

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

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

In one case, the evaluation of greenhouse gas emissions, this study applies the LCI results to LCIA (life cycle impact assessment). 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.

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

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

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

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

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

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

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

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

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

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

Inclusion of Inputs and Outputs

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

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

DATA

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 tuna packaging were taken from the U.S. LCI Database, which includes plastics data from the American Chemistry Council.

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 database 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, International Energy Agency 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 their fuels and energy database for inclusion in the U.S. LCI database. With the exception of the electricity fuel sources and generation, this U.S. fuels and energy database is used in this analysis. Because of differences in national environmental emissions regulations, as well as differences in fuel characteristics, the use of U.S. emissions factors may not be entirely representative of emissions for Europe.

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.

The data quality goal for this study is to use the best available and most representative data for the materials used and processes performed in terms of time, geographic, and technology coverage.

All 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 various tuna packaging, 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 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 container 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.

METHODOLOGY

There is general consensus among life cycle practitioners on the fundamental methodology for performing LCIs.[4] 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. These areas include the method used to allocate energy requirements and environmental releases among more than one useful product produced by a process, the method used to account for the energy contained in material feedstocks, and the methodology used to allocate environmental burdens for postconsumer recycled content and end-of-life recovery of materials for recycling. LCI practitioners vary to some extent in their approaches to these issues. The following sections describe the approach to each issue used in this study and the justification for the approach used.

Coproduct Credit

One unique feature of life cycle inventories is that the quantification of inputs and outputs are related to a specific amount of product from a process. However, controversy in LCI studies often occurs because it is sometimes difficult or impossible to identify which inputs and outputs are associated with one of multiple products from a process. The practice of allocating inputs and outputs among multiple products from a process is often referred to as "coproduct credit"[5] or "partitioning"[6].

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.

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[4] 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.

[5] 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.

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

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.[7],[8],[9],[10],[11]

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.

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.

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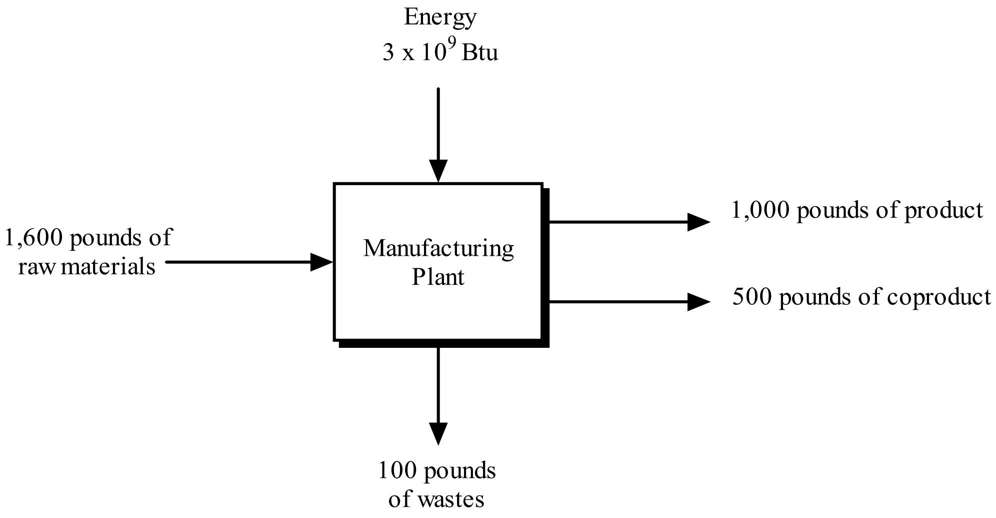
[7] Hunt, Robert G., Sellers, Jere D., and Franklin, William E. **Resource and Environmental Profile Analysis: A Life Cycle Environmental Assessment for Products and Procedures.** Environmental Impact Assessment Review. 1992; 12:245-269.

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

[9] 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.

[10] **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.

