LIFE CYCLE ASSESSMENT OF PREDOMINANT U.S. BEVERAGE CONTAINER SYSTEMS FOR CARBONATED SOFT DRINKS AND DOMESTIC STILL WATER

Final Peer Reviewed Report

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PREFACE

This life cycle assessment of PET bottles and alternative containers for U.S. carbonated soft drinks and domestic bottled non-carbonated (still) water was funded by the National Association for PET Container Resources (NAPCOR). The report was prepared for NAPCOR by Franklin Associates, A Division of Eastern Research Group, Inc. as an independent contractor. The project was managed and primarily authored by Beverly Sauer, Senior LCA Analyst, with support from Mariya Absar.

Franklin Associates gratefully acknowledges the significant contributions of Lauren Laibach of NAPCOR in leading this project, as well as the expert advice and guidance of David Cornell. We also thank the NAPCOR member companies who provided detailed data on PET preform molding, bottle stretch blow molding, and transportation between manufacturing and filling locations. The primary data they provided added considerably to the quality of the PET bottle modeling and results for this LCA report. Franklin Associates also appreciates the insightful comments of the peer review panel members: Beth Quay, Dr. Sue Selke, and Dr. Greg Keoleian. Revisions made in response to their review comments improved the quality and transparency of the report.

Franklin Associates makes no statements about the systems studied other than those presented within the report.

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EXECUTIVE SUMMARY

OVERVIEW

This LCA evaluates environmental impacts for several widely used types and sizes of containers used to package carbonated soft drinks and domestic still (non-carbonated) drinking water purchased at grocery or convenience stores in the U.S. The intended use of the study is to provide NAPCOR and its members with information to understand and communicate environmental impacts for PET containers and how they compare with competing beverage containers in these markets.

The analysis focuses on containers that account for the majority of U.S. sales volume in the defined applications where PET competes with glass and aluminum containers, based on market data. The beverage container systems analyzed are summarized in Table 1. The 2 liter PET CSD bottle is the only multi-serve container included in the analysis. Although no similarly sized aluminum or glass containers are modeled, the 2 liter PET CSD bottle is included because it accounts for a significant share of CSD sales by volume. The study does not include refillable containers that are reused multiple times, with backhauling and cleaning between uses because refillable CSD and bottled water containers of the sizes evaluated in this study are currently not widely used or available to U.S. consumers.

Table 1 shows that two weights are evaluated for PET water bottles used for bottled domestic spring and purified water: a weight representative of widely available lightweight water bottles (often store brands of purified tap water), and a weight representative of more rigid mid-weight bottles (excluding heavy bottles generally used for select premium imported brands of natural water, which account for a much smaller share of sales volume than domestic spring and purified water).

The baseline results for PET bottles are based on 10% postconsumer recycled content, the current average based on NAPCOR information. A sensitivity analysis is included with results for each size and weight of PET bottle run with 0%, 25%, and 50% recycled content.

For aluminum cans, modeling is based on the Aluminum Association's (AA) 2021 aluminum can LCA, but with two scenarios modeled for postconsumer recycled content. The total recycled content of the aluminum can is reported in the AA 2021 study as 73%. The recycled content reported includes postconsumer (PC) scrap and 167 kg of postindustrial (PI) scrap per 1000 kg of can ingot. The AA study treats the PI scrap the same as PC scrap, However, in the methodology used in this LCA, virgin material production burdens are assigned to material's first useful life in a product, and PC material comes into a system with only the burdens for collection and reprocessing. Since PI scrap has not yet been used in a finished product, PI scrap would normally be modeled as coming into a system with virgin material production burdens, unless there is information about PC content in the PI scrap, which is not the case in the 2022 AA report.

One scenario in this analysis follows the approach used in the AA report and treats all the 73% recycled content, both the PC and PI scrap, the same as PC scrap, with no virgin aluminum production burdens, only burdens for scrap reprocessing (shredding and remelting).

A second scenario assigns some virgin material burdens to the PI scrap since it has not had a previous useful life in a product. Since many aluminum products are made with PC recycled content, it is likely that there is at least some PC content in the PI scrap going into aluminum can ingot. Therefore, results for aluminum cans were also run with the PI scrap modeled as a 50/50 mix of virgin and postconsumer aluminum. For this scenario, only the PC content of the PI scrap was included in the calculation of can recycled content, reducing the PC recycled content of the can from 73% to 62.3%. The other half of the PI scrap input was assigned virgin aluminum production burdens.

Table 1. Container System Component Weights

	Size/Beverage	Avg Ctr Wt (g)	Ctrs/ 1000 gal	Postconsumer Recycled	Recycling Rate	Closure Wt (g)	Closure Material	Label Wt (g)	Label Material
PET	500 ml water - light	8.22	7,574	10% (baseline), sensitivity on 0%, 25%, 50%	29.1%	1.00	HDPE	0.23	OPP Film
	500 ml water - avg	11.2							
	16.9 oz CSD	22.1	7,574			2.51		0.32	
	20 oz CSD	22.2	6,400			2.37		0.30	
	2 liter CSD	43.9	1,893			2.28		1.36	
Aluminum Cans	12 oz CSD or water	12.7	10,667	73%, 62.3%	50.4%	*			
	16 oz CSD or water	15.1	8,000			*			
Glass	12 oz CSD	208	10,667	38%	39.6%	2.10	Steel	1.19	Paper**

*For aluminum cans, lid weight is included in the container weight.
**Results are also run for a glass bottle with no paper label.

Two-liter PET bottles and single-serve containers sold in multipacks (16.9 oz CSD in PET, 500 ml water in PET, 12 oz aluminum cans, 12 oz glass bottles) were modeled as transported to grocery stores on semi trucks, while larger single-serve containers sold individually (20 oz CSD in PET, 16 oz aluminum cans) were modeled as transported to convenience stores on single-unit delivery trucks. For containers sold in multipacks, packaging information is provided in Table 2. No multipack packaging was modeled for the containers sold as individual containers (2 liter PET CSD, 20 oz PET CSD, and 16 oz aluminum can).

Table 2. Multipack Packaging for Beverage Containers

	Size/Beverage	Multipack Type	Multipack Wt (g)	Containers/ Multipack	Multipack Wt (g/ctr)	Recycled Content	Recycling Rate
PET	500 ml water	LDPE film shrink wrap	27.2	24	1.13	0%	10%
	16.9 oz CSD	LDPE film ring	4.4	6	0.73	0%	0%
	20 oz CSD	individual bottle					
	2 liter CSD	individual bottle					
Aluminum Cans	12 oz CSD or water	unbleached paperboard	87.3	12	7.27	0%	20.8%
	16 oz CSD or water	individual can					
Glass	12 oz CSD	unbleached paperboard	54.2	4	13.6	0%	20.8%

The analysis examined production of the components of each container system, transport of empty containers to fillers and filled containers to distribution centers, and end-of-life management of the container system components. The following metrics were evaluated for each system:

- **Life cycle inventory (LCI) metrics:** Total energy demand, non-renewable energy demand, solid waste, water consumption
- **Life cycle impact assessment (LCIA) metrics:** Global warming potential (GWP), acidification potential, eutrophication potential, ozone depletion potential, and smog formation potential For GWP, contributing emissions are characterized using factors from the Intergovernmental Panel on Climate Change (IPCC) 2013 assessment report with a 100 year time horizon.[1] For all other LCIA metrics, the TRACI 2.1 method, developed by the United States Environmental Protection Agency (EPA) specific to U.S. conditions and updated in 2012, is used.[2]

BASELINE RESULTS

The results tables presented in this Executive Summary show the magnitude of results for each system, but do not indicate whether differences between results for individual systems are large enough to be considered meaningful when uncertainties in the background data and modeling are taken into account. Statements about meaningful or inconclusive differences between systems are based on tables in Chapters 2 and 3 of the full report that apply uncertainty thresholds to comparisons of individual systems. The following approach is used: Energy differences are not considered meaningful unless the percent difference between two systems' results exceeds 10 percent. For all other metrics evaluated, the percent difference threshold used is 25 percent. Percent difference is defined as the difference between two system totals divided by their average. These threshold guidelines are based on the experience and judgment of ERG's LCA analysts and are not intended to be interpreted as rigorous statistical uncertainty analysis. Rather, they are provided as general guidelines for readers to use when interpreting differences in system

1 IPCC, 2013: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013.

2 Bare, J. C. Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI), Version 2.1 - User's Manual; EPA/600/R-12/554 2012.

results, to ensure that undue importance is not placed on differences that fall within the uncertainties of the underlying data.

Results for the beverage container systems are expressed on the basis of an equivalent volume functional unit of 1,000 gallons of delivered beverage. System expansion recycling methodology is used for the baseline results. With this methodology, the system boundaries are expanded to include recycling processes for containers recovered for recycling, and the system is credited with avoiding virgin material production if the system's recycling rate (RR) exceeds the system's use of recycled content (RC). If the system's RC is greater than its RR, the system is a net consumer of recycled material and is charged with virgin material burdens to make up for the system's net depletion of the available supply of postconsumer recycled material. For the PET container system with a RC of 10% and a RR of 29.1%, the system produces more recycled PET than it used, so the system receives credits for avoiding some virgin PET production. For aluminum cans, the RR is 50.4%, so both RC scenarios (73% and 62.3%) are charged with some virgin aluminum burdens to make up the deficit between RR and RC. For glass containers, the 38% RC is nearly identical to the 39.6% RR, so avoided virgin material credits for RR>RC are minimal.

Results for 1,000 gallons of beverage for each system are summarized in Table 3 for CSD containers and in Table 4 for water containers. For PET water container systems, no comparisons are made with glass bottles, since the glass bottle samples weighed and modeled in the analysis are specifically used for carbonated soft drinks, and glass bottles used for water may vary in size and weight.

Table 3. Summary of Results for CSD Container Systems, 1,000 Gallon Basis, System Expansion Recycling Methodology

System Totals	Units	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Cumulative Energy Demand	MJ	13,355	10,997	6,190	22,197	21,848	16,355	16,045	38,781	37,914
Non-renewable Energy	MJ	12,966	10,707	6,066	16,907	18,112	13,451	14,522	33,852	33,852
Solid Waste	kg	147	120	67.6	381	372	280	272	1,698	1,682
Water Consumption	liters	3,310	2,766	1,541	3,757	3,733	3,093	3,072	9,867	9,736
Global Warming Potential	kg CO2 eq	623	521	296	1,241	1,218	990	969	2,608	2,566
Acidification Potential	kg SO2 eq	2.21	1.87	1.05	6.87	6.70	5.54	5.39	14.6	14.4
Eutrophication Potential	kg N eq	0.11	0.094	0.055	0.19	0.19	0.14	0.14	0.68	0.67
Ozone Depletion Potential	kg CFC-11 eq	5.5E-05	4.6E-05	2.7E-05	7.2E-06	7.2E-06	5.1E-06	5.0E-06	9.1E-06	8.5E-06
Smog Formation Potential	kg O3 eq	38.8	32.5	18.7	75.2	74.0	58.1	57.0	350	348

Applying the percent difference threshold values described previously, the following conclusions can be made for the baseline system expansion results for PET CSD beverage container systems modeled with 10% RC compared with other systems:

- All PET CSD sizes show lower results compared to aluminum and glass container systems for the following metrics: cumulative energy demand, solid waste, global warming potential, acidification potential, and smog formation potential. PET containers also show lower results for non-renewable energy and eutrophication, with the exceptions of comparisons of 16.9 oz PET and 16 oz Al cans with 73% RC, where differences are not large enough to be considered conclusive.

- PET CSD systems consistently show higher ozone depletion results compared to other CSD systems, due mainly to methyl bromide emissions from production of TPA/PTA for PET resin.
- Water consumption comparisons between PET bottles and competing systems are all either lower for PET bottles or inconclusive. Water consumption for all sizes of PET CSD bottles are lower than the 12 oz glass bottle systems. The 2L PET system shows lower water consumption compared to all aluminum can scenarios, while the 16.9 oz PET bottle shows inconclusive differences compared with all aluminum scenarios. The 20 oz PET bottle shows lower water consumption compared with 12 oz can scenarios, but inconclusive differences compared with 16 oz can scenarios.

Table 4. Summary of Results for Water Container Systems, 1,000 Gallon Basis, System Expansion Recycling Methodology

System Totals	Units	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
Cumulative Energy Demand	MJ	7,106	5,610	22,197	21,848	16,355	16,045
Non-renewable Energy	MJ	7,049	5,602	16,907	18,112	13,451	14,522
Solid Waste	kg	77.9	61.2	381	372	280	272
Water Consumption	liters	1,755	1,351	3,757	3,733	3,093	3,072
Global Warming Potential	kg CO2 eq	328	254	1,241	1,218	990	969
Acidification Potential	kg SO2 eq	1.18	0.92	6.87	6.70	5.54	5.39
Eutrophication Potential	kg N eq	0.060	0.047	0.19	0.19	0.14	0.14
Ozone Depletion Potential	kg CFC-11 eq	2.8E-05	2.1E-05	7.2E-06	7.2E-06	5.1E-06	5.0E-06
Smog Formation Potential	kg O3 eq	21.3	16.7	75.2	74.0	58.1	57.0

For PET domestic bottled still water container systems with 10% RC compared to aluminum cans, both the average and lightweight PET bottle systems show notably lower results than the aluminum can scenarios for nearly all metrics evaluated. As with CSD system results, ozone depletion potential results for both PET water bottle systems are significantly higher than ODP results for all aluminum can scenarios.

SENSITIVITY ANALYSES

Several sensitivity analyses were run to examine the effect on results and conclusions, including the following sensitivies summarized here:

- Alternative recycling methodology (cut-off methodology)
- Variations in recycled content for PET bottles
- 21 g preform for 20 oz and 16.9 oz PET bottles
- Updated aluminum data

Additional sensitivities in the main report include:

- Use of equivalent number of containers basis for single-serve containers
- No recycling of PET water bottle film packaging
- Bottle bill recycling rate for all containers

Cut-off Recycling Methodology

Unlike the system expansion methodology used for the baseline results, the cut-off methodology does not consider the balance between a system's recycled content and end-of-life recycling rate. Containers that are recycled at end of life leave the system boundaries with no burdens or credits; recycling simply reduces the amount of containers disposed and the associated disposal impacts. The cut-off methodology favors systems with high recycled content. Results using the cut-off methodology are shown in Table 5 for CSD containers and Table 6 for water containers.

The comparisons of PET and aluminum can systems are somewhat less favorable for PET when cut-off modeling is used, since the PET systems no longer receive avoided virgin PET credits for having a recycling rate that is greater than the system's 10% recycled content, while the aluminum can systems are not penalized for using more recycled aluminum than is replaced by end-of-life recycling of cans. Since the glass bottle recycled content and recycling rate are nearly identical, there is little change in results for glass bottle system results using the cut-off method. In most cases, the PET system results are still lower than or not significantly different from the aluminum systems. Ozone depletion potential results are still higher in all cases for PET systems.

Table 5. Summary of Results for CSD Container Systems, 1,000 Gallon Basis, Cut-off Recycling Methodology

System Totals	Units	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Cumulative Energy Demand	MJ	15,077	12,458	6,965	18,579	20,131	12,506	13,885	33,739	32,872
Non-renewable Energy	MJ	14,654	12,089	6,788	13,681	16,165	10,559	12,764	27,623	27,623
Solid Waste	kg	148	121	68.1	275	313	183	218	1,605	1,590
Water Consumption	liters	3,112	2,597	1,435	3,460	3,539	2,819	2,888	7,559	7,428
Global Warming Potential	kg CO2 eq	657	550	311	951	1,050	729	817	2,201	2,159
Acidification Potential	kg SO2 eq	2.32	1.97	1.10	4.95	5.66	3.81	4.44	11.4	11.3
Eutrophication Potential	kg N eq	0.11	0.097	0.056	0.17	0.18	0.12	0.12	0.55	0.54
Ozone Depletion Potential	kg CFC-11 eq	6.9E-05	5.9E-05	3.4E-05	7.2E-06	7.5E-06	4.6E-06	4.8E-06	1.0E-05	9.3E-06
Smog Formation Potential	kg O3 eq	41.9	35.2	20.2	61.2	66.2	45.1	49.5	271	270

Table 6. Summary of Results for Water Container Systems, 1,000 Gallon Basis, Cut-off Recycling Methodology

System Totals	Units	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
Cumulative Energy Demand	MJ	8,014	6,350	18,579	20,131	12,506	13,885
Non-renewable Energy	MJ	7,907	6,288	13,681	16,165	10,559	12,764
Solid Waste	kg	78.5	61.7	275	313	183	218
Water Consumption	liters	1,658	1,285	3,460	3,539	2,819	2,888
Global Warming Potential	kg CO2 eq	346	269	951	1,050	729	817
Acidification Potential	kg SO2 eq	1.23	0.96	4.95	5.66	3.81	4.44
Eutrophication Potential	kg N eq	0.062	0.049	0.17	0.18	0.12	0.12
Ozone Depletion Potential	kg CFC-11 eq	3.5E-05	2.6E-05	7.2E-06	7.5E-06	4.6E-06	4.8E-06
Smog Formation Potential	kg O3 eq	22.9	18.0	61.2	66.2	45.1	49.5

Variations in PET Recycled Content

The baseline results for PET bottles are based on 10% recycled content. Although recycled PET makes up 10% of the average weight of PET used in U.S. bottles, not all PET bottles in the market have recycled content. Therefore, results for PET bottles were run with 0% recycled content. Results for PET CSD and water bottles were also modeled with 25% and 50% recycled content, corresponding to goals stated by several major beverage companies. Fifty percent RC is a longer-term goal, for 2030, and the 25% RC goal is also a 2025 California goal. Results of the PET recycled content sensitivities for both recycling methodologies for CSD bottles are shown in Table 7, and results for water bottles are shown in Table 8.

For virgin PET CSD and water bottles (0% recycled content) compared to alternative container systems, using no recycled content increases the impacts for the bottle material inputs, but effects on end-of-life modeling are different for the two recycling methodologies.

- For system expansion results, the virgin PET systems get a larger avoided virgin PET credit for end-of-life recycling. Since bottle recycling does not need to replace any recycled content used in the bottle, all the recovered PET is credited with displacing virgin PET production.
- For cut-off recycling methodology, the virgin PET systems show higher results compared to the virgin PET system expansion results, since the cut-off results do not include credits for the recycled bottles avoiding virgin PET production.

For PET bottles evaluated with higher recycled content, using more recycled content reduces the impacts for the bottle material inputs, but effects on end-of-life modeling are different.

- For system expansion results, the 25% RC PET systems' RC is closer to the 29.1% RR, reducing the avoided virgin PET credits compared to the 10% RC PET results. At 50% RC, the PET systems' use of RC is higher than the 29.1% RR, and the PET systems have some virgin PET burdens added to make up the deficit, like the aluminum can systems.
- For cut-off recycling methodology, the 25% RC PET systems show higher results compared to 25% RC system expansion results, since the cut-off results do not include credits for producing more recycled PET than the systems use. However, 50% RC PET systems show more favorable cut-off results compared to system expansion results, since the systems do not get added virgin burdens for using more recycled content than is replaced by PET container recycling.

Table 7. Summary of Results for CSD Container Systems, 1,000 Gallon Basis, Variations in PET Recycled Content

	Units	16.9 oz PET CSD, 0% RC, 29.1% RR	16.9 oz PET CSD, 25% RC, 29.1% RR	16.9 oz PET CSD, 50% RC, 29.1% RR	20 oz PET CSD, 0% RC, 29.1% RR	20 oz PET CSD, 25% RC, 29.1% RR	20 oz PET CSD, 50% RC, 29.1% RR	2L PET CSD, 0% RC, 29.1% RR	2L PET CSD, 25% RC, 29.1% RR	2L PET CSD, 50% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR,
System Totals, System Expansion																
Cumulative Energy Demand	MJ	13,112	13,720	14,328	10,790	11,307	11,823	6,069	6,371	6,673	22,197	21,848	16,355	16,045	38,781	37,914
Non-renewable Energy	MJ	12,667	13,233	13,798	10,400	10,880	11,360	5,855	6,136	6,416	16,904	16,662	13,451	13,236	33,941	33,646
Solid Waste	kg	146	148	150	119	121	123	67.2	68.2	69.2	381	372	280	272	1,698	1,682
Water Consumption	liters	3,145	3,556	3,967	2,626	2,975	3,324	1,459	1,663	1,867	3,757	3,733	3,093	3,072	9,867	9,736
Global Warming Potential	kg CO2 eq	608	645	681	508	539	570	289	307	325	1,241	1,218	990	969	2,608	2,566
Acidification Potential	kg SO2 eq	2.17	2.28	2.40	1.83	1.93	2.03	1.03	1.09	1.15	6.87	6.70	5.54	5.39	14.6	14.4
Eutrophication Potential	kg N eq	0.11	0.12	0.13	0.091	0.10	0.11	0.053	0.058	0.064	0.19	0.19	0.14	0.14	0.68	0.67
Ozone Depletion Potential	kg CFC-11 eq	5.4E-05	5.5E-05	5.5E-05	4.6E-05	4.6E-05	4.7E-05	2.7E-05	2.7E-05	2.7E-05	7.2E-06	7.2E-06	5.1E-06	5.0E-06	9.1E-06	8.5E-06
Smog Formation Potential	kg O3 eq	38.0	39.9	41.8	31.9	33.5	35.2	18.4	19.3	20.3	75.2	74.0	58.1	57.0	350	348
System Totals, Cut-off																
Cumulative Energy Demand	MJ eq	15,858	13,905	11,952	13,121	11,463	9,805	7,353	6,384	5,414	18,579	20,131	12,506	13,885	33,739	32,872
Non-renewable Energy	MJ eq	15,331	13,359	11,387	12,643	10,970	9,296	7,081	6,102	5,123	13,690	14,726	10,559	11,479	27,635	27,340
Solid Waste	kg SW	148	147	145	121	120	118	68.5	67.6	66.7	275	313	183	218	1,605	1,590
Water Consumption	liter H2O	3,079	3,161	3,242	2,569	2,638	2,707	1,419	1,460	1,500	3,460	3,539	2,819	2,888	7,559	7,428
Global Warming Potential	kg CO2 eq	680	624	568	569	521	474	323	295	267	951	1,050	729	817	2,201	2,159
Acidification Potential	kg SO2 eq	2.39	2.21	2.04	2.03	1.88	1.73	1.14	1.05	0.96	4.95	5.66	3.81	4.44	11.4	11.3
Eutrophication Potential	kg N eq	0.12	0.11	0.10	0.10	0.093	0.087	0.058	0.054	0.050	0.17	0.18	0.12	0.12	0.55	0.54
Ozone Depletion Potential	kg CFC-11 eq	7.6E-05	5.8E-05	3.9E-05	6.5E-05	4.9E-05	3.3E-05	3.8E-05	2.9E-05	1.9E-05	7.2E-06	7.5E-06	4.6E-06	4.8E-06	1.0E-05	9.3E-06
Smog Formation Potential	kg O3 eq	43.6	39.3	35.0	36.6	33.0	29.3	21.0	18.9	16.8	61.2	66.2	45.1	49.5	271	270

Table 8. Summary of Results for Water Container Systems, 1,000 Gallon Basis, Variations in PET Recycled Content

	Units	500 ml PET Water - Avg, 0% RC, 29.1% RR	500 ml PET Water - Avg, 25% RC, 29.1% RR	500 ml PET Water - Avg, 50% RC, 29.1% RR	500 ml PET Water - Lt, 0% RC, 29.1% RR	500 ml PET Water - Lt, 25% RC, 29.1% RR	500 ml PET Water - Lt, 50% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
System Totals, System Expansion											
Cumulative Energy Demand	MJ	6,983	7,291	7,599	5,520	5,746	5,972	22,197	21,848	16,355	16,045
Non-renewable Energy	MJ	6,751	7,038	7,325	5,326	5,537	5,747	16,904	16,662	13,451	13,236
Solid Waste	kg	77.5	78.6	79.6	60.9	61.6	62.4	381	372	280	272
Water Consumption	liters	1,671	1,880	2,088	1,290	1,442	1,595	3,757	3,733	3,093	3,072
Global Warming Potential	kg CO2 eq	320	339	357	249	262	276	1,241	1,218	990	969
Acidification Potential	kg SO2 eq	1.15	1.21	1.27	0.90	0.94	0.99	6.87	6.70	5.54	5.39
Eutrophication Potential	kg N eq	0.058	0.064	0.069	0.046	0.050	0.054	0.19	0.19	0.14	0.14
Ozone Depletion Potential	kg CFC-11 eq	2.8E-05	2.8E-05	2.8E-05	2.1E-05	2.1E-05	2.1E-05	7.2E-06	7.2E-06	5.1E-06	5.0E-06
Smog Formation Potential	kg O3 eq	20.9	21.9	22.9	16.4	17.1	17.9	75.2	74.0	58.1	57.0
System Totals, Cut-off											
Cumulative Energy Demand	MJ eq	8,410	7,420	6,430	6,641	5,914	5,188	18,579	20,131	12,506	13,885
Non-renewable Energy	MJ eq	8,124	7,125	6,126	6,390	5,656	4,923	13,690	14,726	10,559	11,479
Solid Waste	kg SW	78.8	77.9	77.0	61.9	61.3	60.6	275	313	183	218
Water Consumption	liter H2O	1,642	1,683	1,724	1,273	1,303	1,333	3,460	3,539	2,819	2,888
Global Warming Potential	kg CO2 eq	357	329	300	277	256	235	951	1,050	729	817
Acidification Potential	kg SO2 eq	1.27	1.18	1.09	0.99	0.92	0.86	4.95	5.66	3.81	4.44
Eutrophication Potential	kg N eq	0.063	0.060	0.056	0.050	0.047	0.044	0.17	0.18	0.12	0.12
Ozone Depletion Potential	kg CFC-11 eq	3.9E-05	2.9E-05	2.0E-05	2.9E-05	2.2E-05	1.5E-05	7.2E-06	7.5E-06	4.6E-06	4.8E-06
Smog Formation Potential	kg O3 eq	23.8	21.6	19.5	18.6	17.0	15.4	61.2	66.2	45.1	49.5

Reduced Weight for 16.9 oz and 20 oz PET CSD Bottles

Some 16.9 and 20 oz PET CSD bottles are changing to a 21 g preform. While this is only a 1 gram reduction from the average weight used in the baseline results, it represents about a 5% reduction in bottle weight and weight-related impacts. Reducing weight reduces impacts across all bottle life cycle stages since less material needs to be produced to make the bottle, and a lighter bottle requires less energy for molding, transport, and disposal.

Results for 21 g PET CSD bottles with 10% recycled content are shown in Table 9. Compared to the baseline weight containers, the 21 g PET bottles compare more favorably with alternative systems for all results other than ozone depletion, which is still higher for PET systems due to emissions associated with production of PET resin precursor material.