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



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

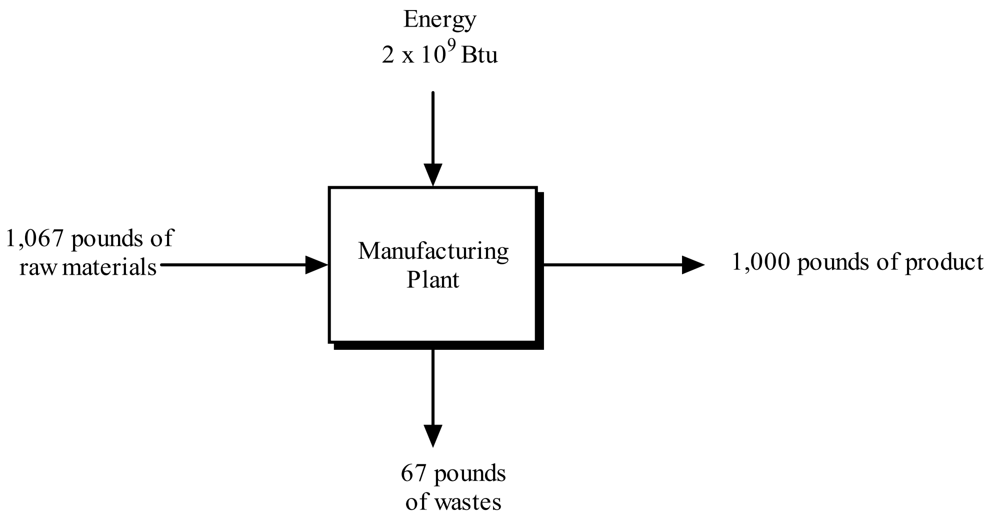


Figure A-3. Flow diagram illustrating coproduct mass allocation for a product.

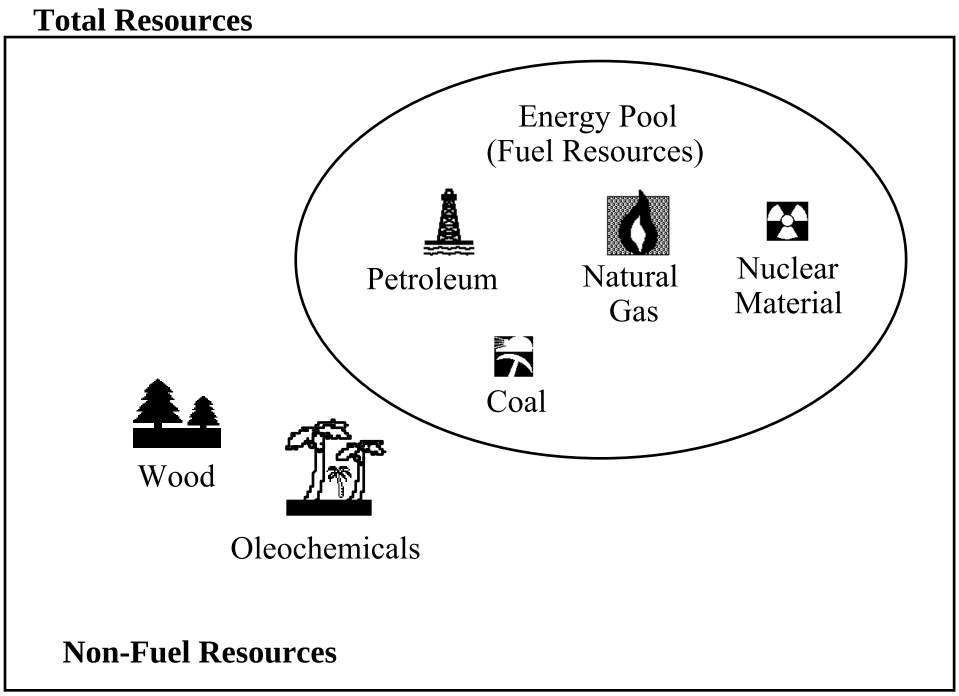


Figure A-4. Illustration of the Energy of Material Resource concept.

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

Recycling

Recycling is 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.

Steel food cans are made from BOF steel, which contains 33 percent postconsumer recycled scrap. This recycled content is treated as closed-loop recycling, carrying no burdens for virgin production. After use, steel food cans are recycled at a rate of 62 percent. The recycling rate is greater than the closed-loop recycled content of the steel; thus, the additional 29 percent of cans that are recycled (62 percent recycling – 33 percent recycled content) are modeled as open-loop recycling, since the end use (and subsequent recovery/recycling) of that recycled material is not known. For open-loop recycling, the energy and emissions of virgin material manufacture, recycling, and eventual disposal of the recycled material are divided evenly between the first and second product. This analysis assumes that the recycled material replaces virgin material when producing the second product.