Table 9. Summary of Results for 21 g PET CSD Bottles and Other CSD Container Systems, 1,000 Gallon Basis

System Totals, System Expansion	Units	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Cumulative Energy Demand	MJ eq	12,804	10,485	22,197	21,848	16,355	16,045	38,781	37,914
Non-renewable Energy	MJ eq	12,358	10,094	16,904	16,662	13,451	13,236	33,941	33,646
Solid Waste	kg SW	141	114	381	372	280	272	1,698	1,682
Water Consumption	liter H2O	3,164	2,630	3,757	3,733	3,093	3,072	9,867	9,736
Global Warming Potential	kg CO2 eq	596	495	1,241	1,218	990	969	2,608	2,566
Acidification Potential	kg SO2 eq	2.12	1.79	6.87	6.70	5.54	5.39	14.6	14.4
Eutrophication Potential	kg N eq	0.11	0.090	0.19	0.19	0.14	0.14	0.68	0.67
Ozone Depletion Potential	kg CFC-11 eq	5.2E-05	4.4E-05	7.2E-06	7.2E-06	5.1E-06	5.0E-06	9.1E-06	8.5E-06
Smog Formation Potential	kg O3 eq	37.2	31.0	75.2	74.0	58.1	57.0	350	348

System Totals, Cut-off	Units	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Cumulative Energy Demand	MJ eq	14,464	11,888	18,579	20,131	12,506	13,885	33,739	32,872
Non-renewable Energy	MJ eq	13,942	11,417	13,690	14,726	10,559	11,479	27,635	27,340
Solid Waste	kg SW	142	115	275	313	183	218	1,605	1,590
Water Consumption	liter H2O	2,978	2,472	3,460	3,539	2,819	2,888	7,559	7,428
Global Warming Potential	kg CO2 eq	629	523	951	1,050	729	817	2,201	2,159
Acidification Potential	kg SO2 eq	2.22	1.87	4.95	5.66	3.81	4.44	11.4	11.3
Eutrophication Potential	kg N eq	0.11	0.093	0.17	0.18	0.12	0.12	0.55	0.54
Ozone Depletion Potential	kg CFC-11 eq	6.5E-05	5.5E-05	7.2E-06	7.5E-06	4.6E-06	4.8E-06	1.0E-05	9.3E-06
Smog Formation Potential	kg O3 eq	40.1	33.6	61.2	66.2	45.1	49.5	271	270

Aluminum Data Used

The modeling of virgin and recycled aluminum used in the baseline aluminum can results are based on unit process data sets from a 2013 report by the Aluminum Association (AA). An updated report was published by AA in January 2022; however, the updated report no longer publishes data at a unit process level, only at an aggregated cradle-to-material level, so it is not possible to use the 2022 AA data to update our detailed aluminum models or to align modeling of 2022 aluminum production background processes such as electricity generation to use the same corresponding data sets used in the PET and glass models.

To check how use of updated aluminum production data affects results for aluminum containers, results were run replacing the detailed 2013 virgin and recycled aluminum models with the cradle-to-aluminum data from the 2022 AA report, recognizing that the background modeling and data sets used to generate the cradle-to-gate aluminum results may not be directly comparable to corresponding data sets used in the PET and glass models (e.g., data used for modeling background electricity, process and transportation fuels, etc.). In addition, the 2022 AA tables include only a short list of cradle-to-gate emissions, while detailed LCA models for production of fuels and electricity include a much more extensive list of emissions.

Table 10 shows a comparison of results per kg for the 73% RC aluminum material in the cans using the detailed 2013 AA aluminum LCA and the cradle-to-gate results from the 2022 AA LCA. The table shows that aluminum can material results modeled with the 2022 cradle-to-aluminum data give somewhat higher results for energy, solid waste, and global warming potential, but lower results for acidification and smog formation, while results for water consumption and eutrophication potential differ by 5% or less. The biggest difference seen is much lower acidification results for the 2022 cradle-to-gate data. Acidification impacts are generally associated with fuel-related emissions, so the difference between the 2013 AA data (modeled using AA unit process data with ERG background data sets) and the 2022 AA aggregated cradle-to-aluminum results is likely related to differences in the background data sets used for fuels and electricity.

Table 10. Comparison of Results for 2013 and 2022 Aluminum Data

	Aluminum Content Only (per kg can material)		
Impact	2013 Alum Data	2022 Alum Data	2022 % of 2013
Cumulative Energy Demand	31.6	37.1	118%
Non-renewable Energy	21.9	25.2	115%
Solid Waste	0.75	0.91	122%
Water Consumption	2.04	2.01	98%
Global Warming Potential	2.01	2.20	110%
Acidification Potential	0.014	0.0025	18%
Eutrophication Potential	1.8E-04	1.9E-04	105%
Smog Formation Potential	0.10	0.083	83%

Results for PET bottles with 10% recycled content and aluminum cans modeled with the 2022 AA cradle-to-aluminum data are provided in Table 11 for CSD systems and in Table 12 for bottled water systems. As in other sensitivity tables, system expansion results are shown at the top of each table and cut-off results at the bottom. Differences in the aluminum material data have a smaller effect when put in the perspective of the can life cycle results, since other aluminum can life stages such as can manufacturing energy, can transport, packaging, and disposal of cans that are not recycled are not affected by the change in aluminum data. The change in aluminum data does affect end-of-life can recycling results using system expansion modeling, however, since it affects the impacts for aluminum recycling and the virgin aluminum burdens for the difference between RC and RR.

Aluminum can system results using the 2022 aluminum data still show higher results than the PET systems. It should be noted that Table 11 and Table 12 do not include results for ozone depletion (the only metric where PET consistently showed higher results than aluminum systems modeled with 2013 data) because the cradle-to-aluminum tables in the 2022 AA report did not include sufficient information to be able to evaluate ozone depletion results.

Table 11. Summary of Results for PET CSD Bottles and Aluminum Container Systems Using AA 2022 Cradle-to-Aluminum Results, 1,000 Gallon Basis

	Units	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
System Totals, System Expansion								
Cumulative Energy Demand	MJ	13,355	10,997	6,190	22,933	22,504	17,009	16,627
Non-renewable Energy	MJ	12,893	10,592	5,967	17,050	16,767	13,580	13,329
Solid Waste	kg	147	120	67.6	411	402	306	298
Water Consumption	liters	3,310	2,766	1,541	3,796	3,723	3,127	3,062
Global Warming Potential	kg CO2 eq	623	521	296	1,247	1,222	996	973
Acidification Potential	kg SO2 eq	2.21	1.87	1.05	3.68	3.67	2.71	2.70
Eutrophication Potential	kg N eq	0.11	0.094	0.055	0.19	0.19	0.14	0.13
Smog Formation Potential	kg O3 eq	38.8	32.5	18.7	67.0	66.7	50.8	50.5
System Totals, Cut-off								
Cumulative Energy Demand	MJ	15,077	12,458	6,965	19,329	20,773	13,173	14,455
Non-renewable Energy	MJ	14,542	11,974	6,689	14,134	14,979	10,953	11,704
Solid Waste	kg	148	121	68.1	297	341	203	242
Water Consumption	liters	3,112	2,597	1,435	3,456	3,538	2,815	2,887
Global Warming Potential	kg CO2 eq	657	550	311	978	1,065	753	830
Acidification Potential	kg SO2 eq	2.32	1.97	1.10	3.44	3.55	2.47	2.57
Eutrophication Potential	kg N eq	0.11	0.097	0.056	0.18	0.18	0.12	0.13
Smog Formation Potential	kg O3 eq	41.9	35.2	20.2	58.8	62.3	43.0	46.1

Table 12. Summary of Results for PET Water Bottles and Aluminum Container Systems Using AA 2022 Cradle-to-Aluminum Results, 1,000 Gallon Basis

	Units	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
System Totals, System Expansion							
Cumulative Energy Demand	MJ	7,106	5,610	22,933	22,504	17,009	16,627
Non-renewable Energy	MJ	6,866	5,410	17,050	16,767	13,580	13,329
Solid Waste	kg	77.9	61.2	411	402	306	298
Water Consumption	liters	1,755	1,351	3,796	3,723	3,127	3,062
Global Warming Potential	kg CO2 eq	328	254	1,247	1,222	996	973
Acidification Potential	kg SO2 eq	1.18	0.92	3.68	3.67	2.71	2.70
Eutrophication Potential	kg N eq	0.060	0.047	0.19	0.19	0.14	0.13
Smog Formation Potential	kg O3 eq	21.3	16.7	67.0	66.7	50.8	50.5
System Totals, Cut-off							
Cumulative Energy Demand	MJ	8,014	6,350	19,329	20,773	13,173	14,455
Non-renewable Energy	MJ	7,724	6,096	14,134	14,979	10,953	11,704
Solid Waste	kg	78.5	61.7	297	341	203	242
Water Consumption	liters	1,658	1,285	3,456	3,538	2,815	2,887
Global Warming Potential	kg CO2 eq	346	269	978	1,065	753	830
Acidification Potential	kg SO2 eq	1.23	0.96	3.44	3.55	2.47	2.57
Eutrophication Potential	kg N eq	0.062	0.049	0.18	0.18	0.12	0.13
Smog Formation Potential	kg O3 eq	22.9	18.0	58.8	62.3	43.0	46.1

SUMMARY

PET beverage container systems accounting for the largest share of U.S. CSD and bottled domestic still water sales compare favorably with the predominant aluminum and glass container systems for these applications. PET CSD systems modeled with 10% recycled content have lower or similar results compared to aluminum and glass systems for nearly all impacts evaluated, for both the system expansion and cut-off recycling methodologies. For cumulative energy demand, non-renewable energy demand, and water consumption, some comparisons of 16.9 oz and 20 oz PET CSD systems with 16 oz aluminum cans show lower or comparable results for PET when system expansion methodology is used, but higher results for PET when cut-off recycling methodology is used. However, 16 oz aluminum cans represent a very small share of CSD sales in aluminum cans.

Cut-off recycling methodology is less favorable than system expansion for PET systems with 10% RC because no credits are given for the systems producing more recycled PET than they consume. Cut-off recycling is more favorable than system expansion for aluminum cans since there are no virgin aluminum burdens added to make up for the deficit between the cans' high recycled content and lower recycling rate.

When PET bottles are modeled with different levels of recycled content, results other than ozone depletion potential are generally lower than or comparable to aluminum cans and glass bottles when using system expansion methodology. However, when using cut-off methodology, some results for single-serving PET CSD bottles compared with aluminum cans become higher for PET (mainly energy results for 16.9 oz PET CSD bottles with 0% and 25% RC).

All comparisons of PET CSD bottles (all sizes) with glass bottles and all comparisons of PET water bottles, both lightweight and average weight, with aluminum cans show lower results for PET regardless of recycling methodology. The only impact that is consistently higher for PET systems compared with aluminum and glass systems is ozone depletion potential. The higher results for PET systems are mainly associated with emissions of methyl bromide from production of terephthalic acid, a precursor to PET resin.

CHAPTER 1. STUDY OVERVIEW AND METHODOLOGY

INTRODUCTION

This study provides the National Association for PET Container Resources (NAPCOR) and their members with information about the life cycle environmental impacts for polyethylene terephthalate (PET) bottles and competing containers used to package soft drinks and water in the U.S. Life cycle assessment (LCA) is recognized as a scientific method for making comprehensive, quantified evaluations of the environmental benefits and tradeoffs for the entire life cycle of a product system, beginning with raw material extraction and continuing through material production, product fabrication, use, reuse or recycling where applicable, and final disposition.

The information from an LCA can be used as the basis for further study of the potential improvement of resource use and environmental impacts associated with the beverage container systems evaluated. It can also pinpoint areas (e.g., material components or processes) where changes would be most beneficial in terms of reducing energy use or potential impacts.

The LCA has been conducted following internationally accepted standards for LCI and LCA methodology as outlined in the ISO 14040 and 14044 standard documents[3].

An LCA consists of four phases:

- Goal and scope definition
- Life cycle inventory (LCI)
- Life cycle impact assessment (LCIA)
- Interpretation of results

The LCI phase identifies and quantifies the material inputs, energy consumption, water consumption, and environmental emissions (atmospheric emissions, waterborne wastes, and solid wastes) over the defined scope of the study.

In the LCIA phase, the inventory of emissions is classified into categories in which the emissions may contribute to impacts on human health or the environment. Within each impact category, the emissions are then normalized to a common reporting basis, using characterization factors that express the impact of each substance relative to a reference substance.

3 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.

STUDY GOAL AND SCOPE

In this section, the goal and scope of the study is defined, including information on data sources used and methodology.

STUDY GOAL AND INTENDED USE

The purpose of this LCA is to evaluate environmental impacts for the predominant types and sizes of containers currently used to package carbonated soft drinks and non-carbonated domestic water purchased at grocery or convenience stores in the U.S. The study does not include refillable glass containers that are reused multiple times, with backhauling and cleaning between uses, because refillable CSD and bottled water containers of the sizes evaluated in this study are currently not widely used or available to the majority of U.S. consumers. The decline in use of refillable beverage containers is documented in several sources. For example, figures published by the Container Recycling Institute show that refillable bottles represented less than 0.5% of soft drink bottles in 1998.[4] The Living Landscape of Reuse Solutions database[5], which tracks reusable solutions to eliminate waste across the globe, had identified just 90 reusable food/beverage packaging programs operating in the United States as of May 2021, and only a quarter of those had moved beyond the pilot/start-up stage of operation.[6]

The intended use of the study is to provide NAPCOR and its members with information to understand and communicate environmental impacts for PET containers and how they compare with the most widely available competing beverage container systems in the U.S.

PUBLIC USE OF RESULTS

NAPCOR wishes to be able to use this study to share comparative results for PET and competing container systems with members and external parties. ISO 14044:2006, Section 6.1 states: "In order to decrease the likelihood of misunderstandings or negative effects on external interested parties, a panel of interested parties shall conduct critical reviews on LCA studies where the results are intended to be used to support a comparative assertion intended to be disclosed to the public."[7] This report has been peer reviewed by a panel of three external LCA experts, who evaluated the report's compliance with ISO standards 14040/14044 as well as evaluating the study's data sources, modeling assumptions, and conclusions. The panel's report, including responses to panel comments, is included as Appendix B of this report.

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4 Container Recycling Institute. The Decline of Refillable Beverage Bottles in the U.S. Accessed at https://www.container-recycling.org/index.php/53-facts-a-statistics/glass/428-the-decline-of-refillable-beverage-bottles-in-the-us

5 Database accessible at https://www.reuselandscape.org/database

6 Presentation by Moss & Mollusk Consulting to the U.S. Plastics Pact on May 4, 2021. Slides are confidential to Pact members.

7 Comparative assertion is defined in ISO 14044 section 3.6 as "environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function."

NAPCOR may use the peer-reviewed LCA report to inform the general public about the environmental profiles of the examined beverage container systems. Comparative statements should be limited to specific statements about the environmental metrics that are included in the report.

SYSTEMS STUDIED

The following beverage container systems for domestic still water and carbonated soft drinks (CSD) are analyzed:

- PET bottles
  - 500 ml domestic still water bottle sold in multipacks
    - Light weight
    - Mid-weight
  - 16.9 oz CSD bottle sold in multipacks
  - 20 oz CSD bottle sold individually
  - 2 liter CSD bottle sold individually
- Aluminum can (used for CSD or water)
  - 12 oz can sold in multipacks
  - 16 oz can sold individually
- Glass bottle (used for CSD)
  - 12 oz bottle sold in multipacks

The analysis focuses on containers that account for the majority of U.S. sales volume in CSD and domestic still water applications where PET competes with glass and aluminum containers. Information used by NAPCOR to identify PET containers with the largest market shares is based on data from Beverage Marketing Corporation's DrinkTell™ and SBA-CCI, Inc., a PET container consultancy. SBA-CCI starts with accurate total gallonage data supplied by Beverage Marketing Corporation and then calculates the gallonage share for PET containers in various end-use applications. The 2021 market data indicated the following:

- **For CSD:** 45.8% of all CSD gallonage packaged in PET in 2021 was packaged in the 2-liter format. Similarly, 14.3% was packaged in the 20-fl.oz. format, and 9.2% was packaged in 16.9-fl.oz (1/2 liter) containers. The 2-liter and 16.9 oz formats are most popular in the grocery channel, and the 20-fl.oz. is the most common PET package in the cold-distribution channels, such as bottles sold individually in convenience stores.
- **For bottled still (non-carbonated) water:** 70.1% of all bottled still water packaged in PET was packaged in the 1/2-liter size. (This does not include still water packaged in sizes larger than 2-liter, which is typically used for home and office delivery.)

Almost all containers analyzed are considered single-serve containers. The 2 liter PET CSD bottle is the only multi-serve container in the analysis but is included because it accounts for the largest share of CSD sales by volume. No multi-serve aluminum or glass containers are available in the U.S. market. For aluminum cans, the vast majority of CSD sales are in 12 oz cans. Some brands of bottled water are also sold in aluminum cans. Sixteen-ounce aluminum cans are not commonly used for CSD or water but are mainly used for energy drinks and alcoholic beverages; however, 16 oz cans are included as a "best case" for aluminum cans since they have a higher product-to-packaging ratio compared to 12 oz cans.

For PET bottles, the weight and recycled content can vary considerably within a defined bottle size and use category, making it difficult to define a representative industry average. In particular, there are large ranges in weight for different brands of PET bottles used for bottled water, where weights range from less than 10 grams to over 20 grams per 500 ml bottle, with the heaviest weights for premium brands, usually imported, which are excluded from this analysis.

The baseline model evaluates two weights for PET water bottles used for domestic spring and purified water: a weight representative of widely available lightweight water bottles (often store brands of purified tap water), and a weight representative of more rigid mid-weight bottles (excluding heavy bottles generally used for select premium imported brands of natural water, which account for a much smaller share of sales volume than domestic spring and purified water). The PET water bottle weights are for bottles used for still water. Aluminum can weights did not show variation based on whether the can contents were carbonated or non-carbonated.

Recycled content of PET bottles can also vary. Some brands have published their current levels of recycled content and/or targets for increased use of rPET in the coming years. The baseline results for PET bottles are based on 10% postconsumer recycled content, the current national average for bottles calculated by NAPCOR taking total RPET usage into bottle applications (as reported by reclaimers through their annual survey) and dividing by the total weight of PET resin used to make bottles sold in the U.S. during that year. A sensitivity analysis is included with results for each size and weight of PET bottle run with 0% recycled content as well as 25% and 50% recycled content. Twenty-five percent recycled content in PET bottles is a common brand goal, and fifty percent recycled content is a stated future goal of some brands. For example, PepsiCo and The Coca-Cola Company have both stated 50% as a target recycled content goal by 2030.[8] Twenty-five and 50 percent recycled content levels are also included in some legislation, such as California Assembly Bill 793, which calls for 25% postconsumer recycled content in plastic containers by 2025 and 50% by 2030.[9]

As noted above, the analysis focuses on containers in CSD and bottled water markets where PET competes with aluminum and glass containers. Aluminum cans and glass bottles are also widely used for beer and other alcoholic beverages, but PET is not a major player in the single-serve alcoholic beverage market at the current time. Therefore, the container weights for aluminum were based solely on cans that package soft drinks and water, and

[8] Packaging (pepsico.com), Sustainable Packaging | The Coca-Cola Company
[9] Plastic Minimum Content Standards (AB 793) - CalRecycle Home Page

glass containers were limited to containers used for soft drinks. In certain cases glass is used to package bottled still water (generally premium brands), but given limited availability and large variation in the sizes and shapes of glass packaging used for bottled water, no glass bottles are modeled for domestic still water.

To validate published data on container weights and develop representative data on containers for which no published industry average data were available, samples of leading national brands of each container type were purchased in the Boston and Kansas City areas and weighed by ERG. The results presented in this report use the average weight of each container type (as well as closures and labels, where relevant) based on these samples and data provided by PET bottle producers.

- For PET CSD bottles, a minimum of three samples each were purchased and weighed of top-selling brands from The Coca-Cola Company, PepsiCo, and Keurig-Dr Pepper, including regular and diet Coke, Pepsi, and Dr Pepper, in each PET CSD size modeled. The average sample weights for CSD bottles agreed well with the bottle weights reported by the PET bottle converters providing manufacturing data for this analysis (see report section PET Bottle Manufacturing).
- For the 500 ml PET water bottles, two sets of results are presented in this report. The "light" water bottle average weight of 8.22 g is based on the average weight of bottles weighing less than 10 g purchased and weighed by ERG, including at least three samples each of the following nationally sold brands: Aquafina (PepsiCo), PureLife (Nestle), Great Value (WalMart), 365 (Whole Foods), and Refreshe (Safeway/Albertsons/Jewel-Osco). The "average weight" water bottle results use the average weight of bottles greater than 10 g reported by the data providers (11.2 g).
- For 12 oz aluminum cans, at least three samples each were weighed of the same CSD brands weighed for PET containers (regular and diet Coke, Pepsi, and Dr Pepper), as well as La Croix flavored water. The 12 oz can weights are slightly lower than the 12 oz can weight of 12.98 g published by the Aluminum Association in 2014.[10] (More recent AA can reports do not publish individual weights of different can sizes, only a composite weight for the market mix of all sizes of aluminum beverage cans.) For 16 oz aluminum cans, all CSD samples found were Coca-Cola brands and showed consistent weights. No published industry data on weights of 16 oz aluminum cans was identified for comparison.
- For 12 oz glass bottles, samples of multiple brands were purchased and weighed, including samples of products from Coca-Cola, PepsiCo, and Keurig Dr. Pepper, as well as other brands including Stewart's root beer, Jones soda, and Reed's ginger beer. The Coca-Cola bottles were notably heavier than the other bottles and were excluded from the averaged weight to avoid any potential weight bias for glass bottles. All samples used steel crowns as closures except for one sample that had a reattachable aluminum closure. The bottles also had a mix of coated paper labels and labeling printed directly on the bottle, so both options were modeled in the results (see section Closures, Labels, Multipacks, Tier Sheets),

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[10] The Aluminum Association. Aluminum Can Life-Cycle Update Report Briefing. December 2014.

A limited number of samples of 12 and 16 oz aluminum cans and 12 oz glass bottles used for beer and cider were also weighed for comparison and showed similar weights to corresponding CSD containers. Container weights for non-alcoholic and alcoholic beverages tended to show more variation by beverage brand rather than by type of beverage.

Table 13 summarizes the weights for containers modeled in this analysis and associated closures and labels. The weights shown in the table are for containers used for bottled still water and carbonated soft drinks. Yellow highlighting indicates the container weights used in the LCA. For PET bottles, there were small variations in the preform weights reported by different data providers for each bottle. While 16.9 oz and 20 oz bottles generally use the same preforms, the table shows very small difference in 16.9 oz and 20 oz bottle weights, both for the average sample weights and average data provider weights. This most likely means that the averaged 16.9 oz and 20 oz sample weights and averaged reported weights represent different mixes of bottle producers with slightly different preform weights. The two recycled contents modeled for aluminum cans are discussed in more detail in the report section Aluminum Can Manufacturing.

Table 13. Container System Component Weights

					Avg Container Wt (g)					
	Size/Beverage	**Ctrs/ 1000 gal**	**Recycled Content**	**Recycling Rate**	**Samples**	**Data providers**	**Closure Wt (g)**	**Closure Material**	**Label Wt (g)**	**Label Material**
PET	500 ml water	7,574	10% (baseline), sensitivity on 0%, 25%, 50%	29.1%	8.22	11.2	1.00	HDPE	0.23	OPP Film
	16.9 oz CSD	7,574			22.1	21.6	2.51		0.32	
	20 oz CSD	6,400			22.2	21.7	2.37		0.30	
	2 liter CSD	1,893			43.9	44.1	2.28		1.36	
Aluminum Cans	12 oz CSD or water	10,667	73%, 62.3%	50.4%	12.7		*			
	16 oz CSD or water	8,000			15.1		*			
Glass	12 oz CSD	10,667	38%	39.6%	208		2.10	Steel	1.19	Paper**

*For aluminum cans, the 2021 LCA report from the Aluminum Association does not break out material and converting data for can bodies and lids, so lid results are included in the primary container results by stage and no separate closure results are shown.
**Results are also run for a glass bottle with no paper label.

Table 14 provides information on multipack packaging modeled for each container system, based on surveys of stores and samples purchased and weighed by ERG staff from the Boston and Kansas City areas. More information on modeling for multipack packaging can be found in the report section Closures, Labels, Multipacks, Tier Sheets.

Table 14. Multipack Packaging for Beverage Containers

	Size/Beverage	Multipack Type	Multipack Wt (g)	Containers/ Multipack	Multipack Wt (g/ctr)	Recycled Content	Recycling Rate
PET	500 ml water	LDPE film shrink wrap	27.2	24	1.13	0%	10%
	16.9 oz CSD	LDPE film ring	4.4	6	0.73	0%	0%
	20 oz CSD	individual bottle					
	2 liter CSD	individual bottle					
Aluminum Cans	12 oz CSD or water	unbleached paperboard	87.3	12	7.27	0%	20.8%
	16 oz CSD or water	individual can					
Glass	12 oz CSD	unbleached paperboard	54.2	4	13.6	0%	20.8%

FUNCTIONAL UNIT

The function of the beverage containers is to deliver packaged beverage to consumers. Results for the beverage container systems are expressed on the basis of an equal volume of beverage delivered, 1,000 gallons. Because there are variations in the volume of single-serving containers that consumers may purchase interchangeably, a sensitivity analysis is included with results presented on the basis of 7,374 containers, the number of 500 ml/16.9 oz containers required to deliver 1,000 gallons. The 500 ml/16.9 oz PET bottle is used as the reference container for the equivalent number of containers basis because both CSD and water are packaged in this size PET bottle, and this size PET bottle is closer in volume to the 12 oz and 16 oz non-PET containers than the 20 oz PET bottle. The 2 liter multi-serve PET CSD container is excluded from the equivalent number of containers comparison since it would not be purchased interchangeably with smaller single-serving containers.

SCOPE AND BOUNDARIES

This LCA quantifies energy consumption, water consumption, solid waste, and environmental impacts for the life cycle of the container systems. Results for the primary container (PET bottle, aluminum can, glass bottle) are broken out by the following stages:

- Raw material production (virgin and recycled inputs for the primary container)
- Primary container manufacture
- Primary container transport to filler
- Transport of filled container to distribution center*
- Transport of filled containers to stores*
- Primary container end-of-life management

*Data for filled container transport are based on the total weight of packaging (primary container, caps, labels, multipack packaging) transported and do not include impacts associated with the weight of the beverage in the containers.

Results for associated packaging elements in the tables and figures are shown on an aggregated life cycle basis covering all stages from raw material extraction through end of life, rather than broken out by individual life cycle stages. These include the following, as applicable for each system:

- Caps
- Labels
- Multipack packaging (includes film wraps for PET water bottles, film ring carriers for 16.9 oz PET CSD bottles, paperboard boxes used for 12 oz cans, and paperboard carriers used for 12 oz glass bottles)
- Paperboard tier sheets used between pallet layers of empty PET bottles, aluminum cans, and glass bottles. Other transport packaging was excluded due to very small amounts consumed for shipping containers for 1,000 gallons of beverage.

The following are not included in the study:

- **Beverage production.** Production of the water or CSD packaged in the containers is excluded from the scope of the analysis. For the baseline functional unit of equivalent number of gallons of beverage delivered, this would be the same for all containers used for a specific beverage.
- **Secondary and tertiary packaging components whose weight per functional unit is less than 0.5% of the container weight.** Companies providing data for preform molding and bottle blowing for PET containers reported the types and amounts of packaging used to transport preforms and bottles, including reusable plastic containers used for preforms, tier sheets and film used for layers of empty bottles on pallets, and reusable pallets. When amounts of packaging were allocated to the basis of 1,000 gallons of packaged beverage, only paperboard tier sheets accounted for more than 0.5% of the weight of primary containers required. The same was true for packaging used to ship pallet loads of empty aluminum cans and glass bottles.
- **Other life cycle stages.** Impacts associated with container filling, storage of filled containers at retail stores, consumer transportation of filled containers from retail location to consumers' homes, refrigerated storage by consumers, and beverage consumption impacts (e.g., for ice added to beverages, use of disposable or reusable cups for consuming beverages) are excluded from the analysis. For these stages, there is either insufficient data available to differentiate between container systems, or data is not directly dependent on container type.
- **Miscellaneous materials and additives.** Selected materials such as catalysts, pigments, ancillary materials, or other additives which total less than one percent by weight of the net process inputs are typically not included in assessments. Omitting miscellaneous materials and additives keeps the scope of the study focused. It is possible that production of some substances used in small amounts may be energy and resource intensive or may release toxic emissions; however, the impacts would have to be very large in proportion to their mass in order to significantly affect overall results and conclusions. For this study, the use of metals (e.g., antimony, cobalt, titanium) to create catalysts used in PET manufacture does affect the eutrophication results and so the mining/processing step has been included in this case; however, the production of the catalyst itself is excluded. With the exception of

the metals used for creating the catalysts used in the manufacture of PET, the results for the resin are not expected to be understated by any significant amount due to substances that may be used in small amounts.

- **Capital equipment, facilities, and infrastructure.** The energy and wastes associated with the manufacture of buildings, roads, pipelines, motor vehicles, industrial machinery, etc. are not included. The energy and emissions associated with production of capital equipment, facilities, and infrastructure generally become negligible when averaged over the total output of product or service provided over their useful lifetimes.
- **Space conditioning.** The fuels and power consumed to heat, cool, and light manufacturing establishments are omitted from the calculations when possible. For manufacturing plants that carry out thermal processing or otherwise consume large amounts of energy, space conditioning energy is quite low compared to process energy. The data collection forms developed for this project specifically requested that the data provider either exclude energy use for space conditioning or indicate if the reported energy requirements included space conditioning. Energy use for space conditioning, lighting, and other overhead activities is not expected to make a significant contribution to total energy use for the resin system.
- **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.

The geographic scope of the analysis is containers for water and CSD produced and sold in the U.S. The majority of the data used in the modeling is from North American databases (U.S. LCI database, Franklin Associates' private database). In cases where it was necessary to use supplemental data from a European database, the data sets were adapted to the extent possible to represent North American inputs and practices.

INVENTORY AND IMPACT ASSESSMENT RESULTS CATEGORIES

The full inventory of emissions generated in an LCA study is lengthy and diverse, making it difficult to interpret emissions profiles in a concise and meaningful manner. Life cycle impact assessment (LCIA) helps to interpret the emissions inventory. LCIA is defined in ISO 14044 Section 3.4 as the "phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product." In the LCIA phase, the inventory of emissions is first classified into categories in which the emissions may contribute to impacts on human health or the environment. Within each impact category, the emissions are then normalized to a common reporting basis, using characterization factors that express the impact of each substance relative to a reference substance.

The LCI and LCIA results categories and methods applied in this study are displayed in Table 1. This study addresses global, regional, and local impact categories. For most of the impact categories examined, the TRACI 2.1 method, developed by the United States Environmental Protection Agency (EPA) specific to U.S. conditions and updated in 2012, is employed.[11] For the category of Global Warming Potential (GWP), contributing elementary flows are characterized using factors reported by the Intergovernmental Panel on Climate Change (IPCC) in 2013 with a 100 year time horizon.[12] In addition, the following LCI results are included in the results reported in the analysis:

- **Energy demand**: this method is a cumulative inventory of all forms of energy used for process energy, transportation energy, and feedstock energy. Process energy and transportation energy represent fuel that is irretrievably expended, while feedstock energy is the energy content of the raw materials extracted from nature as feedstocks for plastic or paperboard materials. Although the energy content of the finished item is less than the energy value of the extracted material resources due to processing losses, the majority of the feedstock energy remains embodied in the finished packaging items and is available for future use, e.g., if postconsumer packaging is disposed at end of life by waste-to-energy combustion, or remains embodied in items that are recycled. For each of the energy categories listed — process, transportation, and feedstock — both renewable and non-renewable energy demand are included. Non-renewable energy demand is reported separately in the results to assess consumption of fuel resources that can be depleted.
- **Total solid waste** is assessed as a sum of the inventory values associated with this category.
- **Water consumption** is assessed as a sum of the inventory values associated with this category and does not include any assessment of water scarcity issues.

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11 Bare, J. C. Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI), Version 2.1 - User's Manual; EPA/600/R-12/554 2012.

12 IPCC, 2013: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013.

Table 15. Summary of LCI/LCIA Impact Categories

	Impact/Inventory Category	Description	Unit	LCIA/LCI Methodology
LCI Categories	Total energy demand	Measures the total energy from point of extraction; results include both renewable and non-renewable energy sources.	MJ	Cumulative energy inventory
	Non-renewable energy demand	Measures the fossil and nuclear energy from point of extraction.	MJ	Energy inventory
	Expended energy	Energy that is irretrievably expended for process and transportation steps; excludes feedstock energy (energy content of raw materials extracted from nature for use as material feedstock)	MJ	Energy inventory
	Solid waste by weight	Measures quantity of fuel and process waste to a specific fate (e.g., landfill, WTE) for final disposal on a mass basis	kg	Cumulative solid waste inventory
	Water consumption	Freshwater withdrawals which are evaporated, incorporated into products and waste, transferred to different watersheds, or disposed into the land or sea after usage	Liters	Cumulative water consumption inventory
LCIA Categories	Global warming potential	Represents the heat trapping capacity of the greenhouse gases. Important emissions: CO_2 fossil, CH_4, N_2O	kg CO_2 equivalents (eq)	IPCC (2013) GWP 100a*
	Acidification potential	Quantifies the acidifying effect of substances on their environment. Important emissions: SO_2, NO_x, NH_3, HCl, HF, H_2S	kg SO_2 eq	TRACI v2.1
	Eutrophication potential	Assesses impacts from excessive load of macro-nutrients to the environment. Important emissions: NH_3, NO_x, COD and BOD, N and P compounds	kg N eq	TRACI v2.1
	Ozone depletion potential	Measures stratospheric ozone depletion. Important emissions: CFC compounds and halons	kg CFC-11 eq	TRACI v2.1
	Smog formation potential	Determines the formation of reactive substances (e.g. tropospheric ozone) that cause harm to human health and vegetation. Important emissions: NO_x, BTEX, NMVOC, CH_4, C_2H_6, C_4H_{10}, C_3H_8, C_6H_{14}, acetylene, Et-OH, formaldehyde	kg O_3 eq	TRACI v2.1

Litter and Marine Debris

Litter, particularly when it ends up as marine debris, is an area of global concern, much of which is concentrated on the issue of "ocean plastic." In addition to the challenges of reliably quantifying the amount of leakage of CSD and bottled water containers into the environment and the ultimate destination of leaked containers (e.g., land, freshwater bodies, oceans), there is no established methodology for quantifying the environmental and health effects of litter and marine debris. There is a project underway to develop a marine debris methodology for life cycle assessments, but completion is not expected until 2025.[13] For these reasons, litter and marine debris are excluded from this analysis.

DATA SOURCES

The analysis uses the most recent data available for each process for each container system.

- PET resin: 2020 NAPCOR PET resin study[14]
- Resins used for other packaging components (HDPE for PET bottle closures, LDPE for film multipacks, PP for PET bottle labels): Resin reports developed for the Plastics Division of the American Chemistry Council (ACC) in 2021[15,16,17]
- Recycled PET used in bottles, end-of-life recycling of PET bottles and HDPE closures: 2018 APR recycled resin LCA[18] The data for recycled PET is specific to recycling PET into food-grade resin, and includes solid-stating.
- Coated and uncoated unbleached paperboard used in beverage multipacks and tier sheets: Data sets developed by Franklin Associates for the Environmental Paper Calculator version 3.2 using public and private sources[19]
- PET preform and bottle manufacturing: supplier data collected for this project
- Primary and secondary aluminum used in aluminum cans: 2013 Aluminum Association LCA[20]

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13 MarILCA. Integrating potential environmental impacts of marine litter into LCA. See https://marilca.org/.

14 Cradle-to-Resin Life Cycle Analysis of Polyethylene Terephthalate Resin. Prepared for NAPCOR by Franklin Associates, a Division of ERG. March 2020. https://napcor.com/wp-content/uploads/2020/05/Final-Revised-Virgin-PET-Resin-LCA.pdf

15 Cradle-to-Resin Life Cycle Analysis of High Density Polyethylene (HDPE) Resin. Prepared for ACC by Franklin Associates, a Division of ERG. October 2020. https://www.americanchemistry.com/better-policy-regulation/plastics/resources/cradle-to-gate-life-cycle-analysis-of-high-density-polyethylene-hdpe-resin

16 Cradle-to-Resin Life Cycle Analysis of Low Density Polyethylene (LDPE) Resin. Prepared for ACC by Franklin Associates, a Division of ERG. April 2020. https://www.americanchemistry.com/better-policy-regulation/plastics/resources/cradle-to-gate-life-cycle-analysis-of-low-density-polyethylene-ldpe-resin

17 Cradle-to-Resin Life Cycle Analysis of Polypropylene (PP) Resin. Prepared for ACC by Franklin Associates, a Division of ERG. February 2021. https://www.americanchemistry.com/better-policy-regulation/plastics/resources/cradle-to-gate-life-cycle-analysis-of-polypropylene-pp-resin

18 Life Cycle Impacts for Postconsumer Recycled Resins: PET, HDPE, and PP. Prepared for the Association of Plastic Recyclers (APR) by Franklin Associates, a Division of ERG. December 2018. https://plasticsrecycling.org/images/library/2018-APR-LCI-report.pdf

19 Documentation for the Environmental Paper Calculator Version 3.2. Submitted to Environmental Paper Network by Franklin Associates, A Division of ERG. September 2012.

- Aluminum can recycled content and converting processes: 2021 Aluminum Association LCA [21]
- Virgin and recycled glass production: Franklin Associates private database
- Glass bottle recycled content: 38%, from Owens Illinois 2021 Sustainability report[22]
- End-of-life recycling rates, all containers and packaging: 2020 U.S. EPA Advancing Sustainable Materials Management report[23]
- Electricity used in all processes: US average mix of fuels for 2018 from US EPA eGRID database.[24] The electricity modeling includes the upstream (precombustion) impacts for the fuels used, including fuel extraction and processing, as well as utility combustion of the fuels.
- Production and combustion of process and transportation fuels: US LCI Database[25], linked to updated background data for oil and gas extraction and processing from 2019-2021 resin updates for NAPCOR and ACC.

More detail is provided in the following sections on the modeling for PET preform and bottle manufacturing and aluminum can production.

PET Bottle Manufacturing

Data for the production of PET bottles, including injection molding of preforms and blowing preforms into bottles were collected from three NAPCOR member companies. Each data provider completed separate data forms for each size of preform and for each size of bottle.

Two companies provided data for the full calendar year 2019, and one provided data for a six-month period in 2021-2022. The data were used to compile a production-weighted average for producing a kg of preform of each size and a kg of bottle of each size. When compiling the production-weighted average, output from the company providing 6 months of production data was doubled to represent a year's worth of production for averaging with the other data providers' annual production.

Data providers reported different mixes of on-site and off-site blowing of preforms into bottles and on- and off-site filling of blown bottles. Weighted average distances for

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20 Aluminum Association (2013). The Environmental Footprint of Semi-Finished Aluminum Products in North America.

21 Life Cycle Assessment of North American Aluminum Cans. Prepared for the Aluminum Association by Sphera, May 2021. https://www.aluminum.org/sites/default/files/2021-10/2021AluminumCanLCAReportFullVersion.pdf

22 Owens-Illinois 2021 Sustainability Report Executive Summary. https://www.o-i.com/wp-content/uploads/2021/12/ExecutiveReport_English_Final-1.pdf

23 Advancing Sustainable Materials Management: 2018 Tables and Figures. U.S. EPA. 2018 packaging recycling rates from Table 25 of December 2020 report, accessed at https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/advancing-sustainable-materials-management

24 U.S. EPA Emissions & Generation Resource Integrated Database (eGRID). Data downloadable at https://www.epa.gov/egrid/download-data.

25 U.S. Life Cycle Inventory Database. Accessible at https://www.nrel.gov/lci/.

transport of preforms to blowing locations for each size of PET bottle are shown in the middle column of Table 16, and weighted average transport distances for blown bottles to fillers are shown in the last column. The transportation distances take into account the production-weighted shares of preforms blown into bottles at the production site (0 transport miles) and preforms transported to off-site locations for bottle blowing. Likewise, the final column shows the production-weighted shares of bottles that are filled at the same site where they are blown (0 transport miles) and bottles that are transported to separate filling sites. For transport to off-site operations, each data provider supplied information on the distances for their locations. All transport was reported as truck. More detailed data on the percentages of on- and off-site operations for these steps cannot be shown due to confidentiality concerns.

Table 16. PET Transportation Modeled

Bottle size	Weighted avg miles, preform to bottle blowing	Weighted avg miles, bottle blowing to filler
16.9 oz CSD	249	52.2
20 oz CSD	253	56.7
2 liter CSD	259	78.5
500 ml water	261	35.0

Aluminum Can Manufacturing

The aluminum can system is modeled using the weights of 12 oz and 16 oz aluminum cans and secondary packaging obtained and weighed by ERG staff.

The aluminum can was modeled using data for can material remelting and chill casting, sheet manufacturing, and converting sheet into finished cans from the Aluminum Association's 2021 beverage can LCA.[26] Production of primary and secondary aluminum used in the can was modeled using data from the Aluminum Association's 2013 report.[27] The total recycled content of the aluminum can (including postconsumer and external postindustrial scrap but excluding internal rolling mill scrap circulating within the aluminum can system) is reported as 73% in the 2021 aluminum can LCA. As described in the AA 2021 report, the postindustrial recycled content is modeled the same as postconsumer recycled content, with no virgin material production burdens. However, since at least some of the material in the postindustrial scrap is likely to be virgin material that has not yet had a useful life in a finished product, an additional scenario for the aluminum can is run modeling the postindustrial scrap as a 50/50 mix of virgin and

26 Life Cycle Assessment of North American Aluminum Cans. Prepared for the Aluminum Association by Sphera, May 2021.

27 Aluminum Association (2013). The Environmental Footprint of Semi-Finished Aluminum Products in North America. Accessible at https://legacy-assets.eenews.net/open_files/assets/2014/01/11/document_cw_01.pdf

postconsumer aluminum. For this scenario, the overall postconsumer recycled content of the can is calculated to be 62.3%. See additional discussion in Methodology section Recycled Content Modeling.

The input of unspecified "paint" in the aluminum can LCA sheet manufacturing data set (AA 2021 report Table 3-2) and the input of unspecified "coatings" in the can manufacturing data set (AA 2021 report Table 3-3) were each modeled using liquid epoxy resin as a surrogate. Epoxy was listed in the key material and process datasets used in Table 3-6 of the AA 2021 report. Inputs of unspecified inks in the can manufacturing data set were not included, since no inks were included in the modeling for labels for the PET and glass container systems. Although production of inks was excluded from the modeling, the reported emissions for the can manufacturing data set may include emissions from the printing process.

Closures, Labels, Multipacks, Tier Sheets

Closures

- Closures on PET bottles were modeled as virgin injection molded HDPE. The PET bottle closures are assumed to be left on bottles sent to recycling. At PET reclaimers, caps are separated and sent to HDPE recyclers, so the recycling rate for HDPE closures is modeled the same as PET bottles, 29.1%. As of 2015, the Association of Plastics Recyclers (APR) reported success in efforts to get consumers to recycle plastic bottles with the caps on[28], and confidential unpublished data collected from PET reclaimers by ERG for a 2018 recycled resin study for APR[18] showed that the ratio of cap versus PET bottle material recovered at PET reclaimers was consistent with the range of cap-to-bottle weight ratios for the PET bottles in this study.
- The most common glass bottle closure was a steel crown, modeled as made from steel produced in a basic oxygen furnace with a recycled content of 24%. Steel crown caps used on glass bottles are not re-attachable after removal, and caps put into recycling bins individually are likely to be lost during transport and sorting operations during their small size. However, some percentage of disposed steel crowns may be recovered magnetically for recycling. The closure results modeled for glass bottle systems include a 25% recycling rate for steel crowns, which may be optimistic.
- The aluminum can lid is included in the weight of the aluminum can, so the recycled content of the lid is included in the overall recycled content of the can, and the recycling rate for the can includes both the body and lid.

Labels

- The labels on PET bottles were modeled as oriented polypropylene (OPP) film with 0% recycled content and 0% recycling at end of life. No inks or printing of film labels were modeled.

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28 Plastics News. Recycling Group Declares Success with Caps On. October 28, 2015. Accessed at https://www.plasticsnews.com/article/20151028/NEWS/151029867/recycling-group-declares-success-with-caps-on.

- Labeling for most aluminum cans is printed directly onto the can, so no separate labels were modeled.
- A common label for glass bottles was a coated bleached paper label; however, some glass bottle samples included graphics printed directly on the bottle. Since labels were included for PET bottles, one set of glass bottle system results includes paper labels, while a second set of results provides results with no separate label and no estimated impacts for direct printing/curing of labeling on bottles. For the paper label scenario, the label was modeled with 0% recycled content and 0% recycling at end of life, and no inks or printing were modeled, consistent with the modeling for the PET bottle labels. For the scenario with no paper label, no data were available on the weights of ink directly printed on the glass bottles or on the impacts of the inks used or the bottle direct printing and ink curing process, so no impacts are modeled for the labeling printed on the bottle.

Based on surveys of containers for sale in stores, the most common selling units for the containers were:

- 2 liter PET CSD: sold as individual bottles
- 20 oz PET CSD: sold as individual bottles
- 16.9 oz PET CSD: sold as 6 packs with plastic film ring holders
- 500 ml PET water: both average and light-weight bottles sold as 24-packs shrink-wrapped in plastic film
- 12 oz Al can: sold in paperboard boxes holding 12 cans
- 16 oz Al can: sold as individual can
- 12 oz glass bottle: sold in paperboard carriers holding 4 bottles.

Multipacks were modeled as follows:

- LDPE film shrink wrap used for multipacks of 500 ml PET water bottles and LDPE film rings used for multipacks of 16.9 oz PET CSD bottles were both modeled as virgin film. The recycling rate for plastic film rings was modeled as 0%, and a recycling rate of 10% was used for film shrink wrap, based on the U.S. EPA recycling rate for film bags, wraps, and sacks. A sensitivity analysis is conducted on 0% recycling of film shrink wrap for PET water bottles.
- Clay-coated unbleached paperboard, used for 12-packs of 12 oz Al cans and carriers for 4-packs of glass bottles, was modeled with 0% recycled content and a recycling rate of 20.8% based on the U.S. EPA recycling rate for all types of paperboard packaging other than corrugated.[23] Samples of paperboard packaging for cans and glass bottles had no information on recycled content, and it is expected that recycled content of carriers would be limited, due to the strength needed for carrying multiple units of filled cans and glass bottles.

Tier sheets on pallets of empty container shipped to fillers were modeled as uncoated virgin unbleached paperboard. Since the sheets are uncoated and unbleached, like corrugated boxes, and are removed from service at commercial filling locations, the end-of-life recycling rate was modeled the same as the recycling rate for corrugated removed from service at commercial locations, 95%.

Transport Steps

All empty container transport was modeled based on transport in a semi truck. Transportation of empty PET bottles to fillers used the weighted average of distances reported by the three PET bottle producers. Weighted average distances for all sizes and weights of empty PET bottles were between 150 and 200 miles. The weighted average distances include the share of bottle production for data providers reporting bottles blown on-site at filling locations. Empty container transport distances for aluminum cans and glass bottles were estimated as 150 miles and 600 miles, respectively, based on information provided by a major beverage company.

After filling, it was assumed that distance for transporting filled containers to a distribution center (DC) would be the same for all container types and sizes. An estimate of 50 miles was used. Similarly, the distance for transporting filled bottles from a distribution center to a grocery store or convenience store was modeled as 50 miles for all containers.

Both transportation steps for filled containers (filler to DC, DC to retail) were modeled based on transport in a fully weight-loaded truck. Two-liter PET bottles and single-serve containers sold in multipacks (16.9 oz CSD in PET, 500 ml water in PET, 12 oz aluminum cans, 12 oz glass bottles) were modeled as transported to grocery stores on semi trucks, while larger single-serve containers sold individually (20 oz CSD in PET, 16 oz aluminum cans) were modeled as transported to convenience stores on single-unit delivery trucks. The transportation burdens allocated to the beverage container systems were based on the weight of the empty container and associated closures, labels, and multipack packaging, as applicable for each container type. No burdens associated with the weight of the beverage in the container were allocated to the container system.

DATA QUALITY ASSESSMENT

ISO 14044:2006 lists a number of data quality requirements that should be addressed for studies intended for use in public comparative assertions. The data quality goals for this analysis were to use data that are (1) geographically representative for the beverage container systems based on the locations where material sourcing and production take place, and (2) representative of current industry practices in these regions. As described in the previous section, three PET bottle producers each provided current, geographically representative primary data for PET preform and bottle manufacturing for this LCA. Production of virgin and recycled aluminum and for production of aluminum cans were based on the most recent LCAs available from the Aluminum Association during the data collection phase of the project.

The remaining datasets were updated using geographical and technologically relevant data from government or privately available statistics/studies within the US or drawn from either the U.S. LCI database or Ecoinvent[29]. The data sets used were the most current and

[29] Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., and Weidema, B., 2016. The ecoinvent database version 3 (part I): overview and methodology. The International Journal of Life Cycle

most geographically and technologically relevant data sets available during the data collection time frame.

Consistency, Completeness, Precision: Data evaluation procedures and criteria were applied consistently to all primary data provided by the participating producers for all data collected. All primary data obtained specifically for this study were considered the most representative available for the systems studied. Data sets were reviewed for completeness and material balances, and follow-up was conducted as needed to resolve any questions about the input and output flows, process technology, etc.

Reproducibility: To maximize transparency and reproducibility, the report identifies specific data sources, assumptions, and approaches used in the analysis to the extent possible; however, reproducibility of study results is limited to some extent by the need to protect certain data sets that were judged to be high quality and representative data sets for modeling purposes but could not be shown due to confidentiality.

Uncertainty: Uncertainty issues and uncertainty thresholds applied in interpreting study results are described in the following section.

DATA ACCURACY AND UNCERTAINTY

An important issue to consider when using LCA 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. 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 that must be modeled to compile results for the life cycle of each container system, 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. Primary data collected from actual facilities are considered the best available data for representing industry operations. In this study, primary data were collected for PET bottle manufacturing. All data collected for this study were carefully evaluated before compiling the production-weighted average data sets used to generate results. Data used for modeling production of PET and other resins, end-of-life recycling processes, virgin and recycled aluminum production, and aluminum can production were from industry association LCAs based on primary data. Supporting

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Assessment, [online] 21(9), pp.1218–1230. Available at: <http://link.springer.com/10.1007/s11367-016-1087-8> [Accessed Sept, 2018].

background data were drawn from credible, widely used databases including the US LCI database and Ecoinvent.

There are several other important points with regard to data accuracy. Each number generally contributes a small part to the total value, so a large error in one data point does not necessarily create a problem. For life cycle stages and process steps that make the largest contribution to results, special care is taken with the data quality.

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 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 final fabrication step for a plastic component changes the amounts of resin inputs to that process, and so on back to the quantities of crude oil and natural gas extracted.

In addition to the accuracy of the underlying data sets used to model each unit process, an added dimension to this analysis is the possible variations in container weights, recycled content, and other parameters for the container systems studied. Because of this, the life cycle model was set up as a dynamic model capable of evaluating a wide range of user-defined scenarios. Sensitivity analyses can then be run to understand the impact of variations in individual modeling parameters and assumptions.

Based on the uncertainties in LCI energy data, energy differences between systems are not considered meaningful unless the percent difference between system results is greater than 10 percent. (Percent difference between systems is defined as the difference between energy totals divided by the average of the two system totals.) This minimum percent difference criterion was developed based on the experience and professional judgment of the analysts. If the percent difference between two systems' results is less than 10 percent, the comparison is considered inconclusive. The threshold guidelines are not intended to be interpreted as rigorous statistical uncertainty analysis, but rather are provided as general guidelines for readers to use when interpreting differences in system results, to ensure that undue importance is not placed on small differences that fall within the uncertainties of the underlying data.

The inventory data on solid waste and water consumption, and the emissions data used to develop the LCIA results (global warming potential, acidification potential, eutrophication potential, ozone depletion potential, and smog formation potential) are based upon the best data available. Some emissions, water, and waste data are reported from industrial sources, and others are based on engineering estimates or published emission factors. Because of these uncertainties, the difference in two systems' environmental emissions, water consumption, and solid waste results are not considered meaningful unless the percent difference exceeds 25%. (Percent difference is defined as the difference between two system totals divided by their average.) This minimum percent difference criterion was developed based on the experience and professional judgment of the analysts. If the percent difference between two systems' results is less than 25%, the comparison is considered inconclusive. Again, the threshold guidelines are not intended to be interpreted as rigorous statistical uncertainty analysis, but rather are provided as general guidelines for readers to use when interpreting differences in system results, to ensure that undue importance is not placed on small differences that fall within the uncertainties of the underlying data.

In addition to the uncertainty of the LCI emissions data, there is uncertainty associated with the application of LCIA methodologies to aggregated LCI emissions. For example, two systems may release the same total amount of the same substance, but one quantity may represent a single high-concentration release to a stressed environment while the other quantity may represent the aggregate of many small dilute releases to environments that are well below threshold limits for the released substance. The actual impacts would likely be very different for these two scenarios, but the life cycle inventory does not track the temporal and spatial resolution or concentrations of releases in sufficient detail for the LCIA methodology to model the aggregated emission quantities differently. Therefore, it is not possible to state with complete certainty that differences in potential impacts for two systems are significant differences. Although there is uncertainty associated with LCIA methodologies, all LCIA methodologies are applied to different beverage container system models uniformly. Therefore, comparative results can be determined with a greater confidence than absolute results for one system. Since the emissions results used as the starting point for the LCIA are considered to have a 25 percent uncertainty, and the LCIA characterization method, although applied equally to all systems, may introduce additional uncertainty, a 25 percent difference is used here as the minimum threshold required for a meaningful difference in LCIA results.

Although GWP results are generally dominated by fossil CO_2 emissions, which are closely tied to energy use, a 25% threshold is used for GWP results rather than a 10% threshold as used for energy results. The higher threshold is used for GWP because there can be significant variations in the fossil CO_2 emissions associated with the same quantity of MJ of energy, depending on the type(s) of fuel used to provide the energy. For example, a facility using coal as boiler fuel may have energy requirements similar to a facility using natural gas as boiler fuel, but the GWP profiles will be very different. Because LCI data sets are often based on a limited sample of facilities or literature sources, the fuel-related CO_2 emissions for a process are likely to have a higher uncertainty than energy results for the process. Additionally, GWP results can also be strongly influenced by small emissions of substances with high GWP characterization factors. As noted above, when primary data are not available, emissions data are often based on emissions factors that may over- or under-represent actual releases from industrial facilities.