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.

GENERAL DECISIONS

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

Geographic Scope

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

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

Precombustion Energy and Emissions

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

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

Electricity Fuel Profile

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

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

The following components of each system are not included in this 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. These types of capital equipment are used to produce large quantities of product output over a useful life of many years. Thus, energy and emissions associated with production of these facilities and equipment generally become negligible when allocated to 1,000-pound product output modules.

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

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

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

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

Emissions from Combustion and Landfilling of Postconsumer Waste. 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 packaging 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, emissions from incineration of packaging components in mixed MSW are not included in the analysis.

Similarly, emissions of methane and carbon dioxide from aerobic and anaerobic decomposition of landfilled paperboard components are not estimated for this analysis, nor are estimates of leachate from landfilled packaging items included. Historically, LCI studies have not included emissions from landfilled materials because of a lack of data of suitable quality.

Although some packaging components in this study contain bio-based materials (such as paperboard) that may degrade in a landfill, the fate of degradable materials in a landfill is a very complex subject. A large number of variables come into play, such as moisture, permeability of cover, temperature, pH of surroundings, and time. Landfill decomposition generally is strongly affected by moisture content, which is highly variable from landfill to landfill, and even more so from place to place within a landfill. Anaerobic decomposition proceeds only under a narrow range of environmental conditions, including appropriate temperature, pH, and moisture level.

Decomposition in a landfill proceeds by some combination of aerobic and anaerobic processes. At first, there is air entrapped in the landfill, but with time, probably within a few weeks or months, the conditions become anaerobic. Time is also an element to consider. It may take a century or more for degradable material to decompose completely in a landfill, although many products are suspected to partially decompose rapidly at first.

Even when degradable materials decompose, not all gas produced by the decomposition enters the atmosphere. Some methane reacts with other chemicals in a landfill, some is oxidized in the soil, and some is recovered and flared or burned as a fuel. Possibly an even greater fraction of CO_2 generated never makes it through the landfill cover because it is soluble in water and may exit the landfill as leachate.

In summary, emissions from landfills (particularly greenhouse gas emissions) are potentially important to consider in LCI calculations, but it is premature to report them along with other LCI emissions data until there is general agreement among experts on an acceptable methodology for estimating actual releases.

Readers interested in this topic may wish to refer to the report EPA530-R-02-006, **Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks**, 2nd edition, May 2002, available at www.epa.gov. This report presents data on net GHG releases from WTE combustion and landfilling of various products and materials in municipal solid waste. It is beyond the scope of this study to attempt to evaluate the applicability of the EPA GHG methodology and models to the specific packaging components studied in this analysis.

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 tuna packaging system analysis. The flow diagrams are shown as cradle-to-gate (material). The flow diagrams included are shown in Figures B-1 through B-6 as listed below.

- Steel cans
- Bleached kraft paper
- PET resin
- PP resin
- Aluminum foil
- Coated unbleached kraft paperboard