METHODOLOGY

The LCA has been conducted following internationally accepted standards for LCA as outlined in the ISO 14040 and 14044 standards, which provide guidance and requirements for conducting LCA studies. However, for some specific aspects of LCA, the ISO standards have some flexibility and allow for choices to be made. The following sections describe the approach to each issue used in this study.

Coproduct Allocation

An important feature of life cycle inventories is that the quantification of inputs and outputs are related to a specific amount of useful output from a process. However, it is sometimes difficult or impossible to identify which inputs and outputs are associated with individual products of interest resulting from a single process (or process sequence) that produces multiple useful products. The practice of allocating inputs and outputs among multiple products from a process is often referred to as coproduct allocation or credit.

Co-product 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 co-product credit is less desirable than being able to identify which inputs lead to specific outputs. In this study, co-product allocations are necessary because of multiple useful outputs from some of the "upstream" chemical processes involved in producing the resins used to manufacture plastic.

ERG follows the guidelines for allocating co-product credit shown in the ISO 14044:2006 standard on life cycle assessment requirements and guidelines[30]. In this standard, the preferred hierarchy for handling allocation is (1) avoid allocation where possible, (2) allocate flows based on direct physical relationships to product outputs, (3) use some other relationship between elementary flows and product output. No single allocation method is suitable for every scenario. As described in ISO 14044 section 4.3.4.2, when allocation cannot be avoided, the preferred partitioning approach should reflect the underlying physical relationships between the different products or functions. Allocation methods used for material coproducts, energy coproducts, and cogeneration of electricity and heat in the cradle-to-gate sequence of processes for production of PET resin are described in the 2020 NAPCOR PET report.

Recycled Content Modeling

The PET and glass bottles modeled in the study contain postconsumer (PC) recycled content, while the aluminum cans have both PC and postindustrial (PI) recycled content. Postconsumer material is material that has had a useful life in a finished product and is recovered at the product's end of life for reprocessing and use in another product system. Postindustrial recycled content is typically scrap from converting operations and is material that has not been used in a finished product, unless the scrap material contains some PC content.

In the methodology used in this LCA, virgin material production burdens are assigned to material's first useful life in a product, and PC material comes into a system with only the

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30 International Standards Organization. ISO 14044:2006, Environmental management – Life cycle assessment – Requirements and guidelines.

burdens for collection and reprocessing. Since PI scrap has not yet been used in a finished product, it would normally be modeled as coming into a system with virgin material production burdens, unless there is information about PC content in the PI scrap. In the Aluminum Association 2021 can LCA, the calculation of 73% recycled content in the can includes 167 kg of PI scrap per 1000 kg of can ingot, but no information is provided about the source of the PI scrap or any PC content in the PI scrap. Since many aluminum products are made with PC recycled content, it is likely that there is at least some PC content in the PI scrap going into aluminum can ingot. However, since no information is provided about the PI scrap, and the peer-reviewed Aluminum Association LCA includes PI scrap in the can recycled content, the baseline LCA results in this LCA treat the PI scrap the same as PC scrap and only assign the PI scrap burdens for reprocessing (shredding and remelting).

Results for aluminum cans were also run with the PI scrap modeled with 50% virgin content and 50% PC content. For this approach, only the PC content of the PI scrap was included in the calculation of can recycled content, and the can recycled content drops from 73% to 62.3%. The modeling of PC and PI scrap also has implications for end-of-life recycling calculations, as described in the following section.

Recycling Allocation

When material is used in one system and subsequently recovered, reprocessed, and used in another application, there are different methods that can be used to allocate environmental burdens among different useful lives of the material. In the allocation hierarchy in ISO 14044, avoidance of allocation where possible is the preferred approach. Therefore, system expansion is the baseline approach used in this analysis. In the system expansion approach, the container system boundaries are expanded to include collection and reprocessing of postconsumer containers, as well as the net virgin material displacement or inputs required, based on the balance between the container system's recycled content (RC) and recycling rate (RR).

In the system expansion modeling approach, illustrated in Figure 1, the system boundaries of the beverage container systems are expanded to include collection and reprocessing of postconsumer containers and packaging that are recycled at end of life. The net material impacts or credits for recycling are based on the balance between the system's recycled content (RC) and recycling rate (RR). If the amount of postconsumer material *produced* from the container system at the specified RR is greater than the amount of postconsumer material *used* by the container system at the specified RC, the system is credited for avoiding burdens for the net amount of virgin material production displaced by the excess postconsumer material (RR-RC). However, if a container system uses more postconsumer material than is replaced by container recycling (RC>RR), then it creates a net deficit of postconsumer material, and the system boundaries are expanded to include the additional virgin material required to make up the deficit. For the 10% and 25% RC scenarios evaluated for PET bottles, the 29.1% RR for the bottles is greater than the RC in the bottles, so the PET bottle scenarios receive recycling credits in the end-of-life stage. For the 50% RC scenario for PET bottles, and both RC scenarios for aluminum cans (73% and 62.3%),

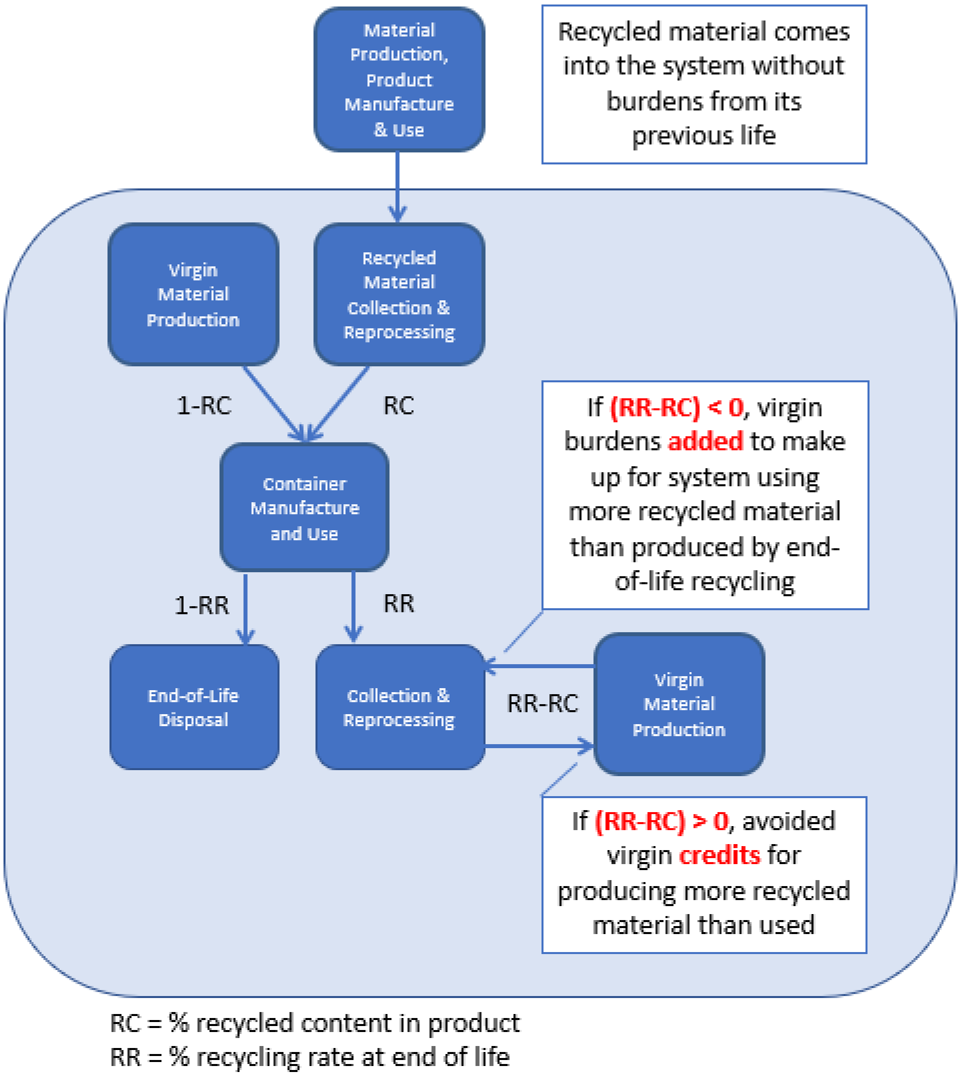

Figure 1. System Expansion Recycling

the container RC is greater than the RR (29.1% for PET bottles, 50.4% RR for aluminum cans). Since the available supplies of recycled PET and aluminum are already fully utilized, the additional recycled material needed to make up the deficit between container RC and RR would need to be shifted away from some other system that uses recycled PET or aluminum, resulting in a net increase in demand for virgin materials. Therefore, for scenarios where RC > RR, virgin PET and aluminum impacts are added to make up for the containers' net depletion of recycled PET and aluminum. For glass bottles, the 38% RC and 39.6% RR are nearly identical, so there are minimal credits for RR exceeding RC.

ISO 14044 states that "whenever several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted to illustrate the consequences of the departure from the selected approach." In this analysis, an alternative methodology that is used for modeling recycling in a sensitivity analysis is the "cut-off" approach.

In the cut-off approach, illustrated in Figure 2, distinct boundaries are drawn between the initial use of the material and subsequent uses of the material after recovery and recycling. All virgin material production burdens are assigned to the first use of the material, and the burdens assigned to the recycled material begin with recovery of the postconsumer material. For containers that are recycled at end of life (EOL), all burdens associated with material recovery, transport, separation and sorting, and reprocessing are assigned to the next system using the recycled material. Burdens associated with the final disposal of the container material are assigned to the last useful life of the material. The cut-off approach is not affected by the balance between a system's recycled content and its recycling rate. No material displacement credit is applied; the system is assigned virgin material inputs only for the virgin content of the container, while EOL container recycling simply reduces the amount of material disposed. Since environmental burdens for collection and reprocessing are generally much lower than burdens for virgin material production, this approach favors systems that have high recycled content, regardless of their recycling rate. The cut-off method is outlined in detail in the 1993 EPA Life-Cycle Assessment: Inventory Guidelines and Principles document and identified as the recycling allocation method 2 (U.S. EPA, 1993).

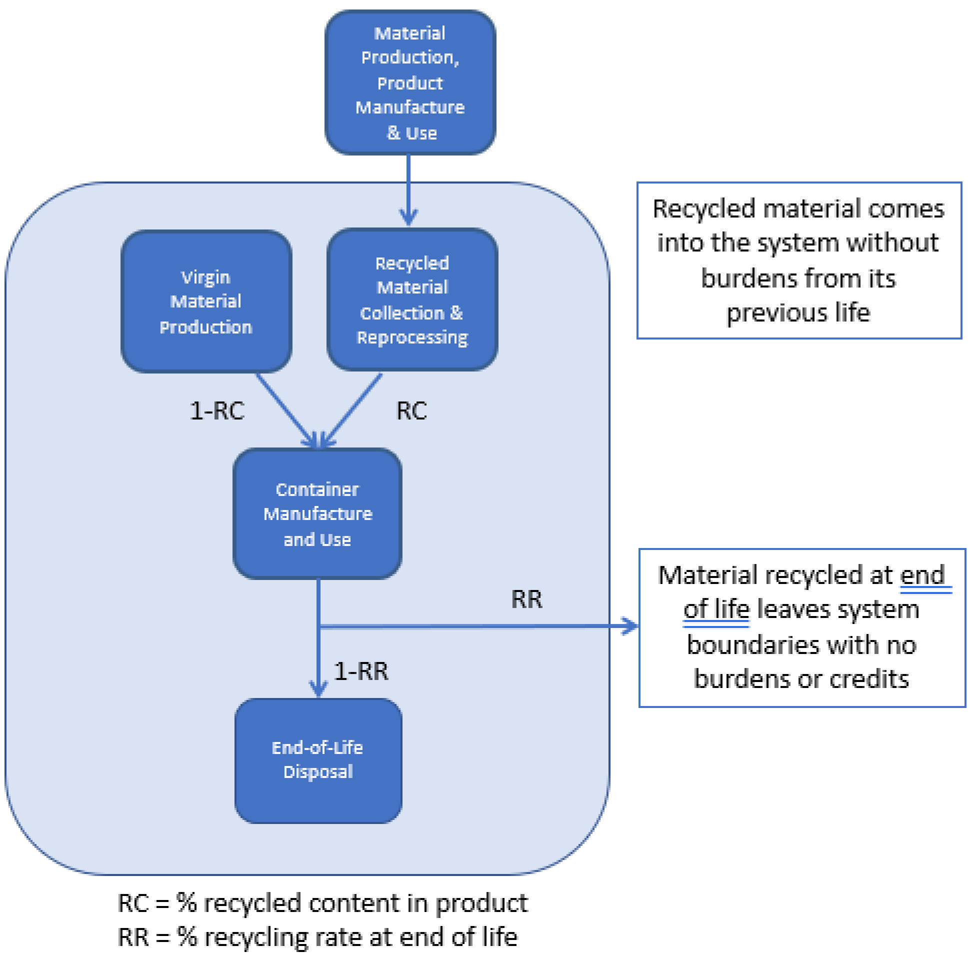

Figure 2. Cut-off Recycling

Because the system expansion modeling approach favors systems with a high recycling rate, and the cut-off approach favors systems with a high recycled content, the system expansion and the cut-off approaches capture the range of options in the ISO recycling allocation hierarchy and have been selected to examine the sensitivity of the LCA results to the choice of recycling allocation methodology.

Landfill and WTE Modeling

In the U.S., 80.4 percent by weight of municipal solid waste (MSW) that is not recovered for recycling or composting is sent to landfill (LF) and 19.6 percent by weight goes to waste-to-energy (WTE) combustion facilities.[31] There are GWP contributions from WTE combustion of postconsumer materials. There can also be GWP burdens and credits associated with landfilled material, depending on the amounts of biogenic carbon in the material, and the degree of decomposition of material containing biogenic carbon. Plastic resins and metals used in the container systems and packaging studied do not decompose to any extent in landfills, so no decomposition is modeled for these items. The baseline results for paperboard packaging items are based on maximum anaerobic decomposition of paperboard packaging that is uncoated or coated on only one side.

Decomposition modeling for paperboard packaging is based on landfill simulation experiments conducted by Eleazar, et al.[32] The landfill simulation experiments analyzed decomposition of office paper, clay-coated magazine paper, newspaper, and corrugated. Experimental data on decomposition of corrugated board is used to estimate decomposition of unbleached paperboard packaging, including pallet tier sheets, and paperboard multipack boxes and carriers. The following paragraphs describe the decomposition modeling based on the landfill simulation experiments and U.S. EPA information on landfill gas management.

For paper and paperboard materials, the cellulose and hemicellulose fractions of the material decompose to some extent, while the lignin fraction of the material tends to decompose to a much lesser extent under anaerobic conditions. Thus, the potentially degradable carbon content of the landfilled material is based on its cellulose and hemicellulose content. Based on the cellulose, hemicellulose, and lignin percentages in corrugated, and the carbon content of each fraction, the total carbon content of corrugated is calculated as 43.2 percent (29.9 percent potentially degradable, 13.3 percent in lignin).

In the landfill decomposition experiments, the following conditions were used to simulate enhanced decomposition in a landfill: addition of a seed of well-decomposed refuse to help initiate decomposition, incubation at about 40°C, and leachate recycling and neutralization. The maximum degree of decomposition in the corrugated samples was 64 percent for the cellulose and 62 percent for the hemicellulose. Overall, 19 percent by weight of the corrugated degraded to produce CO_2 and methane. The remaining biomass carbon content

31 US EPA Advancing Sustainable Materials Management Report, November 2019. 2017 data in Table 35.

32 Eleazar, William, et al. "Biodegradability of Municipal Solid Waste Components in Laboratory-Scale Landfills." Published in Environmental Science & Technology. Volume 31, Number 3, 1997.

did not degrade. Credits for biogenic carbon storage are described in a subsequent section of this report.

The composition of landfill gas as generated is approximately 50 percent by volume methane and 50 percent by volume CO_2. Currently in the US, about 71.2 percent of methane generated from solid waste landfills is converted to CO2 before it is released to the environment: 56.8 percent is burned with energy recovery, 10.6 percent is flared, and about 3.8 percent is oxidized as it travels through the landfill cover.[33] Biomass CO_2 released from decomposition of paper products or from oxidation or combustion of biomass-derived methane to CO_2 is considered carbon neutral, as the CO_2 released represents a return to the environment of the carbon taken up as CO_2 during the plant's growth cycle and does not result in a net increase in atmospheric CO_2. Thus, biomass-derived CO_2 is not included in the GHG results shown in this analysis. Methane releases to the environment from anaerobic decomposition of biomass are not considered carbon neutral, however, since these releases resulting from human intervention have a higher GWP than the CO_2 taken up or released during the natural carbon cycle. The GWP factor used for biogenic methane is lower than the GWP factor for fossil methane, reflecting the impact of biogenic methane in the atmosphere until it converts to carbon-neutral biogenic CO2. The GWP for biogenic methane in this study is 25.25, and the GWP for fossil methane in this study is 28.

The US EPA's Landfill Methane Outreach Program (LMOP) Landfill Database[34] indicates that the majority of landfill gas burned with energy recovery is used to produce electricity. The gross energy recovered from combustion of LF gas from each material is converted to displaced quantities of grid electricity using an efficiency factor of 1 kWh generated per 11,700 Btu of LF gas burned.[35] Each system with energy recovery from landfill gas is credited with avoiding the burdens associated with production of the offset quantity of grid electricity.

Waste-to-energy combustion of postconsumer material is modeled using a similar approach to the landfill gas combustion credit. However, for WTE combustion of packaging, the CO_2 releases are modeled based on the total carbon content of the material oxidizing to CO_2. For combustion of paperboard, the CO_2 produced is considered carbon-neutral biomass CO_2, while the CO_2 from combustion of fossil-derived plastic resins is fossil CO_2 (a net contribution to GWP).

The gross heat produced from WTE combustion of materials is calculated based on the pounds of material burned and the higher heating value of the material. The heat is converted to kWh of electricity using a conversion efficiency of 1 kWh per 19,120 Btu for

33 US EPA report EPA 430-R-15-004 (2015). Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2013, April 2015. Calculated from 2013 data in Table 7-4. Accessed at http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

34 Operational LFG energy projects spreadsheet, sorted by LFGE utilization type and project type. Accessed at http://www.epa.gov/lmop/proj/#1.

35 LMOP Benefits Calculator. Calculations and References tab. Accessed at http://www.epa.gov/lmop/res/lfge_benefitscalc.xls

mass burn facilities[36], and a credit is given for avoiding the GWP associated with producing the equivalent amount of grid electricity.

The net end-of-life burdens for each container system are calculated by summing the individual impacts and credits described above for the fractions of containers and packaging sent to landfill and waste-to-energy combustion.

Biogenic Carbon Storage

A carbon sequestration credit is given to landfilled material with biogenic carbon content that does not decompose, as this carbon was removed from the environment during biomass growth and remains stored in the landfilled material. In this study, there is some biogenic carbon storage in landfilled paperboard packaging. For each kg of biogenic carbon stored in landfilled paperboard that does not decompose, a sequestration credit is given for the equivalent amount of CO_2 that was removed from the atmosphere by the biomass during its growth cycle. Based on the experiments conducted by Eleazar, et al, some fraction of each paper type does not decompose even under favorable landfill conditions.[37] Only carbon storage in the final product is incorporated into this study; carbon uptake in biomass that is later combusted (i.e., carbon re-emitted into the atmosphere as CO_2 within the assessment period) is considered a net zero carbon flow.

Carbon storage credits are not given for fossil-derived resins. The U.S. EPA greenhouse gas accounting methodology does not assign a carbon sequestration credit to landfilling of fossil-derived materials because this is considered a transfer between carbon stocks (from oil deposit to landfill) with no net change in the overall amount of carbon stored.[38]

Because net carbon storage depends on the EOL fate and decomposition modeling of the amount of landfilled degradable materials, the net carbon storage is tracked in the end-of-life stage in this study for landfilled paperboard packaging.

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36 US EPA. Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks. Third Edition. September 2006. Chapter 5 Combustion, section 5.1.5. Calculation is based on 550 kWh produced per ton of MSW burned, with a heat value of 5,000 Btu per pound of MSW. For mass burn facilities, 523 kWh of electricity are delivered per 550 kWh generated. Full report and individual chapters of the report are accessible at http://www.epa.gov/climatechange/wycd/waste/SWMGHGreport.html.

37 Eleazar, William, et al. "Biodegradability of Municipal Solid Waste Components in Laboratory-Scale Landfills." Published in Environmental Science & Technology. Volume 31, Number 3, 1997.

38 US EPA. Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks. Third Edition. September 2006. Section 1.3, subsection Carbon Stocks, Carbon Storage, and Carbon Sequestration. Page 6.

CHAPTER 2. LIFE CYCLE INVENTORY AND IMPACT ASSESSMENT RESULTS

This chapter presents LCI and LCIA results for the beverage container systems, including the following:

Life cycle inventory results:

- Cumulative energy demand
- Feedstock energy
- Non-renewable energy demand
- Solid waste by weight
- Water consumption

Life cycle impact assessment results:

- Global warming potential
- Acidification potential
- Eutrophication potential
- Ozone depletion potential
- Smog formation potential

All results are presented on the basis of delivering 1,000 gallons of beverage. The following system scenarios are included in each table:

- **16.9 oz PET CSD, 10% RC, 29.1% RR**: 22.1 g 16.9 oz PET bottle for carbonated soft drink with 10% postconsumer recycled content (RC) and 29.1% recycling rate (RR)
- **20 oz PET CSD, 10% RC, 29.1% RR**: 22.2 g 20 oz PET bottle for carbonated soft drink with 10% postconsumer recycled content (RC) and 29.1% RR
- **2L PET CSD, 10% RC, 29.1% RR**: 43.9 g 2 liter PET bottle for carbonated soft drink with 10% RC and 29.1% RR
- **500 ml PET Water - Avg,10% RC, 29.1% RR**: 11.2 g 500 ml PET bottle for domestic still water with 10% RC and 29.1% RR
- **500 ml PET Water - Lt,10% RC, 29.1% RR**: 8.2 g 500 ml PET bottle for domestic still water with 10% RC and 29.1% RR
- **12 oz Al can, 73% RC, 50.4% RR**: 12.7 g 12 oz aluminum can for carbonated or uncarbonated beverage with all of the 73% recycled content (both postindustrial and postconsumer content) modeled the same as postconsumer material, with no virgin Al burdens, only collection and reprocessing burdens, and 50.4% RR
- **12 oz Al can, 62.3% RC, 50.4% RR**: 12.7 g 12 oz aluminum can for carbonated or uncarbonated beverage with 62.3% postconsumer recycled content (50% of the postindustrial scrap modeled with virgin Al burdens and 50% of the postindustrial scrap modeled the same as postconsumer material with only collection and reprocessing burdens) and 50.4% RR
- **16 oz Al can, 73% RC, 50.4% RR**: 15.1 g 16 oz aluminum can for carbonated or uncarbonated beverage with all recycled content (both postindustrial and

postconsumer content modeled with no virgin Al burdens, only collection and reprocessing burdens) and 50.4% RR

- **16 oz Al can, 62.3% RC, 50.4% RR**: 15.1 g 16 oz aluminum can for carbonated or uncarbonated beverage with 62.3% postconsumer recycled content (50% of the postindustrial scrap modeled with virgin Al burdens and 50% modeled same as postconsumer material with only collection and reprocessing burdens) and 50.4%
- **12 oz Glass, 38% RC, 39.6% RR**: 208 g 12 oz glass bottle for carbonated soft drinks modeled with 38% RC and 39.6% RR and a paper label.
- **12 oz Glass, no label, 38% RC, 39.6% RR**: 208 g 12 oz glass bottle for carbonated soft drinks modeled with 38% RC and 39.6% RR and no paper label.

Throughout the results sections, the tables and figures break out system results into the following categories:

- **Raw material:** Covers all steps from raw material extraction (or, for recycled content, postconsumer material collection and reprocessing) through production of material ready for converting into a container
- **Converting:** Steps to convert raw material into a finished container. For PET bottles, includes molding preforms and blowing preforms into bottles; for aluminum cans includes rolling ingot into sheet and converting sheet into finished can. For glass bottles, there is not a boundary between glass production and container manufacturing, so results for the combined process are reported in the Raw Material results.
- **Transp empty to filler:** Transportation of empty containers to filler
- **Transp filled to DC:** Transportation of filled containers (with lids, labels, and multipack packaging) from filler to distribution center
- **Transp filled to store:** Transportation of filled containers (with lids, labels, and multipack packaging) from distribution center to store
- **Container EOL:** Results for end-of-life management of containers based on U.S. average recycling rates and U.S. average split of landfill and waste-to-energy combustion for containers not recycled.
- **LC Closure:** Total life cycle results for container closures (where applicable), from raw material extraction through closure manufacturing and end-of-life management
- **LC Label:** Total life cycle results for container labels (where applicable), from raw material extraction through label manufacturing and end-of-life management
- **LC Multipack:** Total life cycle results for container multipacks (where applicable), from raw material extraction through multipack manufacturing and end-of-life management
- **LC Tier Sheets:** Total life cycle results for tier sheets used to ship empty container, from raw material extraction through tier sheet manufacturing and end-of-life management

Within each column of the results tables, color coding is used to identify the life cycle stages making the largest contributions to results for that system (redder = higher contribution, white = lower contribution). The results figures for each LCI or LCA metric expresses each system's results normalized to the basis of results for the system with the highest total impacts for that results metric.

The results tables and figures are all presented on the basis of delivering 1,000 gallons of beverage. In addition to differences in the materials used in the container systems, results also reflect the influence of the weight of containers of each size required to deliver 1,000 gallons. When different sizes of containers are compared on the basis of delivering an equivalent volume of product, larger volume containers tend to show lower results compared to smaller volume containers of the same type, since larger containers generally have a lower ratio of container to product so that less weight of packaging is required to deliver the same amount of beverage in a large container compared to a smaller one. A comparison of the number and weight of each container system required to deliver 1,000 gallons of beverage is presented in Table 17. Of the CSD PET bottles, the table shows that the 16.9 oz bottle system, which is the smallest PET CSD bottle evaluated, uses the highest weight of packaging to deliver 1,000 gallons of beverage. Although Table 13 showed that individual 12 oz aluminum cans weigh less than 16.9 oz bottles, Table 17 shows that the total weight of packaging for 12 oz aluminum cans is higher since more cans are required to deliver 1,000 gallons compared to the larger CSD bottles.

Table 17. Packaging Amounts for 1,000 Gallons of Beverage

	Size/Beverage	g per ctr + closure, label	ctrs/ 1000 gal	kg ctr/ 1000 gal	kg multi-pack/ 1000 gal	Total kg/ 1000 gal
PET	500 ml water, avg	9.5	7,574	71.6	8.58	80.2
	500 ml water, light	12.4	7,574	94.2	8.58	103
	16.9 oz CSD	24.9	7,574	189	5.54	194
	20 oz CSD	24.8	6,400	159		159
	2 liter CSD	47.6	1,893	90.1		90.1
Aluminum Cans	12 oz CSD or water	12.7	10,667	136	77.6	213
	16 oz CSD or water	15.1	8,000	120		120
Glass	12 oz CSD	211.6	10,667	2,257	145	2,402

ENERGY DEMAND

Cumulative Energy Demand

Cumulative energy demand results include all renewable and non-renewable energy sources used for process and transportation energy, as well as material feedstock energy. Process and transportation energy includes direct use of fuels, including the use of fossil fuels, hydropower, nuclear, wind, solar, and other energy sources to generate electricity used by processes, as well as the energy to extract, process and transport the fuels to the point of use. Feedstock energy is the energy content of the resources removed from nature and used as material feedstocks to produce containers and packaging (e.g., the energy content of oil and gas used as material feedstocks for plastic resins, the energy content of wood used as material feedstock to produce paperboard packaging). Energy results for the beverage container systems are shown in Table 18 and Figure 3.

The energy results table shows that raw material production and container converting account for the majority of energy consumption for most systems; however, the aluminum can systems show some differences in contribution compared to other systems. For aluminum cans modeled with 73% recycled content (with external postindustrial scrap content modeled the same as postconsumer scrap), the energy for converting aluminum into cans is greater than the energy for production of can materials. Because the can recycled content (73%) is greater than the can recycling rate (50.4%), the EOL stage shows the impact for adding virgin aluminum production burdens to make up for the deficit between the can's recycled content and its recycling rate. For the scenarios where external postindustrial scrap content of the aluminum cans is modeled as a 50/50 mix of virgin and postconsumer aluminum, the postconsumer recycled content of the can drops to 62.3%. The higher percent virgin aluminum content in the can results in an increase in raw material energy for the cans, but the reduced difference between the cans' recycled content and recycling rate reduces the added virgin aluminum burdens in the EOL stage.

Table 18. Total Energy Demand (MJ) for Beverage Container Systems, 1,000 Gallon Basis, System Expansion

Life Cycle Stage	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Raw material	9,464	8,033	4,697	4,796	3,520	4,710	6,262	4,182	5,561	20,448	20,448
Converting	3,005	2,624	1,451	1,536	1,127	8,483	8,483	7,533	7,533	0	0
Transp empty to filler	83.2	87.4	112	51.9	51.6	221	221	213	213	2,453	2,453
Transp filled to DC	17.4	14.6	8.28	9.45	7.37	20.2	20.2	11.4	11.4	221	221
Transp filled to store	17.4	31.4	8.28	9.45	7.37	20.2	20.2	23.7	23.7	221	221
Container EOL	-1,438	-1,221	-714	-729	-535	4,651	2,750	4,130	2,442	6,620	6,620
LC Closure	1,424	1,136	323	567	567	0	0	0	0	725	725
LC Label	209	166	222	151	151	0	0	0	0	867	0
LC Multipack	448	0	0	636	636	3,736	3,736	0	0	6,968	6,968
LC Tier Sheets	124	125	81.6	77.6	77.6	355	355	262	262	259	259
Total	**13,355**	**10,997**	**6,190**	**7,106**	**5,610**	**22,197**	**21,848**	**16,355**	**16,045**	**38,781**	**37,914**
Feedstock Energy	**5,448**	**4,339**	**2,446**	**2,956**	**2,361**	**966**	**964**	**93.1**	**92.0**	**2,302**	**2,055**
Expended Energy	**7,907**	**6,658**	**3,744**	**4,150**	**3,250**	**21,232**	**20,884**	**16,262**	**15,953**	**36,479**	**35,859**
Expended % of Total	59.2%	60.5%	60.5%	58.4%	57.9%	95.7%	95.6%	99.4%	99.4%	94.1%	94.6%
Non-renewable Energy	**12,893**	**10,592**	**5,967**	**6,866**	**5,410**	**16,904**	**16,662**	**13,451**	**13,236**	**33,941**	**33,646**
% of Total	96.5%	96.3%	96.4%	96.6%	96.4%	76.2%	76.3%	82.2%	82.5%	87.5%	88.7%

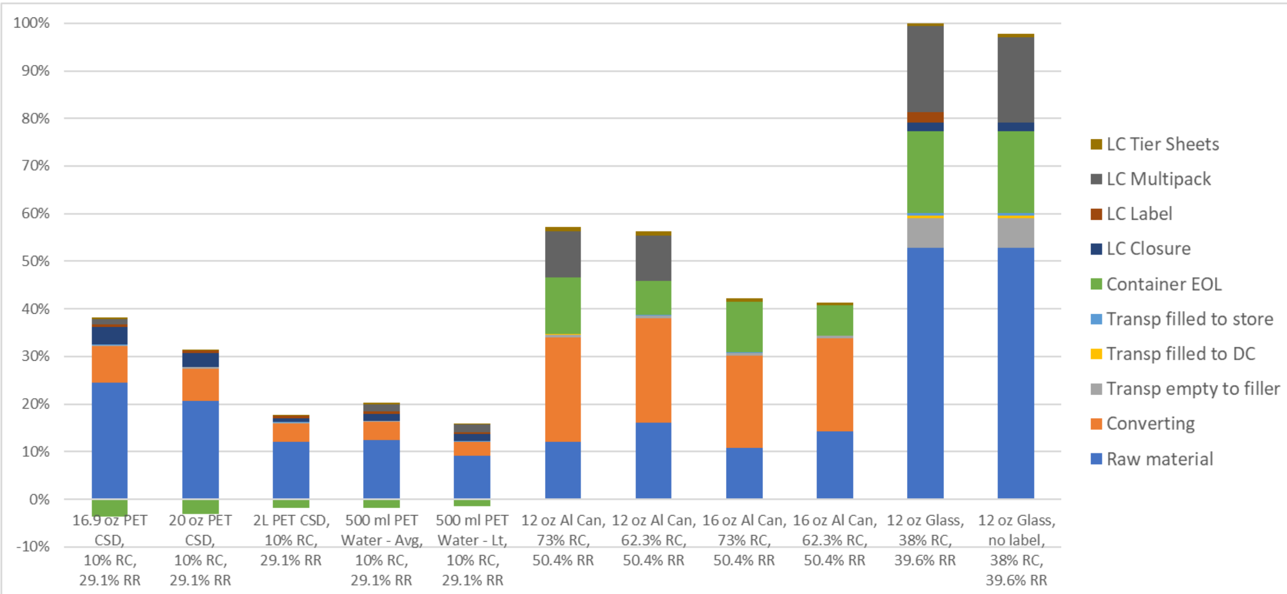

Figure 3. Total Energy Demand (MJ) for Beverage Container Systems, 1,000 Gallon Basis, System Expansion

The results show that filled container transportation energy allocated to each packaging system makes a small contributor to overall results. Container transport and end-of-life management energy are highest for the glass bottle due to its much higher weight compared to other containers. The glass container system also has the highest results for multipacks. As shown in Table 13, the four-pack carriers for glass bottles have the highest weight of multipack per container for the systems studied. PET bottles show the largest end-of-life credits, mainly due to credits for avoided production of virgin PET since the 29.1% recycling rate of the bottles exceeds the 10% recycled content used in the bottles.

Expended Energy

As explained in the Inventory and Impact Assessment Results Categories section, total energy includes both process and transportation energy that has been irretrievably expended, and feedstock energy, which remains embodied in produced materials and is potentially available as a source of energy, e.g., via WTE combustion. The combined process and transportation energy is referred to here as "expended energy." Expended energy accounts for about 60% of total energy demand for PET bottle systems, over 95% of total energy for aluminum cans, and about 94% for 12 oz glass bottles.

Expended energy is a lower percent of the total for the PET bottle systems because a large share of total energy is feedstock energy associated with the natural gas and petroleum used as raw material inputs for the production of the virgin PET content of the bottles as well as for the PET bottle closures, labels, and secondary packaging for multipacks, which are all plastic as well. The aluminum and glass systems have very little feedstock energy, mainly biomass feedstock energy for paperboard tier sheets used for transport of empty containers and paperboard carriers used for multipacks of 12 oz aluminum cans and glass bottles. The aluminum cans also have some feedstock energy for coatings and varnishes applied to the can surfaces.

Non-renewable Energy Demand

Non-renewable energy demand includes the use of fossil fuels (petroleum, natural gas, and coal) for process energy, transportation energy, and as material feedstocks (e.g., oil and gas used as feedstocks for plastics), as well as use of uranium to generate the share of nuclear energy in the average U.S. kWh. More than 95 percent of the total energy for PET container systems comes from non-renewable sources. Although a significant percentage of total energy for PET systems is feedstock energy, both the feedstock energy and expended energy for PET bottle system components are mainly derived from fossil fuel resources. Non-renewable energy accounts for a lesser share of total energy for aluminum and glass containers, ranging from about 76 to 88 percent of total energy. Much of the renewable energy for aluminum and glass systems is biomass energy associated with paperboard multipack packaging. For aluminum can systems, the non-renewable energy demand is also reduced by high use of hydropower for the electricity-intensive smelting process for the virgin aluminum content of the cans.

SOLID WASTE

Solid waste results include the following types of wastes:

- **Process wastes** that are generated by the various processes from raw material acquisition through manufacture of the finished product (container or associated packaging component). Examples include sludges and residues from chemical reactions and material processing steps.
- **Fuel-related wastes** from the production and combustion of fuels used for process energy and transportation energy (e.g., refinery wastes, coal combustion ash)
- **Postconsumer wastes** that result from disposal of containers and packaging at the end of their useful life, including containers and packaging that are sent to landfill, or residuals from disposing of containers and packaging by WTE combustion.

Results for solid waste by weight are shown in Table 19 and Figure 4. For the PET and glass containers, disposal of postconsumer containers that are not recycled is the largest contributor to solid waste. The EOL solid wastes for aluminum cans include not only the weight of cans that are disposed but also the process wastes associated with the added virgin aluminum production burdens to make up the deficit between the can's recycling rate (RR) and recycled content (RC). Large quantities of red mud are produced when bauxite is converted to alumina for virgin aluminum. When comparing the baseline (73% RC) and 50/50 postindustrial scrap (62.3% RC) scenarios for cans, raw material wastes are lower for the 73% RC scenario because 27% of the can material is modeled as virgin material, but EOL wastes are higher because of the added virgin aluminum burdens at end of life to make up for the can's recycled content that is not replaced by the EOL recycling rate (50.4% RR – 73% RC = 22.6% deficit). The opposite trend is seen for 62.3% RC cans:

Raw material burdens are higher because 37.7% of the can material is modeled as virgin aluminum, but the EOL burdens are lower because the deficit between RR and RC is smaller (50.4% RR – 62.3% RC = 11.9% deficit).

Table 19. Solid Wastes (kg) for Beverage Container Systems, 1,000 Gallon Basis, System Expansion

Life Cycle Stage	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Raw material	14.5	12.3	7.19	7.35	5.39	101	140	89.9	124	91.7	91.7
Converting	14.9	13.0	7.11	7.44	5.46	35.3	35.3	31.4	31.4	0	0
Transp empty to filler	0.086	0.091	0.12	0.054	0.054	0.23	0.23	0.22	0.22	2.23	2.23
Transp filled to DC	0.016	0.013	0.0075	0.0086	0.0067	0.021	0.021	0.012	0.012	0.20	0.20
Transp filled to store	0.016	0.029	0.0075	0.0086	0.0067	0.021	0.021	0.022	0.022	0.20	0.20
Container EOL	94.9	80.6	47.1	48.1	35.3	177	129	157	115	1,438	1,438
LC Closure	14.3	11.4	3.26	5.71	5.71	0	0	0	0	25.9	25.9
LC Label	2.29	1.82	2.43	1.65	1.65	0	0	0	0	15.5	0
LC Multipack	5.13	0	0	7.24	7.24	65.8	65.8	0	0	123	123
LC Tier Sheets	0.60	0.60	0.39	0.37	0.37	1.71	1.71	1.26	1.26	1.24	1.24
Total	**147**	**120**	**67.6**	**77.9**	**61.2**	**381**	**372**	**280**	**272**	**1,698**	**1,682**

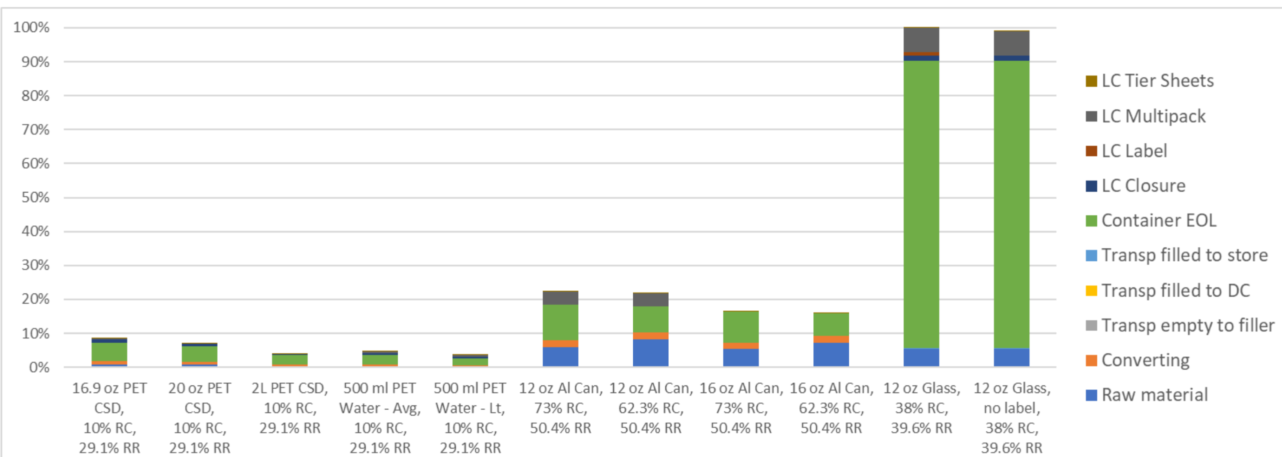

Figure 4. Solid Wastes (kg) for Beverage Container Systems, 1,000 Gallon Basis, System Expansion

WATER CONSUMPTION

Consumptive use of water in this study includes freshwater that is withdrawn from a water source or watershed and not returned to that source. Consumptive water use includes water consumed in chemical reactions, water that is incorporated into a product or waste stream, water that becomes evaporative loss, and water that is discharged to a different watershed or water body than the one from which it was withdrawn. Water consumption results shown for each life cycle stage include process water consumption as well as water consumption associated with production of the electricity and fuels used in that stage. Electricity-related water consumption includes evaporative losses associated with thermal generation of electricity from fossil and nuclear fuels, as well as evaporative losses due to establishment of dams for hydropower.

Water consumption results are shown in Table 20 and Figure 5. As with energy results, water consumption results are dominated by the raw material and converting stages. For PET, the raw material water consumption is mainly associated with electricity use for process energy in the cradle-to-production sequence of process steps to produce PET resin. Water consumption for PTA and PET production processes and refining petroleum feedstock also make significant contributions to PET resin water consumption. For aluminum production, the main contributors to water consumption are process electricity, bauxite mining, and alumina production. For PET and aluminum container converting operations, the majority of water consumption is associated with generation of the electricity used. For glass containers, glass production processes and generation of the electricity used in the processes are the largest contributors to water consumption.

Table 20. Water Consumption (liters) for Beverage Container Systems, 1,000 Gallon Basis, System Expansion

Life Cycle Stage	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Raw material	1,352	1,148	671	685	503	277	355	246	316	6,619	6,619
Converting	1,446	1,248	696	771	566	2,837	2,837	2,519	2,519	0	0
Transp empty to filler	4.10	4.30	5.50	2.55	2.54	10.9	10.9	10.5	10.5	95.3	95.3
Transp filled to DC	0.67	0.57	0.32	0.37	0.29	0.99	0.99	0.56	0.56	8.58	8.58
Transp filled to store	0.67	1.22	0.32	0.37	0.29	0.99	0.99	0.92	0.92	8.58	8.58
Container EOL	121	102	59.9	61.2	44.9	316	214	280	190	2,320	2,320
LC Closure	274	219	62.2	109	109	0	0	0	0	153	153
LC Label	32.1	25.4	34.1	23.1	23.1	0	0	0	0	131	0
LC Multipack	62.1	0	0	91.0	91.0	266	266	0	0	496	496
LC Tier Sheets	16.8	16.9	11.1	10.5	10.5	48.1	48.1	35.5	35.5	35.0	35.0
Total	**3,310**	**2,766**	**1,541**	**1,755**	**1,351**	**3,757**	**3,733**	**3,093**	**3,072**	**9,867**	**9,736**

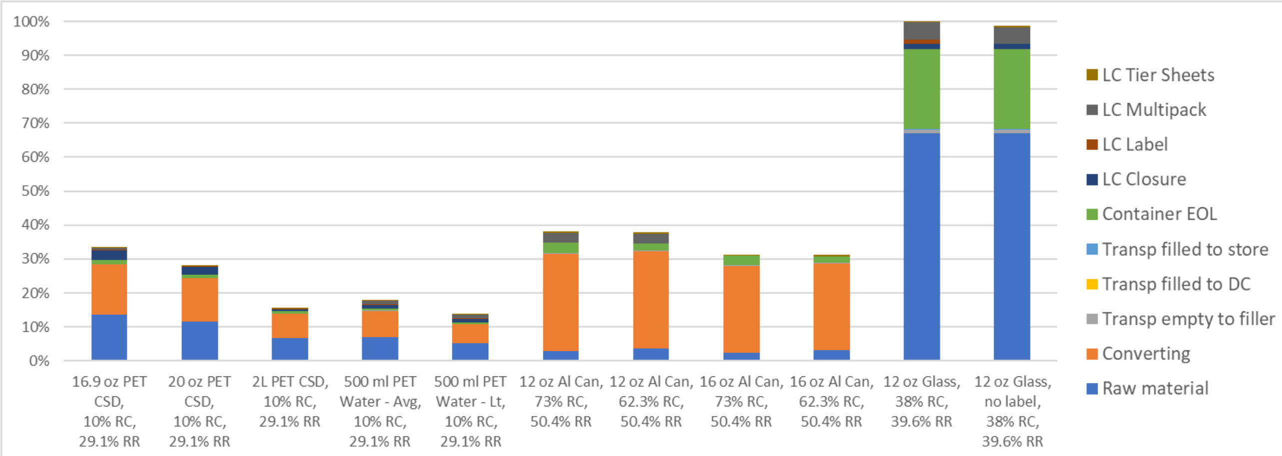

Figure 5. Water Consumption (liters) for Beverage Container Systems, 1,000 Gallon Basis, System Expansion

GLOBAL WARMING POTENTIAL

The atmospheric emissions in this analysis that account for the majority of the total global warming potential for each system are fossil fuel-derived carbon dioxide, methane, and nitrous oxides. For aluminum cans, emissions of tetrafluoromethane (CFC-14) from aluminum smelting account for over 5% of the GWP for the can material.

The 100-year global warming potential (GWP) factors for each of these substances as reported in the Intergovernmental Panel on Climate Change (IPCC) 2013[39] are: fossil carbon dioxide 1, fossil methane 28, and nitrous oxide 265. The GWP factor for a substance represents the relative global warming contribution of a pound of that substance compared to a pound of carbon dioxide. The weights of each greenhouse gas are multiplied by its GWP factor to arrive at the total GWP results.

Table 21 and Figure 6 show life cycle GWP results for the beverage container systems. GWP results are generally closely related to energy results. However, unlike energy from combustion of fuels for process and transportation energy, feedstock energy (which accounts for a high percentage of total energy for PET bottle systems) does not have associated combustion emissions since the energy is embodied in the plastic material. Feedstock energy does result in combustion emissions when material is disposed by combustion at end of life. Because of the high feedstock energy for PET bottle systems, raw material production accounts for a proportionally lower share of GWP results compared to energy results.

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39 IPCC, 2013: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013.

Table 21. Global Warming Potential (kg CO_2 eq) for Beverage Container Systems, 1,000 Gallon Basis, System Expansion

Life Cycle Stage	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Raw material	348	295	173	176	129	297	396	264	352	1,605	1,605
Converting	174	152	84.2	89.6	65.8	490	490	435	435	0	0
Transp empty to filler	6.47	6.80	8.69	4.04	4.01	17.2	17.2	16.6	16.6	192	192
Transp filled to DC	1.36	1.15	0.65	0.74	0.58	1.57	1.57	0.89	0.89	17.3	17.3
Transp filled to store	1.36	2.47	0.65	0.74	0.58	1.57	1.57	1.87	1.87	17.3	17.3
Container EOL	16.5	14.0	8.17	8.34	6.12	299	176	265	157	423	423
LC Closure	51.1	40.7	11.6	20.3	20.3	0	0	0	0	69.8	69.8
LC Label	6.78	5.37	7.20	4.87	4.87	0	0	0	0	41.9	0
LC Multipack	14.3	0	0	20.6	20.6	126	126	0	0	235	235
LC Tier Sheets	3.00	3.02	1.97	1.88	1.88	8.60	8.60	6.34	6.34	6.25	6.25
Total	**623**	**521**	**296**	**328**	**254**	**1,241**	**1,218**	**990**	**969**	**2,608**	**2,566**

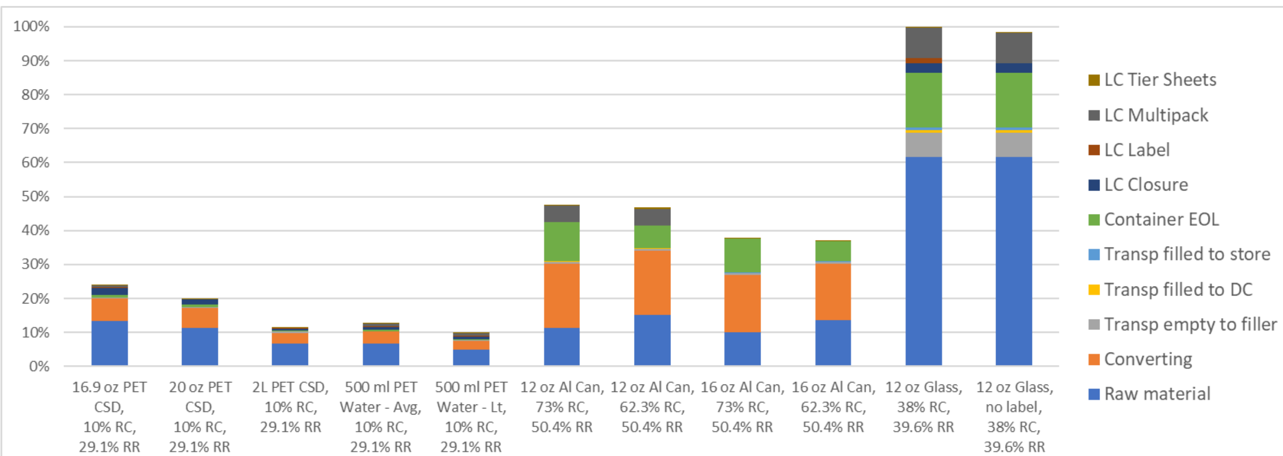

Figure 6. Global Warming Potential (kg CO_2 eq) for Beverage Container Systems, 1,000 Gallon Basis, System Expansion

ACIDIFICATION POTENTIAL

Acidification assesses the potential of emissions to contribute to the formation and deposit of acid rain on soil and water, which can cause serious harm to plant and animal life as well as damage to infrastructure. Acidification potential modeling in TRACI incorporates the results of an atmospheric chemistry and transport model, developed by the U.S. National Acid Precipitation Assessment Program (NAPAP), to estimate total North American terrestrial deposition due to atmospheric emissions of NO_x and SO_2, as a function of the emissions location.[40,41]

Acidification impacts are typically dominated by fossil fuel combustion emissions, particularly sulfur dioxide (SO_2) and nitrogen oxides (NO_x). Emissions from combustion of fossil fuels, especially coal, to generate grid electricity is a significant contributor to acidification impacts for all systems. For the glass container system, emissions of nitrogen oxides are also reported for virgin and recycled glass production processes. Table 22 shows total acidification potential results for the container systems. Results are shown graphically in Figure 7. Acidification results show similar trends to other results, with raw material and converting stages generally dominating results.

Table 22. Acidification Potential (kg SO_2 eq) for Beverage Container Systems, 1,000 Gallon Basis, System Expansion

Life Cycle Stage	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Raw material	1.10	0.94	0.55	0.56	0.41	1.94	2.64	1.72	2.34	9.02	9.02
Converting	0.89	0.78	0.43	0.48	0.35	2.10	2.10	1.86	1.86	0	0
Transp empty to filler	0.020	0.021	0.027	0.012	0.012	0.053	0.053	0.051	0.051	0.58	0.58
Transp filled to DC	0.0041	0.0035	0.0020	0.0022	0.0017	0.0048	0.0048	0.0027	0.0027	0.052	0.052
Transp filled to store	0.0041	0.0061	0.0020	0.0022	0.0017	0.0048	0.0048	0.0046	0.0046	0.052	0.052
Container EOL	-0.14	-0.12	-0.069	-0.070	-0.051	1.98	1.10	1.75	0.98	3.22	3.22
LC Closure	0.20	0.16	0.046	0.081	0.081	0	0	0	0	0.26	0.26
LC Label	0.020	0.016	0.021	0.014	0.014	0	0	0	0	0.11	0
LC Multipack	0.037	0	0	0.055	0.055	0.60	0.60	0	0	1.11	1.11
LC Tier Sheets	0.071	0.072	0.047	0.045	0.045	0.20	0.20	0.15	0.15	0.15	0.15
Total	**2.21**	**1.87**	**1.05**	**1.18**	**0.92**	**6.87**	**6.70**	**5.54**	**5.39**	**14.6**	**14.4**

40 Bare JC, Norris GA, Pennington DW, McKone T. (2003). TRACI: The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts, *Journal of Industrial Ecology,* **6**(3–4): 49–78. Available at URL: http://mitpress.mit.edu/journals/pdf/jiec_6_3_49_0.pdf.

41 Bare JC. (2002). Developing a consistent decision-making framework by using the US EPA's TRACI, AICHE. Available at URL: http://www.epa.gov/nrmrl/std/sab/traci/aiche2002paper.pdf.

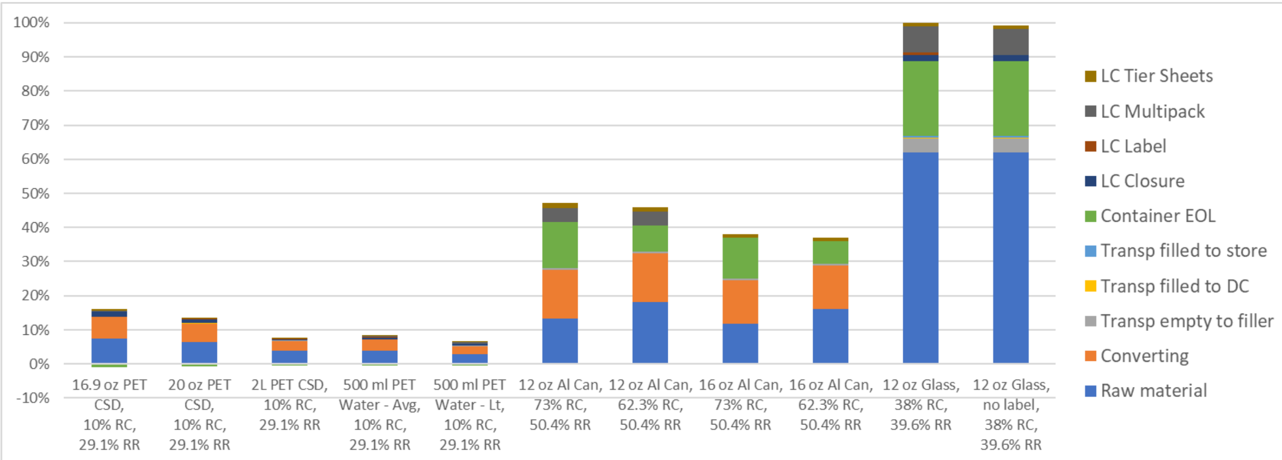

Figure 7. Acidification Potential (kg SO_2 eq) for Beverage Container Systems, 1,000 Gallon Basis, System Expansion

EUTROPHICATION POTENTIAL

Eutrophication occurs when excess nutrients are introduced to surface water causing the rapid growth of aquatic plants. This growth (generally referred to as an “algal bloom”) reduces the amount of dissolved oxygen in the water, thus decreasing oxygen available for other aquatic species. The TRACI characterization factors for eutrophication are the product of a nutrient factor and a transport factor.[42] The nutrient factor is based on the amount of plant growth caused by each pollutant, while the transport factor accounts for the probability that the pollutant will reach a body of water. Atmospheric emissions of nitrogen oxides (NO_x) as well as waterborne emissions of nitrogen, phosphorus, ammonia, biochemical oxygen demand (BOD), and chemical oxygen demand (COD) are the main contributors to eutrophication impacts.