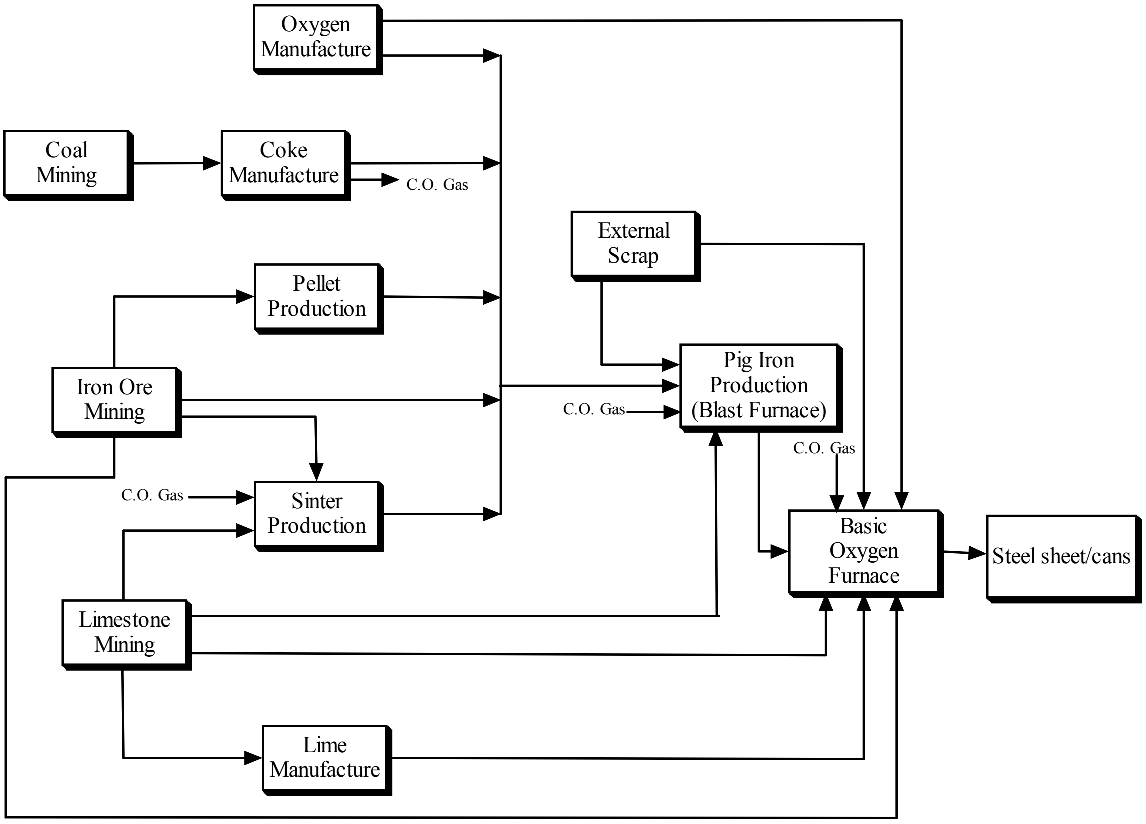


Figure B-1. Flow diagram for the manufacture of steel cans using the basic oxygen furnace.