Eutrophication potential results for the container systems are shown in Table 23 and illustrated in Figure 8. Again, raw material and converting life cycle stages dominate results (along with added virgin aluminum production burdens for aluminum cans in the end-of-life stage for the shortfall between can RC and RR). Paperboard components (multipacks for aluminum and glass containers, tier sheets for all systems) show higher contributions to eutrophication than for other results, due mainly to waterborne emissions from paperboard production.

42 Bare JC, Norris GA, Pennington DW, McKone T. (2003). TRACI: The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts, *Journal of Industrial Ecology,* **6**(3–4): 49–78. Available at URL: http://mitpress.mit.edu/journals/pdf/jiec_6_3_49_0.pdf.

Table 23. Eutrophication Potential (kg N eq) for Beverage Container Systems, 1,000 Gallon Basis, System Expansion

Life Cycle Stage	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Raw material	0.072	0.061	0.036	0.036	0.027	0.036	0.045	0.032	0.040	0.39	0.39
Converting	0.020	0.018	0.010	0.012	0.0088	0.069	0.069	0.061	0.061	0	0
Transp empty to filler	0.0012	0.0013	0.0016	7.6E-04	7.6E-04	0.0033	0.0033	0.0031	0.0031	0.037	0.037
Transp filled to DC	2.6E-04	2.2E-04	1.2E-04	1.4E-04	1.1E-04	3.0E-04	3.0E-04	1.7E-04	1.7E-04	0.0033	0.0033
Transp filled to store	2.6E-04	3.9E-04	1.2E-04	1.4E-04	1.1E-04	3.0E-04	3.0E-04	3.0E-04	3.0E-04	0.0033	0.0033
Container EOL	-8.3E-04	-7.1E-04	-4.1E-04	-4.2E-04	-3.1E-04	0.028	0.017	0.025	0.015	0.15	0.15
LC Closure	0.0077	0.0061	0.0017	0.0031	0.0031	0	0	0	0	0.0060	0.0060
LC Label	8.3E-04	6.6E-04	8.8E-04	6.0E-04	6.0E-04	0	0	0	0	0.013	0
LC Multipack	0.0018	0	0	0.0026	0.0026	0.034	0.034	0	0	0.063	0.063
LC Tier Sheets	0.0082	0.0082	0.0054	0.0051	0.0051	0.023	0.023	0.017	0.017	0.017	0.017
Total	**0.11**	**0.094**	**0.055**	**0.060**	**0.047**	**0.19**	**0.19**	**0.14**	**0.14**	**0.68**	**0.67**

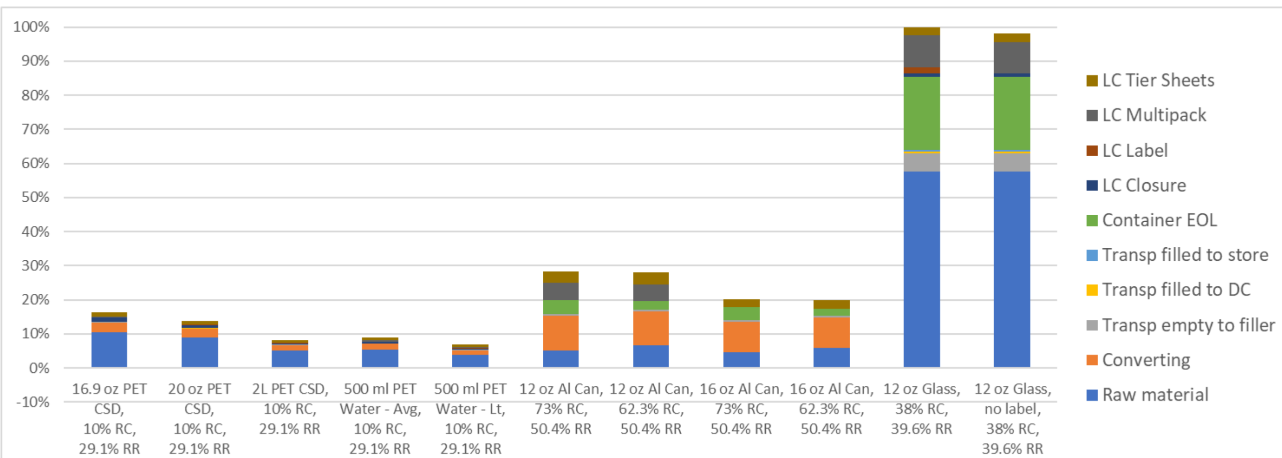

Figure 8. Eutrophication Potential (kg N eq) for Beverage Container Systems, 1,000 Gallon Basis, System Expansion

OZONE DEPLETION POTENTIAL

Stratospheric ozone depletion is the reduction of the protective ozone within the stratosphere caused by emissions of ozone-depleting substance such as CFCs and halons. The ozone depletion impact category characterizes the potential to destroy ozone based on a chemical's reactivity and lifetime. Damage related to ozone depletion can include skin cancer, cataracts, material damage, immune system suppression, crop damage, and other plant and animal effects.

Ozone depletion potential (ODP) results for the container systems are shown in Table 24 and Figure 9Figure 9. The life cycle stages with the highest contributions are raw material production and the life cycle of paperboard packaging components. For PET, the main source of ODP is methyl bromide emissions from TPA/PTA production, while the main contributors to raw material ODP for aluminum cans and glass containers are emissions from coal combustion in industrial boilers for production of input materials. For paperboard packaging, there is ODP for emissions from paperboard production. Since raw material production makes the largest contribution to ODP for PET systems, avoided virgin PET credits for end-of-life recycling of PET containers provides substantial ODP credits; however, net ODP is still notably higher for PET container systems compared to aluminum and glass systems.

Table 24. Ozone Depletion Potential (kg CFC-11 eq) for Beverage Container Systems, 1,000 Gallon Basis, System Expansion

Life Cycle Stage	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Raw material	6.8E-05	5.7E-05	3.4E-05	3.4E-05	2.5E-05	2.1E-06	2.3E-06	1.8E-06	2.1E-06	3.7E-06	3.7E-06
Converting	4.0E-08	3.3E-08	2.2E-08	2.8E-08	2.0E-08	8.0E-07	8.0E-07	7.1E-07	7.1E-07	0	0
Transp empty to filler	1.7E-08	1.8E-08	2.3E-08	1.1E-08	1.1E-08	4.6E-08	4.6E-08	4.5E-08	4.5E-08	5.3E-07	5.3E-07
Transp filled to DC	3.7E-09	3.2E-09	1.8E-09	2.0E-09	1.6E-09	4.2E-09	4.2E-09	2.4E-09	2.4E-09	4.8E-08	4.8E-08
Transp filled to store	3.7E-09	6.8E-09	1.8E-09	2.0E-09	1.6E-09	4.2E-09	4.2E-09	5.1E-09	5.1E-09	4.8E-08	4.8E-08
Container EOL	-1.4E-05	-1.2E-05	-7.1E-06	-7.2E-06	-5.3E-06	7.0E-07	3.9E-07	6.2E-07	3.5E-07	2.2E-07	2.2E-07
LC Closure	7.0E-08	5.6E-08	1.6E-08	2.8E-08	2.8E-08	0	0	0	0	3.2E-08	3.2E-08
LC Label	4.8E-09	3.8E-09	5.1E-09	3.4E-09	3.4E-09	0	0	0	0	6.4E-07	0
LC Multipack	8.0E-09	0	0	1.2E-08	1.2E-08	1.1E-06	1.1E-06	0	0	2.0E-06	2.0E-06
LC Tier Sheets	8.8E-07	8.9E-07	5.8E-07	5.5E-07	5.5E-07	2.5E-06	2.5E-06	1.9E-06	1.9E-06	1.8E-06	1.8E-06
Total	**5.5E-05**	**4.6E-05**	**2.7E-05**	**2.8E-05**	**2.1E-05**	**7.2E-06**	**7.2E-06**	**5.1E-06**	**5.0E-06**	**9.1E-06**	**8.5E-06**

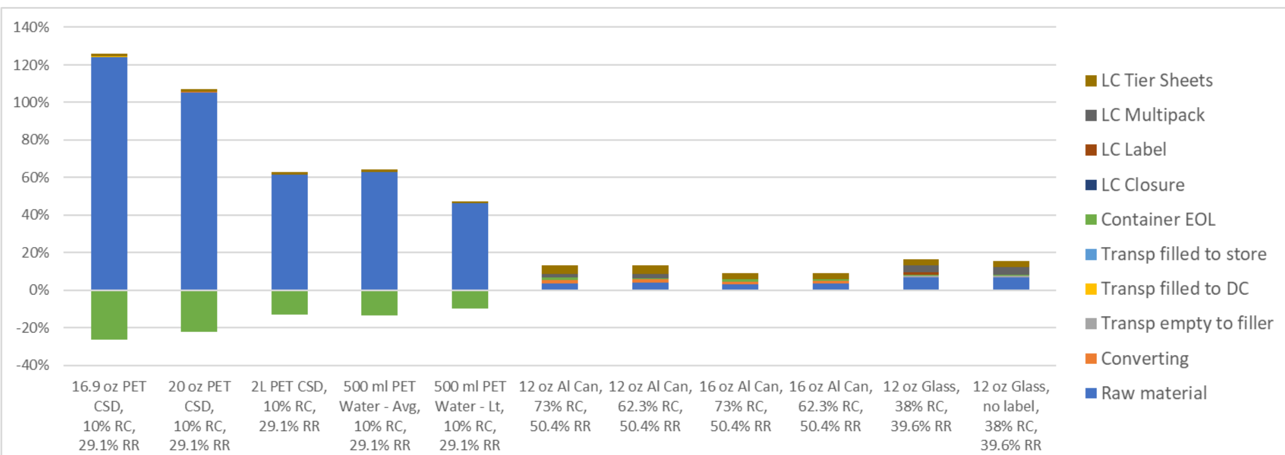

Figure 9. Ozone Depletion Potential (kg CFC-11 eq) for Beverage Container Systems, 1,000 Gallon Basis, System Expansion

PHOTOCHEMICAL SMOG FORMATION POTENTIAL

The photochemical smog formation impact category characterizes the potential of airborne emissions to cause photochemical smog. The creation of photochemical smog occurs when sunlight reacts with NO_x and volatile organic compounds (VOCs), resulting in tropospheric (ground-level) ozone and particulate matter. Endpoints of such smog creation can include increased human mortality, asthma, and deleterious effects on plant growth. Smog formation impacts are generally dominated by emissions associated with fuel combustion, so that impacts are higher for life cycle stages and components that have higher process fuel and transportation fuel requirements. Results for smog formation are shown in Table 25 and Figure 10.

For PET systems, raw material production makes the largest contribution to smog results, mainly associated with process and transportation fuels and extraction of oil and natural gas for use as material feedstocks. For aluminum systems, the relative contributions of raw material production and container converting vary depending on how postindustrial scrap content is treated. For both aluminum production and can converting processes, the majority of smog formation impacts are associated with emissions from fossil fuel combustion to generate electricity used in the processes. For glass systems, container production (raw material and converting) smog impacts are dominated by nitrogen oxide emissions from glass production processes, while EOL burdens are mainly associated with glass recycling.

Table 25. Photochemical Smog Formation Potential (kg O_3 eq) for Beverage Container Systems, 1,000 Gallon Basis, System Expansion

Life Cycle Stage	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Raw material	23.1	19.6	11.5	11.7	8.59	15.2	20.2	13.5	17.9	219	219
Converting	11.1	9.69	5.53	6.65	4.88	30.5	30.5	27.1	27.1	0	0
Transp empty to filler	0.69	0.73	0.93	0.43	0.43	1.84	1.84	1.77	1.77	20.8	20.8
Transp filled to DC	0.15	0.12	0.070	0.080	0.062	0.17	0.17	0.095	0.095	1.87	1.87
Transp filled to store	0.15	0.22	0.070	0.080	0.062	0.17	0.17	0.17	0.17	1.87	1.87
Container EOL	-2.26	-1.92	-1.12	-1.15	-0.84	15.6	9.39	13.8	8.34	82.5	82.5
LC Closure	3.72	2.97	0.84	1.48	1.48	0	0	0	0	2.79	2.79
LC Label	0.42	0.33	0.44	0.30	0.30	0	0	0	0	1.68	0
LC Multipack	0.87	0	0	1.26	1.26	9.53	9.53	0	0	17.8	17.8
LC Tier Sheets	0.78	0.78	0.51	0.49	0.49	2.23	2.23	1.64	1.64	1.62	1.62
Total	**38.8**	**32.5**	**18.7**	**21.3**	**16.7**	**75.2**	**74.0**	**58.1**	**57.0**	**350**	**348**

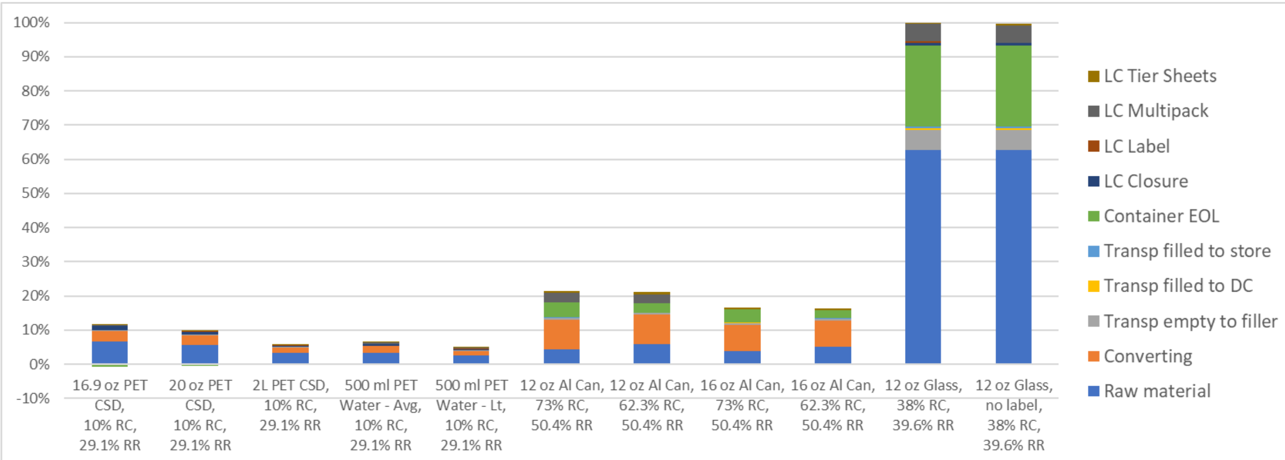

Figure 10. Smog Formation Potential (kg O_3 eq) for Beverage Container Systems, 1,000 Gallon Basis, System Expansion

SUMMARY OF BASELINE RESULTS

A summary of total results for all results for all systems is presented in Table 26. The glass bottle systems have the highest results for most metrics evaluated. After glass bottle systems, the 12 oz aluminum can scenarios show the next highest results for most metrics, although the PET bottle systems show higher results for ozone depletion. The 16.9 oz PET CSD bottle system shows the highest results of the PET bottle systems, since more 16.9 oz bottles are required to deliver 1,000 gallons, and the 16.9 oz PET CSD bottles are heavier than the 500 ml PET water bottles.

Table 26. Summary of Results, All Beverage Container Systems, 1,000 Gallon Basis, System Expansion

System Totals	Units	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Cumulative Energy Demand	MJ	13,355	10,997	6,190	7,106	5,610	22,197	21,848	16,355	16,045	38,781	37,914
Non-renewable Energy	MJ	12,966	10,707	6,066	7,049	5,602	16,907	18,112	13,451	14,522	33,852	33,852
Solid Waste	kg	147	120	67.6	77.9	61.2	381	372	280	272	1,698	1,682
Water Consumption	liters	3,310	2,766	1,541	1,755	1,351	3,757	3,733	3,093	3,072	9,867	9,736
Global Warming Potential	kg CO2 eq	623	521	296	328	254	1,241	1,218	990	969	2,608	2,566
Acidification Potential	kg SO2 eq	2.21	1.87	1.05	1.18	0.92	6.87	6.70	5.54	5.39	14.6	14.4
Eutrophication Potential	kg N eq	0.11	0.094	0.055	0.060	0.047	0.19	0.19	0.14	0.14	0.68	0.67
Ozone Depletion Potential	kg CFC-11 eq	5.5E-05	4.6E-05	2.7E-05	2.8E-05	2.1E-05	7.2E-06	7.2E-06	5.1E-06	5.0E-06	9.1E-06	8.5E-06
Smog Formation Potential	kg O3 eq	38.8	32.5	18.7	21.3	16.7	75.2	74.0	58.1	57.0	350	348

MEANINGFUL DIFFERENCES IN RESULTS

As discussed previously, there is inherent uncertainty in life cycle data, models, and impact assessment methods. Based on the experience and judgment of ERG's LCA analysts, energy differences should not be considered meaningful unless the percent difference exceeds 10 percent. For all other impact categories and solid waste and water consumption, the percent difference between two systems' results should not be considered meaningfully different unless it exceeds 25 percent. Percent difference is defined as the difference between two system totals divided by their average. The threshold guidelines are not intended to be interpreted as rigorous statistical uncertainty analysis, but rather are provided as general guidelines for readers to use when interpreting differences in system results, to ensure that undue importance is not placed on differences that fall within the uncertainties of the underlying data.

The following tables show the calculated percent differences between PET and alternative systems in the CSD and bottled water categories and use color coding to indicate which percent differences in the comparisons of PET bottle results and alternative aluminum and glass container system results are large enough to be considered meaningful. The percent differences are calculated using the PET system as the reference system such that negative values mean the PET system has lower results than the alternative system. The cells in the tables are color coded as follows:

- **Green**: Reference PET bottle system results can be considered lower than alternative system
- **Red**: Reference PET bottle system can be considered higher than alternative system
- **Gray**: Difference is not large enough to be considered meaningful

Table 27. Comparison of 16.9 oz PET CSD with Other CSD Containers, 1,000 Gallon Basis, System Expansion

Results	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Cumulative Energy Demand	10%	-50%	-48%	-20%	-18%	-98%	-96%
Non-renewable Energy	10%	-26%	-33%	-4%	-11%	-89%	-89%
Solid Waste	25%	-89%	-87%	-62%	-60%	-168%	-168%
Water Consumption	25%	-13%	-12%	7%	7%	-100%	-99%
Global Warming Potential	25%	-66%	-65%	-46%	-44%	-123%	-122%
Acidification Potential	25%	-103%	-101%	-86%	-84%	-147%	-147%
Eutrophication Potential	25%	-54%	-53%	-22%	-21%	-144%	-143%
Ozone Depletion Potential	25%	153%	154%	166%	166%	143%	146%
Smog Formation Potential	25%	-64%	-62%	-40%	-38%	-160%	-160%

Table 28. Comparison of 20 oz PET CSD with Other CSD Containers, 1,000 Gallon Basis, System Expansion

System Totals	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Cumulative Energy Demand	10%	-67%	-66%	-39%	-37%	-112%	-110%
Non-renewable Energy	10%	-45%	-51%	-23%	-30%	-104%	-104%
Solid Waste	25%	-104%	-103%	-80%	-78%	-174%	-173%
Water Consumption	25%	-30%	-30%	-11%	-10%	-112%	-112%
Global Warming Potential	25%	-82%	-80%	-62%	-60%	-133%	-133%
Acidification Potential	25%	-114%	-113%	-99%	-97%	-154%	-154%
Eutrophication Potential	25%	-69%	-68%	-38%	-37%	-151%	-151%
Ozone Depletion Potential	25%	146%	146%	161%	161%	134%	138%
Smog Formation Potential	25%	-79%	-78%	-56%	-55%	-166%	-166%

Table 29. Comparison of 2L PET CSD with Other CSD Containers, 1,000 Gallon Basis, System Expansion

System Totals	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Cumulative Energy Demand	10%	-113%	-112%	-90%	-89%	-145%	-144%
Non-renewable Energy	10%	-94%	-100%	-76%	-82%	-139%	-139%
Solid Waste	25%	-140%	-139%	-122%	-120%	-185%	-185%
Water Consumption	25%	-84%	-83%	-67%	-66%	-146%	-145%
Global Warming Potential	25%	-123%	-122%	-108%	-106%	-159%	-159%
Acidification Potential	25%	-147%	-146%	-136%	-135%	-173%	-173%
Eutrophication Potential	25%	-112%	-111%	-87%	-85%	-170%	-170%
Ozone Depletion Potential	25%	116%	117%	137%	138%	100%	105%
Smog Formation Potential	25%	-120%	-119%	-102%	-101%	-180%	-180%

Table 30. Comparison of Average Weight 500 ml PET Water Bottle with Aluminum Cans, 1,000 Gallon Basis, System Expansion

System Totals	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
Cumulative Energy Demand	10%	-103%	-102%	-79%	-77%
Non-renewable Energy	10%	-82%	-88%	-62%	-69%
Solid Waste	25%	-132%	-131%	-113%	-111%
Water Consumption	25%	-73%	-72%	-55%	-55%
Global Warming Potential	25%	-116%	-115%	-101%	-99%
Acidification Potential	25%	-142%	-140%	-130%	-128%
Eutrophication Potential	25%	-105%	-104%	-79%	-78%
Ozone Depletion Potential	25%	117%	118%	138%	139%
Smog Formation Potential	25%	-112%	-111%	-93%	-91%

Table 31. Comparison of Lightweight 500 ml PET Water Bottle with Aluminum Cans, 1,000 Gallon Basis, System Expansion

System Totals	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
Cumulative Energy Demand	10%	-119%	-118%	-98%	-96%
Non-renewable Energy	10%	-100%	-106%	-82%	-89%
Solid Waste	25%	-145%	-144%	-128%	-127%
Water Consumption	25%	-94%	-94%	-78%	-78%
Global Warming Potential	25%	-132%	-131%	-118%	-117%
Acidification Potential	25%	-153%	-152%	-143%	-142%
Eutrophication Potential	25%	-121%	-121%	-98%	-97%
Ozone Depletion Potential	25%	96%	96%	121%	121%
Smog Formation Potential	25%	-127%	-126%	-111%	-109%

For PET CSD beverage container systems with 10% RC, the following conclusions can be made for the baseline system expansion results:

- All PET CSD sizes show lower results compared to aluminum and glass containers systems for the following metrics: cumulative energy demand, solid waste, global warming potential, acidification potential, and smog formation potential. Almost all comparisons were lower for non-renewable energy and eutrophication, with the exceptions of comparisons of 16.9 oz PET and 16 oz Al can with 73% RC, where differences were not large enough to be considered conclusive.
- PET CSD systems consistently showed higher ozone depletion results compared to other CSD systems, due mainly to methyl bromide emissions from production of TPA/PTA for PET resin.
- PET CSD systems have more feedstock energy than aluminum and glass systems due to the use of petroleum and natural gas as material feedstocks for PET bottles, HDPE closures, PP film labels, and film rings for 16.9 oz PET bottle multipacks. Unlike expended process and transportation energy, the majority of the feedstock energy remains embodied in the finished items and is available for future use, e.g., if postconsumer packaging is disposed at end of life by waste-to-energy combustion, or remains embodied in items that are recycled.
- Water consumption comparisons were all either lower for PET bottles or inconclusive. Water consumption for all sizes of PET CSD bottles were lower than the 12 oz glass bottle systems. The 2L PET system showed lower water consumption compared to all aluminum can scenarios, while the 16.9 oz PET bottle showed inconclusive differences compared with all aluminum scenarios. The 20 oz PET bottle showed lower water consumption compared with 12 oz can scenarios, but inconclusive differences compared with 16 oz can scenarios.

For PET bottled water container systems, no comparisons are made with glass bottles, since the glass bottles modeled are specifically used for carbonated soft drinks, and glass bottles used for water may vary in size and weight. The following conclusions can be made for the baseline PET bottled water container systems with 10% RC compared to aluminum cans:

- Both the average and lightweight PET bottle systems show notably lower results for all aluminum can scenarios for the majority of metrics evaluated: total energy demand, expended energy, non-renewable energy, solid waste, water consumption, global warming potential, acidification potential, eutrophication potential, and smog formation potential.
- As with CSD systems, PET bottled water systems have higher feedstock energy compared to the aluminum can scenarios evaluated.
- Ozone depletion potential results for both PET water bottle systems are significantly higher than ODP results for all aluminum can scenarios. The higher ODP results for PET water bottles are associated with methyl bromide emissions from background processes leading up to PET resin production.

CHAPTER 3. SENSITIVITY ANALYSIS

CUT-OFF RECYCLING METHODOLOGY

As described in the methodology section Recycling Allocation, there are different methods that can be used to allocate environmental burdens among different useful lives of the material that is used in one system and subsequently recovered, reprocessed, and used in another application. In the allocation hierarchy in ISO 14044, avoidance of allocation where possible is the preferred approach, so system expansion (defined in the Recycling Allocation section) is used for the baseline results. Since ISO 14044 states that "whenever several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted to illustrate the consequences of the departure from the selected approach," results are presented here for an alternative recycling methodology widely used in LCA, the "cut-off" approach.

In contrast to the system expansion methodology used for the baseline results, the cut-off recycling methodology does not consider the balance between a system's use of recycled content and its end-of-life recycling rate. Products that are recycled at end-of-life leave the system boundaries with no burdens or credits. Recycling simply reduces the disposal burdens assigned to the system. With the cut-off approach, PET systems with 10% recycled content and a 29.1% recycling rate do not receive a credit for excess recycled PET avoiding production of virgin PET, and aluminum cans do not receive additional virgin aluminum burdens to make up for the cans consuming more recycled aluminum than is replaced by the 50.4% end-of-life recycling rate. Therefore, system comparisons using cut-off recycling methodology are less favorable for PET containers and more favorable for aluminum containers. Results by life cycle stage for each environmental metric for each system evaluated with cut-off recycling methodology are provided in APPENDIX A. Summaries of system life cycle results using cut-off recycling methodology are presented in Table 32. Percent differences between PET and alternative systems using cut-off recycling methodology are shown in Table 33 through Table 37.

Differences in comparative conclusions for 16.9 oz and 20 oz PET bottles versus aluminum and glass containers for cut-off modeling compared to system expansion modeling are discussed following Table 33 and Table 34. For 2 liter CSD bottles and both 500 ml water bottles, all comparative conclusions are the same for both system expansion and cut-off modeling results. Overall, the use of cut-off modeling has the most effect on comparisons of 16.9 oz PET CSD bottles and 16 oz aluminum cans. The comparisons of these systems are less favorable for PET when cut-off modeling is used.

Table 32. Summary of Results, All Beverage Container Systems, 1,000 Gallon Basis, Cut-off Recycling

System Totals	Units	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Cumulative Energy Demand	MJ	15,077	12,458	6,965	8,014	6,350	18,579	20,131	12,506	13,885	33,739	32,872
Non-renewable Energy	MJ	14,654	12,089	6,788	7,907	6,288	13,681	16,165	10,559	12,764	27,623	27,623
Solid Waste	kg	148	121	68.1	78.5	61.7	275	313	183	218	1,605	1,590
Water Consumption	liters	3,112	2,597	1,435	1,658	1,285	3,460	3,539	2,819	2,888	7,559	7,428
Global Warming Potential	kg CO2 eq	657	550	311	346	269	951	1,050	729	817	2,201	2,159
Acidification Potential	kg SO2 eq	2.32	1.97	1.10	1.23	0.96	4.95	5.66	3.81	4.44	11.4	11.3
Eutrophication Potential	kg N eq	0.11	0.097	0.056	0.062	0.049	0.17	0.18	0.12	0.12	0.55	0.54
Ozone Depletion Potential	kg CFC-11 eq	6.9E-05	5.9E-05	3.4E-05	3.5E-05	2.6E-05	7.2E-06	7.5E-06	4.6E-06	4.8E-06	1.0E-05	9.3E-06
Smog Formation Potential	kg O3 eq	41.9	35.2	20.2	22.9	18.0	61.2	66.2	45.1	49.5	271	270

Table 33. Comparison of 16.9 oz PET CSD with Other CSD Containers, 1,000 Gallon Basis, Cut-off Recycling

Results	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Cumulative Energy Demand	10%	-21%	-29%	19%	8%	-76%	-74%
Non-renewable Energy	10%	7%	-10%	32%	14%	-61%	-61%
Solid Waste	25%	-60%	-72%	-21%	-38%	-166%	-166%
Water Consumption	25%	-11%	-13%	10%	7%	-83%	-82%
Global Warming Potential	25%	-37%	-46%	-10%	-22%	-108%	-107%
Acidification Potential	25%	-72%	-84%	-49%	-63%	-132%	-132%
Eutrophication Potential	25%	-42%	-47%	-3%	-9%	-131%	-130%
Ozone Depletion Potential	25%	162%	161%	175%	174%	149%	152%
Smog Formation Potential	25%	-38%	-45%	-7%	-17%	-147%	-146%

Cut-off comparisons of 16.9 oz PET bottles with aluminum containers:

- In all cut-off comparisons with aluminum can scenarios, ozone depletion is higher for the 16.9 oz PET bottle, and water comparisons are inconclusive. These conclusions are the same as for system expansion modeling in Table 27.
- Other comparisons with 12 oz cans show the same trends as the system expansion results, except that non-renewable energy shifts from lower for PET to an inconclusive difference.
- In cut-off comparisons of 16.9 oz PET and 16 oz cans modeled with 73% RC, most percent differences are higher for PET or inconclusive. Acidification is still lower for PET compared to both 16 oz cans, and solid waste results are lower for 16.9 oz PET compared to 16 oz cans with 62.3% RC.

All percent difference comparisons of results for 16.9 oz PET bottles and 12 oz glass bottles show the same trends for both system expansion and cut-off modeling.

Table 34. Comparison of 20 oz PET CSD with Other CSD Containers, 1,000 Gallon Basis, Cut-off Recycling

System Totals	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Cumulative Energy Demand	10%	-39%	-47%	0%	-11%	-92%	-90%
Non-renewable Energy	10%	-12%	-29%	14%	-5%	-78%	-78%
Solid Waste	25%	-78%	-89%	-41%	-57%	-172%	-172%
Water Consumption	25%	-29%	-31%	-8%	-11%	-98%	-96%
Global Warming Potential	25%	-53%	-63%	-28%	-39%	-120%	-119%
Acidification Potential	25%	-86%	-97%	-64%	-77%	-141%	-141%
Eutrophication Potential	25%	-57%	-62%	-19%	-25%	-140%	-139%
Ozone Depletion Potential	25%	156%	155%	171%	169%	142%	145%
Smog Formation Potential	25%	-54%	-61%	-25%	-34%	-154%	-154%

Cut-off comparisons of 20 oz PET bottles with aluminum containers:

- In all cut-off comparisons of 20 oz PET CSD with aluminum can scenarios, ozone depletion and water trends are the same as for system expansion modeling in Table 28.
- All other cut-off comparisons with 12 oz aluminum can scenarios show the same trends as the system expansion results.
- In comparisons with 16 oz can scenarios, a few changes are seen from system expansion. For cut-off comparisons of 20 oz PET CSD and cans modeled with 73% RC, non-renewable energy becomes higher for PET, and total energy, eutrophication, and smog results become inconclusive; however, solid waste, GWP and acidification all remain lower for PET. For comparisons with 62.3% RC 16 oz cans, the only change from system expansion is that the non-renewable energy comparison becomes inconclusive.

All meaningful difference comparisons of results for 20 oz PET bottles and 12 oz glass bottles show the same trends for both system expansion and cut-off modeling.

Table 35. Comparison of 2L PET CSD with Other CSD Containers, 1,000 Gallon Basis, Cut-off Recycling

System Totals	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Cumulative Energy Demand	10%	-91%	-97%	-57%	-66%	-132%	-130%
Non-renewable Energy	10%	-67%	-82%	-43%	-61%	-121%	-121%
Solid Waste	25%	-120%	-129%	-92%	-105%	-184%	-184%
Water Consumption	25%	-83%	-85%	-65%	-67%	-136%	-135%
Global Warming Potential	25%	-101%	-109%	-80%	-90%	-150%	-150%
Acidification Potential	25%	-127%	-135%	-110%	-120%	-165%	-164%
Eutrophication Potential	25%	-103%	-106%	-70%	-76%	-163%	-162%
Ozone Depletion Potential	25%	130%	128%	153%	150%	110%	115%
Smog Formation Potential	25%	-101%	-107%	-76%	-84%	-172%	-172%

Table 36. Comparison of Average Weight 500 ml PET Water Bottle with Aluminum Cans, 1,000 Gallon Basis, Cut-off Recycling

System Totals	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
Cumulative Energy Demand	10%	-79%	-86%	-44%	-54%
Non-renewable Energy	10%	-53%	-69%	-29%	-47%
Solid Waste	25%	-111%	-120%	-80%	-94%
Water Consumption	25%	-70%	-72%	-52%	-54%
Global Warming Potential	25%	-93%	-101%	-71%	-81%
Acidification Potential	25%	-120%	-128%	-102%	-113%
Eutrophication Potential	25%	-96%	-99%	-62%	-67%
Ozone Depletion Potential	25%	132%	130%	153%	151%
Smog Formation Potential	25%	-91%	-97%	-65%	-73%

Table 37. Comparison of Lightweight 500 ml PET Water Bottle with Aluminum Cans, 1,000 Gallon Basis, Cut-off Recycling

System Totals	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
Cumulative Energy Demand	10%	-98%	-104%	-65%	-74%
Non-renewable Energy	10%	-74%	-88%	-51%	-68%
Solid Waste	25%	-127%	-134%	-99%	-112%
Water Consumption	25%	-92%	-93%	-75%	-77%
Global Warming Potential	25%	-112%	-119%	-92%	-101%
Acidification Potential	25%	-135%	-142%	-119%	-129%
Eutrophication Potential	25%	-113%	-116%	-82%	-87%
Ozone Depletion Potential	25%	113%	110%	139%	137%
Smog Formation Potential	25%	-109%	-114%	-86%	-93%

EQUIVALENT NUMBER OF CONTAINERS BASIS

As described in the Functional Unit section, the baseline results are presented on the basis of the number of containers of each size required to deliver 1,000 gallons of beverage. For single-serving containers (all containers in this study other than 2L PET bottles), consumers may purchase containers of different volumes interchangeably, without consideration for the difference in amount of beverage delivered. Therefore, results for single-serving containers are presented here on the basis of 7,574 containers, the number of 16.9 oz/500 ml containers required to deliver 1,000 gallons of beverage. The table headings show the amount of beverage delivered in 7,574 containers of each size. The aluminum and glass containers are smaller than the PET containers, so equivalent numbers of aluminum and glass containers deliver less beverage than the same number of PET containers. Twelve oz aluminum and glass containers deliver about 29% less beverage than 16.9 oz PET bottles, and 16 oz aluminum cans deliver about 5% less beverage. Compared to 20 oz PET bottles, 12 oz aluminum and glass containers deliver 40% less beverage, and 16 oz aluminum cans deliver 20% less product.

Table 38 presents total results for the equivalent number of containers basis for both system expansion and cut-off recycling. For the equivalent number of containers basis, results for 16.9 oz and 20 oz PET CSD bottles are very similar, except for the additional impacts for multipack packaging included in the 16.9 oz PET CSD bottle results. Because the same preform can be blown into either size bottle, the average bottle weight is very similar for 16.9 oz and 20 oz PET CSD bottles. As a result, all bottle production, transport, and end-of-life values are very similar for 16.9 oz and 20 oz PET bottles on an equivalent number of containers basis.

Table 38. Summary of Results, All Single-Serving Beverage Container Systems, 7,574 Container Basis, System Expansion and Cut-off Recycling

Results per 7,574 Containers	Units	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Gallons/7,574 containers		1,000	1,183		1,000	1,000	710	710	947	947	710	710
System Totals, System Expansion	**Units**											
Cumulative Energy Demand	MJ	13,355	13,014	24,773	7,106	5,610	15,761	15,514	15,484	15,191	27,537	26,921
Non-renewable Energy	MJ	12,966	12,671	24,278	7,049	5,602	12,005	12,861	12,735	13,748	24,037	24,037
Solid Waste	kg	147	142	271	77.9	61.2	271	264	265	258	1,205	1,194
Water Consumption	liters	3,310	3,273	6,165	1,755	1,351	2,668	2,651	2,928	2,908	7,006	6,913
Global Warming Potential	kg CO2 eq	623	616	1,184	328	254	881	865	937	918	1,852	1,822
Acidification Potential	kg SO2 eq	2.21	2.22	4.22	1.18	0.92	4.88	4.76	5.25	5.10	10.3	10.3
Eutrophication Potential	kg N eq	0.11	0.11	0.22	0.060	0.047	0.14	0.14	0.13	0.13	0.49	0.48
Ozone Depletion Potential	kg CFC-11 eq	5.5E-05	5.5E-05	1.1E-04	2.8E-05	2.1E-05	5.1E-06	5.1E-06	4.8E-06	4.7E-06	6.5E-06	6.0E-06
Smog Formation Potential	kg O3 eq	38.8	38.5	75.0	21.3	16.7	53.4	52.5	55.0	54.0	249	247
System Totals, Cut-off	**Units**											
Cumulative Energy Demand	MJ	15,077	14,743	27,876	8,014	6,350	13,192	14,294	11,840	13,145	23,956	23,341
Non-renewable Energy	MJ	14,654	14,307	27,167	7,907	6,288	9,715	11,478	9,996	12,084	19,614	19,614
Solid Waste	kg	148	143	273	78.5	61.7	195	223	174	206	1,140	1,129
Water Consumption	liters	3,112	3,073	5,745	1,658	1,285	2,457	2,513	2,669	2,734	5,367	5,274
Global Warming Potential	kg CO2 eq	657	651	1,247	346	269	675	746	690	774	1,563	1,533
Acidification Potential	kg SO2 eq	2.32	2.33	4.42	1.23	0.96	3.52	4.02	3.61	4.20	8.12	8.04
Eutrophication Potential	kg N eq	0.11	0.11	0.23	0.062	0.049	0.12	0.13	0.11	0.12	0.39	0.38
Ozone Depletion Potential	kg CFC-11 eq	6.9E-05	6.9E-05	1.4E-04	3.5E-05	2.6E-05	5.1E-06	5.3E-06	4.4E-06	4.6E-06	7.1E-06	6.6E-06
Smog Formation Potential	kg O3 eq	41.9	41.6	80.7	22.9	18.0	43.4	47.0	42.7	46.8	193	191

Percent differences between PET and alternative systems using the equivalent number of containers basis are shown in Table 39 through Table 42.

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- **CSD Comparisons**. Despite the higher amount of beverage delivered by the PET CSD bottles, both PET CSD systems still show lower results compared to aluminum containers for cumulative energy demand, solid waste, GWP, acidification, and smog formation when using system expansion recycling modeling. When using cut-off recycling methodology and the equivalent number of containers basis, most results for PET CSD containers are higher than aluminum results or show an inconclusive difference. In most cases, the PET CSD systems show lower results than the smaller aluminum can systems for solid waste and acidification. Comparisons of PET CSD bottles with the same number of smaller glass bottles show the same trends as comparisons based on 1,000 gallons. All results other than ozone depletion are lower for the PET CSD systems compared to glass for both recycling methodologies.
- **Packaged Water Comparisons**. Comparisons of PET water bottles with the same number of smaller aluminum cans show the same trends as comparisons based on 1,000 gallons. All results other than ozone depletion are lower for the PET water bottle systems for both recycling methodologies.

Table 39. Comparison of 16.9 oz PET CSD with Other Single-Serving CSD Containers, 7,574 Container Basis

Results	**% Diff Threshold**	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Gallons/7,574 containers		710	710	947	947	710	710
System Totals, System Expansion							
Cumulative Energy Demand	10%	-17%	-15%	-15%	-13%	-69%	-67%
Non-renewable Energy	10%	8%	1%	2%	-6%	-60%	-60%
Solid Waste	25%	-59%	-57%	-57%	-55%	-157%	-156%
Water Consumption	25%	21%	22%	12%	13%	-72%	-70%
Global Warming Potential	25%	-34%	-33%	-40%	-38%	-99%	-98%
Acidification Potential	25%	-75%	-73%	-81%	-79%	-129%	-129%
Eutrophication Potential	25%	-21%	-20%	-17%	-15%	-126%	-124%
Ozone Depletion Potential	25%	166%	166%	168%	168%	158%	160%
Smog Formation Potential	25%	-32%	-30%	-35%	-33%	-146%	-146%
System Totals, Cut-off							
Cumulative Energy Demand	10%	13%	5%	24%	14%	-45%	-43%
Non-renewable Energy	10%	41%	24%	38%	19%	-29%	-29%
Solid Waste	25%	-28%	-40%	-16%	-33%	-154%	-154%
Water Consumption	25%	24%	21%	15%	13%	-53%	-52%
Global Warming Potential	25%	-3%	-13%	-5%	-16%	-82%	-80%
Acidification Potential	25%	-41%	-54%	-44%	-58%	-111%	-110%
Eutrophication Potential	25%	-9%	-14%	3%	-4%	-110%	-108%
Ozone Depletion Potential	25%	172%	171%	176%	175%	163%	165%
Smog Formation Potential	25%	-4%	-12%	-2%	-11%	-129%	-128%

Table 40. Comparison of 20 oz PET CSD with Other Single-Serving CSD Containers, 7,574 Container Basis

System Totals	**% Diff Threshold**	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Gallons/7,574 containers		710	710	947	947	710	710
System Totals, System Expansion							
Cumulative Energy Demand	10%	-19%	-18%	-17%	-15%	-72%	-70%
Non-renewable Energy	10%	5%	-1%	-1%	-8%	-62%	-62%
Solid Waste	25%	-62%	-60%	-60%	-58%	-158%	-158%
Water Consumption	25%	20%	21%	11%	12%	-73%	-71%
Global Warming Potential	25%	-35%	-34%	-41%	-39%	-100%	-99%
Acidification Potential	25%	-75%	-73%	-81%	-79%	-129%	-129%
Eutrophication Potential	25%	-21%	-20%	-16%	-15%	-125%	-124%
Ozone Depletion Potential	25%	166%	166%	168%	168%	158%	161%
Smog Formation Potential	25%	-32%	-31%	-35%	-33%	-146%	-146%

System Totals, Cut-off							
Cumulative Energy Demand	10%	11%	3%	22%	11%	-48%	-45%
Non-renewable Energy	10%	38%	22%	35%	17%	-31%	-31%
Solid Waste	25%	-31%	-44%	-19%	-36%	-155%	-155%
Water Consumption	25%	22%	20%	14%	12%	-54%	-53%
Global Warming Potential	25%	-4%	-14%	-6%	-17%	-82%	-81%
Acidification Potential	25%	-41%	-53%	-43%	-58%	-111%	-110%
Eutrophication Potential	25%	-8%	-13%	4%	-3%	-109%	-108%
Ozone Depletion Potential	25%	172%	172%	176%	175%	163%	165%
Smog Formation Potential	25%	-4%	-12%	-3%	-12%	-129%	-129%

Table 41. Comparison of Average Weight 500 ml PET Water Bottle with Aluminum Cans, 7,574 Container Basis

System Totals	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
Gallons/7,574 containers		710	710	947	947
System Totals, System Expansion					
Cumulative Energy Demand	10%	-76%	-74%	-74%	-73%
Non-renewable Energy	10%	-52%	-58%	-57%	-64%
Solid Waste	25%	-111%	-109%	-109%	-107%
Water Consumption	25%	-41%	-41%	-50%	-49%
Global Warming Potential	25%	-92%	-90%	-96%	-95%
Acidification Potential	25%	-122%	-121%	-127%	-125%
Eutrophication Potential	25%	-78%	-77%	-74%	-73%
Ozone Depletion Potential	25%	138%	138%	141%	142%
Smog Formation Potential	25%	-86%	-85%	-88%	-87%
System Totals, Cut-off					
Cumulative Energy Demand	10%	-49%	-56%	-39%	-49%
Non-renewable Energy	10%	-21%	-37%	-23%	-42%
Solid Waste	25%	-85%	-96%	-75%	-90%
Water Consumption	25%	-39%	-41%	-47%	-49%
Global Warming Potential	25%	-65%	-73%	-67%	-76%
Acidification Potential	25%	-96%	-106%	-98%	-109%
Eutrophication Potential	25%	-67%	-71%	-57%	-62%
Ozone Depletion Potential	25%	149%	147%	156%	154%
Smog Formation Potential	25%	-62%	-69%	-60%	-68%

Table 42. Comparison of Lightweight 500 ml PET Water Bottle with Aluminum Cans, 7,574 Container Basis

System Totals	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
Gallons/7,574 containers		710	710	947	947
System Totals, System Expansion					
Cumulative Energy Demand	10%	-95%	-94%	-94%	-92%
Non-renewable Energy	10%	-73%	-79%	-78%	-84%
Solid Waste	25%	-126%	-125%	-125%	-123%
Water Consumption	25%	-66%	-65%	-74%	-73%
Global Warming Potential	25%	-110%	-109%	-115%	-113%
Acidification Potential	25%	-137%	-135%	-140%	-139%
Eutrophication Potential	25%	-98%	-97%	-94%	-93%
Ozone Depletion Potential	25%	120%	121%	124%	125%
Smog Formation Potential	25%	-105%	-103%	-107%	-105%
System Totals, Cut-off					
Cumulative Energy Demand	10%	-70%	-77%	-60%	-70%
Non-renewable Energy	10%	-43%	-58%	-46%	-63%
Solid Waste	25%	-104%	-113%	-95%	-108%
Water Consumption	25%	-63%	-65%	-70%	-72%
Global Warming Potential	25%	-86%	-94%	-88%	-97%
Acidification Potential	25%	-114%	-123%	-116%	-125%
Eutrophication Potential	25%	-87%	-91%	-77%	-83%
Ozone Depletion Potential	25%	134%	132%	142%	140%
Smog Formation Potential	25%	-83%	-89%	-81%	-89%

VARIATIONS IN RECYCLED CONTENT FOR PET BOTTLES

As noted in the Systems Studied section, the baseline results for PET bottles in the report are for a recycled content level of 10%, which is the overall average for PET containers. However, not all PET bottles have recycled content, and others have more than 10% recycled content. In addition, many large beverage companies have reported goals for reducing greenhouse gas and other impacts. For reducing packaging impacts for PET containers, increasing recycled content (RC) is a key focus for many companies. This section presents results for PET bottles with 0% RC as well as higher RC levels of 25% and 50%. All RC results are based on solid-stated food-grade recycled PET from mechanical recycling. While increased use of RC reduces raw material production burdens, at 50% RC, the RC of PET bottles would exceed the bottle recycling rate, which has fluctuated between 22% and 30% over the past 20 years and is currently 29.1%.[23]

Results for PET bottles with 0%, 25%, and 50% recycled content compared to aluminum and glass containers on a 1,000 gallon of beverage basis are presented in Table 43 through Table 49 for both recycling methodologies.

Comparing the PET bottle results for the two recycling methodologies in Table 43 and Table 44 shows that results for 0% RC PET bottles are lower for system expansion than for cut-off methodology. Although material production burdens are higher for virgin bottles in both methodologies, with system expansion all bottle material recycled at end-of-life recycling receives credits for avoiding virgin PET production, while there are no recycling credits with the cut-off method. Results for 25% RC PET bottles are generally similar for both recycling methodologies, since there is only a small difference between the bottle RC and recycling rate. However, for 50% RC PET bottles (and for aluminum containers), cut-off results are generally more favorable than system expansion results since the cut-off method does not include added virgin material burdens to make up for the deficit between the container's use of recycled content exceeding its recycling rate.

For the system expansion recycling methodology, reductions in the material production stage for recycled content are offset by corresponding adjustments to net avoided virgin material credits or penalties based on the difference between the bottle's recycled content and the bottle 29.1% recycling rate. Therefore, the system expansion results in the table do not show large variations for different RC scenarios.

The cut-off recycling methodology is more favorable than system expansion for systems where the RC is higher than the end-of-life recycling rate, such as 50% RC PET bottles and the aluminum containers. However, for 0% and 25% RC PET bottle results, the cut-off method shows higher results compared to system expansion. Virgin PET production is a major contributor to energy and ozone depletion results, so cut-off results for 0% and 25% RC PET (without the avoided virgin PET production credits) are higher compared to system expansion results for these metrics.

For the system expansion method, added virgin burdens would decrease for containers with high recycled content if the recycling rate could be increased, for example, through increased deposit programs. A higher container recycling rate would also be needed to provide postconsumer material needed to meet the increased demand for mechanically recycled rPET content. Chemical recycling of PET is another emerging technology for increasing the rPET supply by utilizing postconsumer PET that is not suitable for mechanical recycling into food-grade bottles or that can cause problems at high levels in the recycled PET supply, such as PET containers with colorants, barrier layers, or residual contamination from non-food contents.

Table 43. Summary of Results, CSD Beverage Container Systems, 1,000 Gallon Basis, Variations in PET Recycled Content

	Units	16.9 oz PET CSD, 0% RC, 29.1% RR	16.9 oz PET CSD, 25% RC, 29.1% RR	16.9 oz PET CSD, 50% RC, 29.1% RR	20 oz PET CSD, 0% RC, 29.1% RR	20 oz PET CSD, 25% RC, 29.1% RR	20 oz PET CSD, 50% RC, 29.1% RR	2L PET CSD, 0% RC, 29.1% RR	2L PET CSD, 25% RC, 29.1% RR	2L PET CSD, 50% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR,
System Totals, System Expansion																
Cumulative Energy Demand	MJ	13,112	13,720	14,328	10,790	11,307	11,823	6,069	6,371	6,673	22,197	21,848	16,355	16,045	38,781	37,914
Non-renewable Energy	MJ	12,667	13,233	13,798	10,400	10,880	11,360	5,855	6,136	6,416	16,904	16,662	13,451	13,236	33,941	33,646
Solid Waste	kg	146	148	150	119	121	123	67.2	68.2	69.2	381	372	280	272	1,698	1,682
Water Consumption	liters	3,145	3,556	3,967	2,626	2,975	3,324	1,459	1,663	1,867	3,757	3,733	3,093	3,072	9,867	9,736
Global Warming Potential	kg CO2 eq	608	645	681	508	539	570	289	307	325	1,241	1,218	990	969	2,608	2,566
Acidification Potential	kg SO2 eq	2.17	2.28	2.40	1.83	1.93	2.03	1.03	1.09	1.15	6.87	6.70	5.54	5.39	14.6	14.4
Eutrophication Potential	kg N eq	0.11	0.12	0.13	0.091	0.10	0.11	0.053	0.058	0.064	0.19	0.19	0.14	0.14	0.68	0.67
Ozone Depletion Potential	kg CFC-11 eq	5.4E-05	5.5E-05	5.5E-05	4.6E-05	4.6E-05	4.7E-05	2.7E-05	2.7E-05	2.7E-05	7.2E-06	7.2E-06	5.1E-06	5.0E-06	9.1E-06	8.5E-06
Smog Formation Potential	kg O3 eq	38.0	39.9	41.8	31.9	33.5	35.2	18.4	19.3	20.3	75.2	74.0	58.1	57.0	350	348
System Totals, Cut-off																
Cumulative Energy Demand	MJ eq	15,858	13,905	11,952	13,121	11,463	9,805	7,353	6,384	5,414	18,579	20,131	12,506	13,885	33,739	32,872
Non-renewable Energy	MJ eq	15,331	13,359	11,387	12,643	10,970	9,296	7,081	6,102	5,123	13,690	14,726	10,559	11,479	27,635	27,340
Solid Waste	kg SW	148	147	145	121	120	118	68.5	67.6	66.7	275	313	183	218	1,605	1,590
Water Consumption	liter H2O	3,079	3,161	3,242	2,569	2,638	2,707	1,419	1,460	1,500	3,460	3,539	2,819	2,888	7,559	7,428
Global Warming Potential	kg CO2 eq	680	624	568	569	521	474	323	295	267	951	1,050	729	817	2,201	2,159
Acidification Potential	kg SO2 eq	2.39	2.21	2.04	2.03	1.88	1.73	1.14	1.05	0.96	4.95	5.66	3.81	4.44	11.4	11.3
Eutrophication Potential	kg N eq	0.12	0.11	0.10	0.10	0.093	0.087	0.058	0.054	0.050	0.17	0.18	0.12	0.12	0.55	0.54
Ozone Depletion Potential	kg CFC-11 eq	7.6E-05	5.8E-05	3.9E-05	6.5E-05	4.9E-05	3.3E-05	3.8E-05	2.9E-05	1.9E-05	7.2E-06	7.5E-06	4.6E-06	4.8E-06	1.0E-05	9.3E-06
Smog Formation Potential	kg O3 eq	43.6	39.3	35.0	36.6	33.0	29.3	21.0	18.9	16.8	61.2	66.2	45.1	49.5	271	270
Cut-off Results as % of System Expansion Results																
Cumulative Energy Demand		121%	101%	83%	122%	101%	83%	121%	100%	81%	84%	92%	76%	87%	87%	87%
Non-renewable Energy		121%	101%	83%	122%	101%	82%	121%	99%	80%	81%	88%	78%	87%	81%	81%
Solid Waste		102%	99%	97%	102%	99%	96%	102%	99%	96%	72%	84%	66%	80%	95%	95%
Water Consumption		98%	89%	82%	98%	89%	81%	97%	88%	80%	92%	95%	91%	94%	77%	76%
Global Warming Potential		112%	97%	83%	112%	97%	83%	112%	96%	82%	77%	86%	74%	84%	84%	84%
Acidification Potential		110%	97%	85%	110%	97%	85%	111%	97%	84%	72%	84%	69%	82%	79%	78%
Eutrophication Potential		110%	93%	79%	110%	93%	79%	110%	93%	79%	90%	96%	84%	91%	81%	80%
Ozone Depletion Potential		140%	106%	71%	140%	106%	71%	140%	106%	71%	100%	105%	91%	97%	110%	110%
Smog Formation Potential		115%	98%	84%	115%	98%	83%	114%	98%	83%	81%	89%	78%	87%	77%	77%