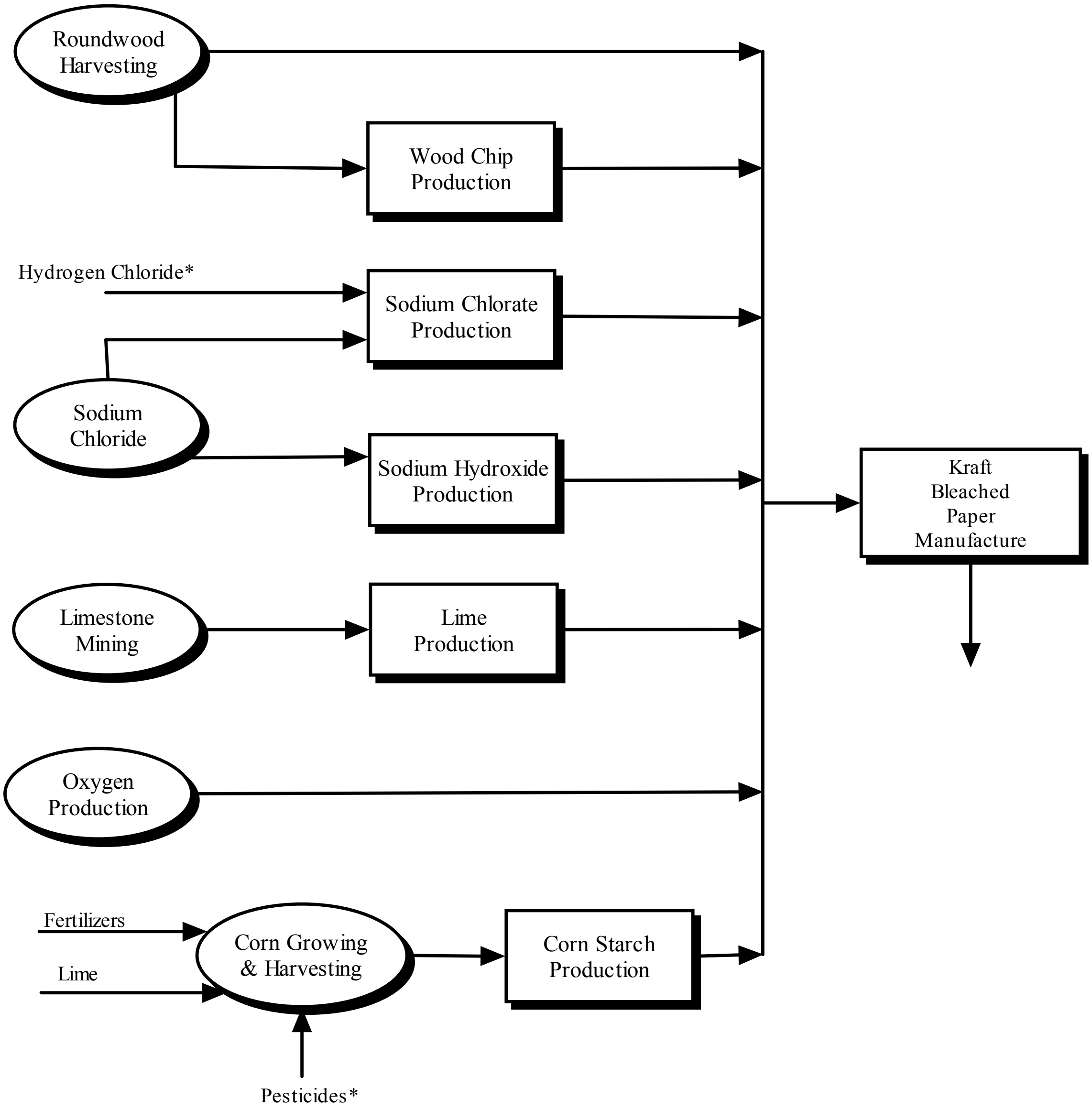


Figure B-2. Flow diagram for the manufacture of bleached paper.
* These materials are considered negligible in the model.

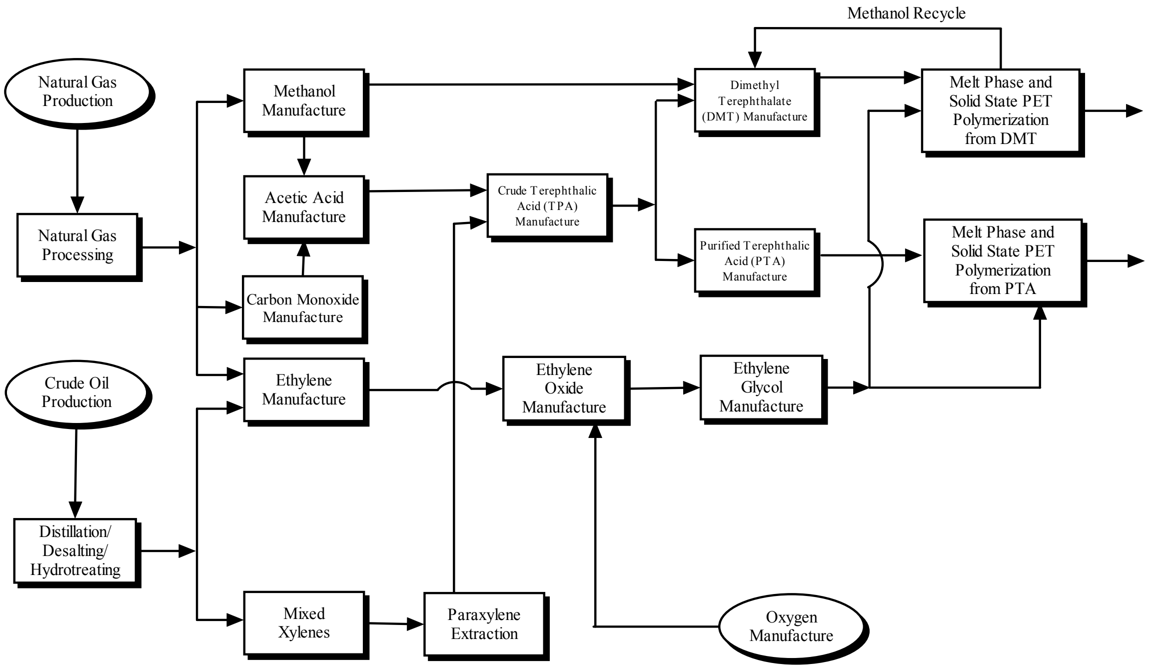


Figure B-3. Flow diagram for the manufacture of polyethylene terephthalate(PET) resin.

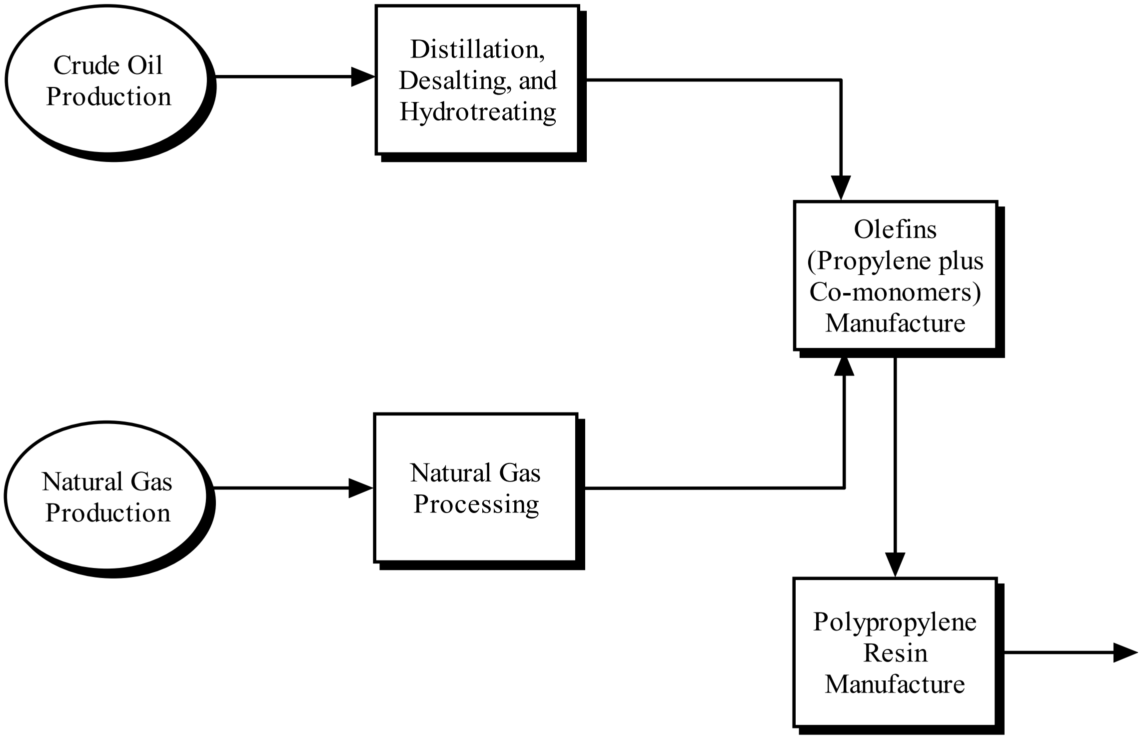


Figure B-4. Flow diagram for the manufacture of polypropylene (PP) resin.

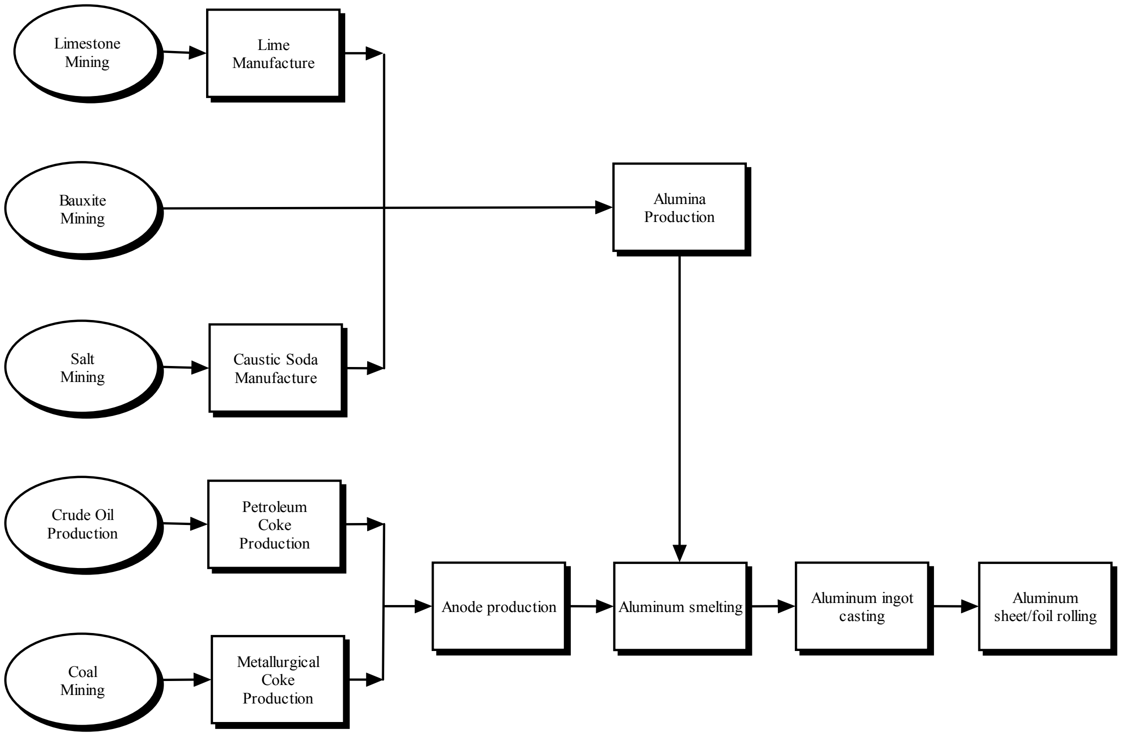


Figure B-5. Flow diagram for the manufacture of 1,000 pounds of primary aluminum foil.

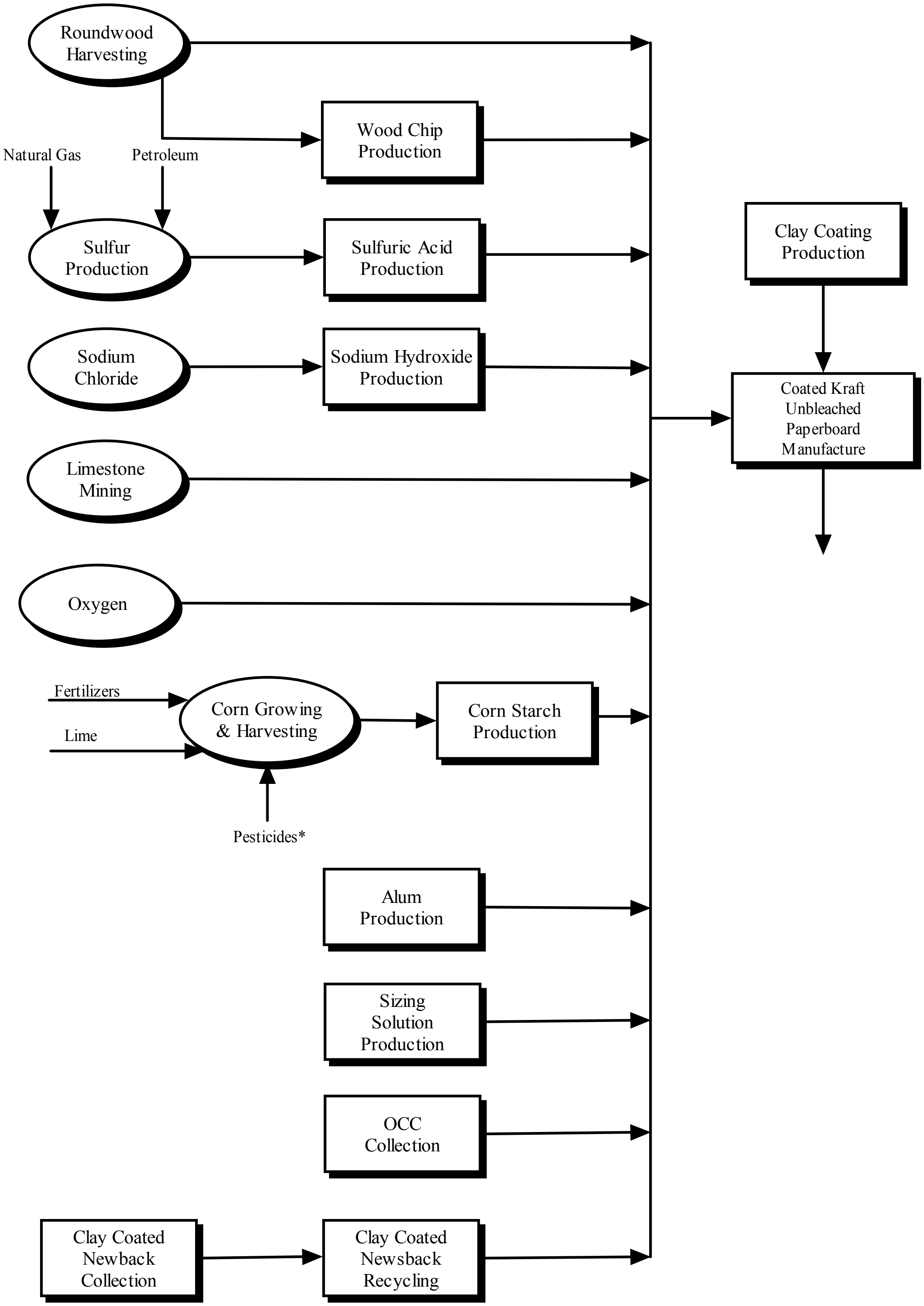


Figure B-6. Flow diagram for the manufacture of clay-coated unbleached paperboard.
* These materials are considered negligible in the model.

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 tuna packaging. 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
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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 has been unambiguously restated. The goal of the tuna packaging study is to explore the relationship between the weight and material composition of primary tuna packages and the associated life cycle profile of each tuna package. The report includes discussion of the results for the tuna packages, 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.

Steel food cans are made from BOF steel, which contains 33 percent postconsumer recycled scrap. This recycled content is treated as closed-loop recycling, carrying no burdens for virgin production. After use, steel food cans are recycled at a rate of 62 percent. The recycling rate is greater than the closed-loop recycled content of the steel; thus, the additional 29 percent of cans that are recycled (62 percent recycling – 33 percent recycled content) are modeled as open-loop recycling, since the end use (and subsequent recovery/recycling) of that recycled material is not known.

- 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.

Both of these suggested scenarios are likely true for an unknown percent of these packaging systems. However, no data is available to reveal the current scenario for the labels and lids. Therefore, for the lids, we have added the possibility of these scenarios to the Limitations and Assumptions section of the case studies, but have not changed the assumption itself. We agree that the paper labels are more likely left on the steel cans and so have assumed that these are incinerated within the steel recycling. We have included the landfilling of the ash after incineration for the paper labels on 62 percent of the steel cans. No energy credit has been given for the incineration of the paper labels.

- 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.

  A limitation has been added to the Limitations and Assumptions section of each case study stating that transportation from the packaging plant to the filling plants is not included.

- 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.

  This comment pertains to the Milk Container LCI only and is answered in the Peer Review Appendix of that case study.

- "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 Data Sources section of the Methodology appendix.

Tuna Packaging LCI

- The report assumes filling, storage, distribution, and consumer activities are equivalent for all containers. However, this statement is not strictly true. Tuna in laminated packages may not contain the water found in cans. This difference can affect transportation energy requirements as well as water emissions, since some consumers drain canned tuna water to sewer.

  This statement has been revised to say these processes are not included in the boundaries of the project.

- Consumers may not consume all the tuna in a 12oz package and may refrigerate the leftovers; smaller sizes may be more appropriate for smaller households.

A discussion of this has been added to the Limitations and Assumptions section.

- Tables 5 and 6 present solid waste results but the table rows are labeled “Total Energy”.

  This error has been corrected.

- The report states on page 37, “The steel can and plastic canister systems of this analysis are assumed to be recycled once (n=1).” The container descriptions need to be corrected; “canister” is referring to the Coffee Packaging LCI.

  That sentence has been deleted, and the Recycling section revised.