Table 44. Summary of Results, Bottled Water Container Systems, 1,000 Gallon Basis, Variations in PET Recycled Content

	Units	500 ml PET Water - Avg, 0% RC, 29.1% RR	500 ml PET Water - Avg, 25% RC, 29.1% RR	500 ml PET Water - Avg, 50% RC, 29.1% RR	500 ml PET Water - Lt, 0% RC, 29.1% RR	500 ml PET Water - Lt, 25% RC, 29.1% RR	500 ml PET Water - Lt, 50% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
System Totals, System Expansion											
Cumulative Energy Demand	MJ	6,983	7,291	7,599	5,520	5,746	5,972	22,197	21,848	16,355	16,045
Non-renewable Energy	MJ	6,751	7,038	7,325	5,326	5,537	5,747	16,904	16,662	13,451	13,236
Solid Waste	kg	77.5	78.6	79.6	60.9	61.6	62.4	381	372	280	272
Water Consumption	liters	1,671	1,880	2,088	1,290	1,442	1,595	3,757	3,733	3,093	3,072
Global Warming Potential	kg CO2 eq	320	339	357	249	262	276	1,241	1,218	990	969
Acidification Potential	kg SO2 eq	1.15	1.21	1.27	0.90	0.94	0.99	6.87	6.70	5.54	5.39
Eutrophication Potential	kg N eq	0.058	0.064	0.069	0.046	0.050	0.054	0.19	0.19	0.14	0.14
Ozone Depletion Potential	kg CFC-11 eq	2.8E-05	2.8E-05	2.8E-05	2.1E-05	2.1E-05	2.1E-05	7.2E-06	7.2E-06	5.1E-06	5.0E-06
Smog Formation Potential	kg O3 eq	20.9	21.9	22.9	16.4	17.1	17.9	75.2	74.0	58.1	57.0
System Totals, Cut-off											
Cumulative Energy Demand	MJ eq	8,410	7,420	6,430	6,641	5,914	5,188	18,579	20,131	12,506	13,885
Non-renewable Energy	MJ eq	8,124	7,125	6,126	6,390	5,656	4,923	13,690	14,726	10,559	11,479
Solid Waste	kg SW	78.8	77.9	77.0	61.9	61.3	60.6	275	313	183	218
Water Consumption	liter H2O	1,642	1,683	1,724	1,273	1,303	1,333	3,460	3,539	2,819	2,888
Global Warming Potential	kg CO2 eq	357	329	300	277	256	235	951	1,050	729	817
Acidification Potential	kg SO2 eq	1.27	1.18	1.09	0.99	0.92	0.86	4.95	5.66	3.81	4.44
Eutrophication Potential	kg N eq	0.063	0.060	0.056	0.050	0.047	0.044	0.17	0.18	0.12	0.12
Ozone Depletion Potential	kg CFC-11 eq	3.9E-05	2.9E-05	2.0E-05	2.9E-05	2.2E-05	1.5E-05	7.2E-06	7.5E-06	4.6E-06	4.8E-06
Smog Formation Potential	kg O3 eq	23.8	21.6	19.5	18.6	17.0	15.4	61.2	66.2	45.1	49.5
Cut-off Results as % of System Expansion Results											
Cumulative Energy Demand		120%	102%	85%	120%	103%	87%	84%	92%	76%	87%
Non-renewable Energy		120%	101%	84%	120%	102%	86%	81%	88%	78%	87%
Solid Waste		102%	99%	97%	102%	99%	97%	72%	84%	66%	80%
Water Consumption		98%	90%	83%	99%	90%	84%	92%	95%	91%	94%
Global Warming Potential		112%	97%	84%	111%	98%	85%	77%	86%	74%	84%
Acidification Potential		110%	97%	86%	110%	98%	87%	72%	84%	69%	82%
Eutrophication Potential		109%	94%	81%	109%	95%	82%	90%	96%	84%	91%
Ozone Depletion Potential		140%	106%	71%	140%	106%	72%	100%	105%	91%	97%
Smog Formation Potential		114%	99%	85%	113%	99%	87%	81%	89%	78%	87%

Table 45. Comparison of 16.9 oz PET CSD with Other CSD Containers, 1,000 Gallon Basis, Variations in PET Recycled Content

		PET with 0% RC compared to alternatives						PET with 25% RC compared to alternatives						PET with 50% RC compared to alternatives					
Results, System Expansion	**% Diff Threshold**	**12 oz Al Can, 73% RC, 50.4% RR**	**12 oz Al Can, 62.3% RC, 50.4% RR**	**16 oz Al Can, 73% RC, 50.4% RR**	**16 oz Al Can, 62.3% RC, 50.4% RR**	**12 oz Glass, 38% RC, 39.6% RR**	**12 oz Glass, no label, 38% RC, 39.6% RR,**	**12 oz Al Can, 73% RC, 50.4% RR**	**12 oz Al Can, 62.3% RC, 50.4% RR**	**16 oz Al Can, 73% RC, 50.4% RR**	**16 oz Al Can, 62.3% RC, 50.4% RR**	**12 oz Glass, 38% RC, 39.6% RR**	**12 oz Glass, no label, 38% RC, 39.6% RR,**	**12 oz Al Can, 73% RC, 50.4% RR**	**12 oz Al Can, 62.3% RC, 50.4% RR**	**16 oz Al Can, 73% RC, 50.4% RR**	**16 oz Al Can, 62.3% RC, 50.4% RR**	**12 oz Glass, 38% RC, 39.6% RR**	**12 oz Glass, no label, 38% RC, 39.6% RR,**
Cumulative Energy Demand	10%	-51%	-50%	-22%	-20%	-99%	-97%	-47%	-46%	-18%	-16%	-95%	-94%	-43%	-42%	-13%	-11%	-92%	-90%
Non-renewable Energy	10%	-29%	-27%	-6%	-4%	-91%	-91%	-24%	-23%	-2%	0%	-88%	-87%	-20%	-19%	3%	4%	-84%	-84%
Solid Waste	25%	-89%	-87%	-63%	-60%	-168%	-168%	-88%	-86%	-62%	-59%	-168%	-168%	-87%	-85%	-60%	-58%	-168%	-167%
Water Consumption	25%	-18%	-17%	2%	2%	-103%	-102%	-5%	-5%	14%	15%	-94%	-93%	5%	6%	25%	25%	-85%	-84%
Global Warming Potential	25%	-68%	-67%	-48%	-46%	-124%	-123%	-63%	-62%	-42%	-40%	-121%	-120%	-58%	-57%	-37%	-35%	-117%	-116%
Acidification Potential	25%	-104%	-102%	-88%	-85%	-148%	-148%	-100%	-98%	-83%	-81%	-146%	-145%	-96%	-95%	-79%	-77%	-143%	-143%
Eutrophication Potential	25%	-58%	-57%	-26%	-25%	-146%	-145%	-49%	-48%	-16%	-15%	-141%	-140%	-40%	-39%	-7%	-6%	-137%	-136%
Ozone Depletion Potential	25%	153%	153%	166%	166%	143%	146%	153%	154%	166%	166%	143%	146%	153%	154%	166%	166%	143%	146%
Smog Formation Potential	25%	-66%	-64%	-42%	-40%	-161%	-161%	-61%	-60%	-37%	-35%	-159%	-159%	-57%	-56%	-33%	-31%	-157%	-157%
Results, Cut Off		PET with 0% RC compared to alternatives						PET with 25% RC compared to alternatives						PET with 50% RC compared to alternatives					
Cumulative Energy Demand	10%	-16%	-24%	24%	13%	-72%	-70%	-29%	-37%	11%	0%	-83%	-81%	-43%	-51%	-5%	-15%	-95%	-93%
Non-renewable Energy	10%	11%	4%	37%	29%	-57%	-56%	-2%	-10%	23%	15%	-70%	-69%	-18%	-26%	8%	-1%	-83%	-82%
Solid Waste	25%	-60%	-71%	-21%	-38%	-166%	-166%	-61%	-72%	-22%	-39%	-167%	-166%	-62%	-74%	-23%	-40%	-167%	-167%
Water Consumption	25%	-12%	-14%	9%	6%	-84%	-83%	-9%	-11%	11%	9%	-82%	-81%	-7%	-9%	14%	12%	-80%	-78%
Global Warming Potential	25%	-33%	-43%	-7%	-18%	-106%	-104%	-42%	-51%	-16%	-27%	-112%	-110%	-50%	-60%	-25%	-36%	-118%	-117%
Acidification Potential	25%	-70%	-81%	-46%	-60%	-131%	-130%	-76%	-87%	-53%	-67%	-135%	-135%	-83%	-94%	-61%	-74%	-139%	-139%
Eutrophication Potential	25%	-40%	-44%	0%	-6%	-130%	-129%	-46%	-51%	-7%	-13%	-134%	-132%	-53%	-57%	-14%	-20%	-138%	-136%
Ozone Depletion Potential	25%	165%	164%	177%	176%	154%	156%	155%	154%	170%	169%	141%	144%	137%	135%	158%	156%	118%	123%
Smog Formation Potential	25%	-34%	-41%	-3%	-13%	-145%	-144%	-44%	-51%	-14%	-23%	-149%	-149%	-54%	-62%	-25%	-34%	-154%	-154%

Table 46. Comparison of 20 oz PET CSD with Other CSD Containers, 1,000 Gallon Basis, Variations in PET Recycled Content

		PET with 0% RC compared to alternatives						PET with 25% RC compared to alternatives						PET with 50% RC compared to alternatives					
Results, System Expansion	**% Diff Threshold**	**12 oz Al Can, 73% RC, 50.4% RR**	**12 oz Al Can, 62.3% RC, 50.4% RR**	**16 oz Al Can, 73% RC, 50.4% RR**	**16 oz Al Can, 62.3% RC, 50.4% RR**	**12 oz Glass, 38% RC, 39.6% RR**	**12 oz Glass, no label, 38% RC, 39.6% RR,**	**12 oz Al Can, 73% RC, 50.4% RR**	**12 oz Al Can, 62.3% RC, 50.4% RR**	**16 oz Al Can, 73% RC, 50.4% RR**	**16 oz Al Can, 62.3% RC, 50.4% RR**	**12 oz Glass, 38% RC, 39.6% RR**	**12 oz Glass, no label, 38% RC, 39.6% RR,**	**12 oz Al Can, 73% RC, 50.4% RR**	**12 oz Al Can, 62.3% RC, 50.4% RR**	**16 oz Al Can, 73% RC, 50.4% RR**	**16 oz Al Can, 62.3% RC, 50.4% RR**	**12 oz Glass, 38% RC, 39.6% RR**	**12 oz Glass, no label, 38% RC, 39.6% RR,**
Cumulative Energy Demand	10%	-69%	-68%	-41%	-39%	-113%	-111%	-65%	-64%	-37%	-35%	-110%	-108%	-61%	-60%	-32%	-30%	-107%	-105%
Non-renewable Energy	10%	-48%	-46%	-26%	-24%	-106%	-106%	-43%	-42%	-21%	-20%	-103%	-102%	-39%	-38%	-17%	-15%	-100%	-99%
Solid Waste	25%	-105%	-103%	-81%	-78%	-174%	-174%	-104%	-102%	-79%	-77%	-173%	-173%	-103%	-101%	-78%	-76%	-173%	-173%
Water Consumption	25%	-35%	-35%	-16%	-16%	-116%	-115%	-23%	-23%	-4%	-3%	-107%	-106%	-12%	-12%	7%	8%	-99%	-98%
Global Warming Potential	25%	-84%	-82%	-64%	-62%	-135%	-134%	-79%	-77%	-59%	-57%	-131%	-131%	-74%	-72%	-54%	-52%	-128%	-127%
Acidification Potential	25%	-116%	-114%	-101%	-98%	-155%	-155%	-112%	-110%	-97%	-94%	-153%	-153%	-109%	-107%	-93%	-90%	-151%	-151%
Eutrophication Potential	25%	-73%	-72%	-42%	-41%	-153%	-152%	-64%	-63%	-32%	-31%	-149%	-148%	-56%	-54%	-23%	-22%	-145%	-144%
Ozone Depletion Potential	25%	146%	146%	161%	161%	134%	138%	146%	147%	161%	161%	135%	138%	146%	147%	161%	161%	135%	139%
Smog Formation Potential	25%	-81%	-80%	-58%	-57%	-167%	-166%	-77%	-75%	-54%	-52%	-165%	-165%	-73%	-71%	-49%	-47%	-164%	-163%
Results, Cut Off		PET with 0% RC compared to alternatives						PET with 25% RC compared to alternatives						PET with 50% RC compared to alternatives					
Cumulative Energy Demand	10%	-34%	-42%	5%	-6%	-88%	-86%	-47%	-55%	-9%	-19%	-99%	-97%	-62%	-69%	-24%	-34%	-110%	-108%
Non-renewable Energy	10%	-8%	-15%	18%	10%	-74%	-74%	-22%	-29%	4%	-5%	-86%	-85%	-38%	-45%	-13%	-21%	-99%	-99%
Solid Waste	25%	-77%	-88%	-41%	-57%	-172%	-172%	-79%	-89%	-42%	-58%	-172%	-172%	-80%	-90%	-43%	-59%	-173%	-172%
Water Consumption	25%	-30%	-32%	-9%	-12%	-99%	-97%	-27%	-29%	-7%	-9%	-97%	-95%	-24%	-27%	-4%	-6%	-95%	-93%
Global Warming Potential	25%	-50%	-59%	-25%	-36%	-118%	-117%	-58%	-67%	-33%	-44%	-123%	-122%	-67%	-76%	-42%	-53%	-129%	-128%
Acidification Potential	25%	-84%	-95%	-61%	-75%	-140%	-139%	-90%	-100%	-68%	-81%	-144%	-143%	-97%	-107%	-75%	-88%	-148%	-147%
Eutrophication Potential	25%	-55%	-59%	-16%	-22%	-139%	-138%	-61%	-65%	-22%	-29%	-142%	-141%	-67%	-72%	-29%	-36%	-146%	-144%
Ozone Depletion Potential	25%	160%	159%	173%	172%	147%	150%	149%	147%	166%	164%	133%	136%	128%	126%	151%	149%	108%	112%
Smog Formation Potential	25%	-50%	-57%	-21%	-30%	-152%	-152%	-60%	-67%	-31%	-40%	-157%	-156%	-70%	-77%	-42%	-51%	-161%	-161%

Table 47. Comparison of 2L PET CSD with Other CSD Containers, 1,000 Gallon Basis, Variations in PET Recycled Content

		PET with 0% RC compared to alternatives						PET with 25% RC compared to alternatives						PET with 50% RC compared to alternatives					
Results, System Expansion	**% Diff Threshold**	**12 oz Al Can, 73% RC, 50.4% RR**	**12 oz Al Can, 62.3% RC, 50.4% RR**	**16 oz Al Can, 73% RC, 50.4% RR**	**16 oz Al Can, 62.3% RC, 50.4% RR**	**12 oz Glass, 38% RC, 39.6% RR**	**12 oz Glass, no label, 38% RC, 39.6% RR,**	**12 oz Al Can, 73% RC, 50.4% RR**	**12 oz Al Can, 62.3% RC, 50.4% RR**	**16 oz Al Can, 73% RC, 50.4% RR**	**16 oz Al Can, 62.3% RC, 50.4% RR**	**12 oz Glass, 38% RC, 39.6% RR**	**12 oz Glass, no label, 38% RC, 39.6% RR,**	**12 oz Al Can, 73% RC, 50.4% RR**	**12 oz Al Can, 62.3% RC, 50.4% RR**	**16 oz Al Can, 73% RC, 50.4% RR**	**16 oz Al Can, 62.3% RC, 50.4% RR**	**12 oz Glass, 38% RC, 39.6% RR**	**12 oz Glass, no label, 38% RC, 39.6% RR,**
Cumulative Energy Demand	10%	-114%	-113%	-92%	-90%	-146%	-145%	-111%	-110%	-88%	-86%	-144%	-142%	-108%	-106%	-84%	-83%	-141%	-140%
Non-renewable Energy	10%	-97%	-96%	-79%	-77%	-141%	-141%	-93%	-92%	-75%	-73%	-139%	-138%	-90%	-89%	-71%	-69%	-136%	-136%
Solid Waste	25%	-140%	-139%	-122%	-121%	-185%	-185%	-139%	-138%	-122%	-120%	-185%	-184%	-139%	-137%	-121%	-119%	-184%	-184%
Water Consumption	25%	-88%	-88%	-72%	-71%	-148%	-148%	-77%	-77%	-60%	-60%	-142%	-142%	-67%	-67%	-49%	-49%	-136%	-136%
Global Warming Potential	25%	-125%	-123%	-110%	-108%	-160%	-160%	-121%	-120%	-105%	-104%	-158%	-157%	-117%	-116%	-101%	-100%	-156%	-155%
Acidification Potential	25%	-148%	-147%	-137%	-136%	-174%	-173%	-145%	-144%	-134%	-133%	-172%	-172%	-143%	-142%	-131%	-130%	-171%	-171%
Eutrophication Potential	25%	-114%	-114%	-90%	-89%	-171%	-171%	-108%	-107%	-82%	-81%	-169%	-168%	-101%	-100%	-74%	-73%	-166%	-165%
Ozone Depletion Potential	25%	116%	117%	137%	138%	100%	105%	116%	117%	137%	138%	100%	105%	116%	117%	137%	138%	100%	105%
Smog Formation Potential	25%	-122%	-120%	-104%	-103%	-180%	-180%	-118%	-117%	-100%	-99%	-179%	-179%	-115%	-114%	-97%	-95%	-178%	-178%
Results, Cut Off		PET with 0% RC compared to alternatives						PET with 25% RC compared to alternatives						PET with 50% RC compared to alternatives					
Cumulative Energy Demand	10%	-87%	-93%	-52%	-62%	-128%	-127%	-98%	-104%	-65%	-74%	-136%	-135%	-110%	-115%	-79%	-88%	-145%	-143%
Non-renewable Energy	10%	-64%	-70%	-39%	-47%	-118%	-118%	-77%	-83%	-54%	-61%	-128%	-127%	-91%	-97%	-69%	-77%	-137%	-137%
Solid Waste	25%	-120%	-128%	-91%	-104%	-184%	-183%	-121%	-129%	-92%	-105%	-184%	-184%	-122%	-130%	-93%	-106%	-184%	-184%
Water Consumption	25%	-84%	-85%	-66%	-68%	-137%	-136%	-81%	-83%	-64%	-66%	-135%	-134%	-79%	-81%	-61%	-63%	-134%	-133%
Global Warming Potential	25%	-99%	-106%	-77%	-87%	-149%	-148%	-105%	-112%	-85%	-94%	-153%	-152%	-112%	-119%	-93%	-101%	-157%	-156%
Acidification Potential	25%	-125%	-133%	-108%	-118%	-164%	-163%	-130%	-137%	-114%	-123%	-166%	-166%	-135%	-142%	-119%	-129%	-169%	-169%
Eutrophication Potential	25%	-101%	-104%	-68%	-73%	-162%	-161%	-105%	-109%	-73%	-79%	-164%	-163%	-110%	-114%	-79%	-85%	-166%	-166%
Ozone Depletion Potential	25%	136%	134%	157%	155%	117%	121%	120%	117%	145%	142%	97%	102%	92%	89%	123%	120%	65%	71%
Smog Formation Potential	25%	-98%	-104%	-73%	-81%	-171%	-171%	-106%	-111%	-82%	-90%	-174%	-174%	-114%	-119%	-92%	-99%	-177%	-177%

Table 48. Comparison of Average Weight 500 ml PET Water Bottle with Aluminum Cans, 1,000 Gallon Basis, Variations in PET Recycled Content

		PET with 0% RC compared to others				PET with 25% RC compared to others				PET with 50% RC compared to others			
Results, System Expansion	**% Diff Threshold**	**12 oz Al Can, 73% RC, 50.4% RR**	**12 oz Al Can, 62.3% RC, 50.4% RR**	**16 oz Al Can, 73% RC, 50.4% RR**	**16 oz Al Can, 62.3% RC, 50.4% RR**	**12 oz Al Can, 73% RC, 50.4% RR**	**12 oz Al Can, 62.3% RC, 50.4% RR**	**16 oz Al Can, 73% RC, 50.4% RR**	**16 oz Al Can, 62.3% RC, 50.4% RR**	**12 oz Al Can, 73% RC, 50.4% RR**	**12 oz Al Can, 62.3% RC, 50.4% RR**	**16 oz Al Can, 73% RC, 50.4% RR**	**16 oz Al Can, 62.3% RC, 50.4% RR**
Cumulative Energy Demand	10%	-104%	-103%	-80%	-79%	-101%	-100%	-77%	-75%	-98%	-97%	-73%	-71%
Non-renewable Energy	10%	-86%	-85%	-66%	-65%	-82%	-81%	-63%	-61%	-79%	-78%	-59%	-58%
Solid Waste	25%	-132%	-131%	-113%	-111%	-132%	-130%	-112%	-110%	-131%	-130%	-111%	-109%
Water Consumption	25%	-77%	-76%	-60%	-59%	-67%	-66%	-49%	-48%	-57%	-57%	-39%	-38%
Global Warming Potential	25%	-118%	-117%	-102%	-101%	-114%	-113%	-98%	-96%	-111%	-109%	-94%	-92%
Acidification Potential	25%	-143%	-141%	-131%	-130%	-140%	-139%	-128%	-127%	-138%	-136%	-125%	-124%
Eutrophication Potential	25%	-108%	-107%	-82%	-81%	-101%	-100%	-74%	-73%	-95%	-94%	-67%	-66%
Ozone Depletion Potential	25%	117%	118%	138%	139%	117%	118%	138%	139%	118%	118%	138%	139%
Smog Formation Potential	25%	-113%	-112%	-94%	-93%	-110%	-109%	-90%	-89%	-107%	-106%	-87%	-85%
Results, Cut Off		PET with 0% RC compared to others				PET with 25% RC compared to others				PET with 50% RC compared to others			
Cumulative Energy Demand	10%	-75%	-82%	-39%	-49%	-86%	-92%	-51%	-61%	-97%	-103%	-64%	-73%
Non-renewable Energy	10%	-51%	-58%	-26%	-34%	-63%	-70%	-39%	-47%	-76%	-82%	-53%	-61%
Solid Waste	25%	-111%	-120%	-80%	-94%	-112%	-120%	-81%	-95%	-112%	-121%	-82%	-95%
Water Consumption	25%	-71%	-73%	-53%	-55%	-69%	-71%	-50%	-53%	-67%	-69%	-48%	-50%
Global Warming Potential	25%	-91%	-99%	-69%	-78%	-97%	-105%	-76%	-85%	-104%	-111%	-83%	-93%
Acidification Potential	25%	-118%	-127%	-100%	-111%	-123%	-131%	-106%	-116%	-128%	-135%	-111%	-121%
Eutrophication Potential	25%	-94%	-97%	-59%	-65%	-98%	-102%	-65%	-71%	-103%	-107%	-71%	-76%
Ozone Depletion Potential	25%	137%	135%	157%	156%	121%	119%	146%	143%	93%	90%	124%	121%
Smog Formation Potential	25%	-88%	-94%	-62%	-70%	-95%	-101%	-70%	-78%	-103%	-109%	-79%	-87%

Table 49. Comparison of Lightweight 500 ml PET Water Bottle with Aluminum Cans, 1,000 Gallon Basis, Variations in PET Recycled Content

		PET with 0% RC compared to others				PET with 25% RC compared to others				PET with 50% RC compared to others			
Results, System Expansion	**% Diff Threshold**	**12 oz Al Can, 73% RC, 50.4% RR**	**12 oz Al Can, 62.3% RC, 50.4% RR**	**16 oz Al Can, 73% RC, 50.4% RR**	**16 oz Al Can, 62.3% RC, 50.4% RR**	**12 oz Al Can, 73% RC, 50.4% RR**	**12 oz Al Can, 62.3% RC, 50.4% RR**	**16 oz Al Can, 73% RC, 50.4% RR**	**16 oz Al Can, 62.3% RC, 50.4% RR**	**12 oz Al Can, 73% RC, 50.4% RR**	**12 oz Al Can, 62.3% RC, 50.4% RR**	**16 oz Al Can, 73% RC, 50.4% RR**	**16 oz Al Can, 62.3% RC, 50.4% RR**
Cumulative Energy Demand	10%	-120%	-119%	-99%	-98%	-118%	-117%	-96%	-95%	-115%	-114%	-93%	-91%
Non-renewable Energy	10%	-104%	-103%	-87%	-85%	-101%	-100%	-83%	-82%	-99%	-97%	-80%	-79%
Solid Waste	25%	-145%	-144%	-128%	-127%	-144%	-143%	-128%	-126%	-144%	-143%	-127%	-125%
Water Consumption	25%	-98%	-97%	-82%	-82%	-89%	-89%	-73%	-72%	-81%	-80%	-64%	-63%
Global Warming Potential	25%	-133%	-132%	-120%	-118%	-130%	-129%	-116%	-115%	-127%	-126%	-113%	-111%
Acidification Potential	25%	-154%	-153%	-144%	-143%	-152%	-151%	-142%	-140%	-150%	-149%	-140%	-138%
Eutrophication Potential	25%	-124%	-123%	-101%	-100%	-118%	-117%	-94%	-93%	-113%	-112%	-88%	-87%
Ozone Depletion Potential	25%	96%	96%	121%	121%	96%	97%	121%	121%	96%	97%	121%	122%
Smog Formation Potential	25%	-128%	-127%	-112%	-111%	-126%	-125%	-109%	-108%	-123%	-122%	-106%	-105%
Results, Cut Off		PET with 0% RC compared to others				PET with 25% RC compared to others				PET with 50% RC compared to others			
Cumulative Energy Demand	10%	-95%	-101%	-61%	-71%	-103%	-109%	-72%	-81%	-113%	-118%	-83%	-91%
Non-renewable Energy	10%	-73%	-79%	-49%	-57%	-83%	-89%	-60%	-68%	-94%	-100%	-73%	-80%
Solid Waste	25%	-126%	-134%	-99%	-111%	-127%	-135%	-100%	-112%	-128%	-135%	-101%	-113%
Water Consumption	25%	-92%	-94%	-76%	-78%	-91%	-92%	-74%	-76%	-89%	-91%	-72%	-74%
Global Warming Potential	25%	-110%	-117%	-90%	-99%	-115%	-122%	-96%	-105%	-121%	-127%	-102%	-111%
Acidification Potential	25%	-133%	-140%	-118%	-127%	-137%	-144%	-122%	-131%	-141%	-147%	-127%	-135%
Eutrophication Potential	25%	-111%	-114%	-80%	-86%	-115%	-118%	-85%	-90%	-119%	-122%	-90%	-95%
Ozone Depletion Potential	25%	119%	117%	144%	142%	100%	97%	130%	127%	68%	65%	105%	101%
Smog Formation Potential	25%	-107%	-112%	-83%	-91%	-113%	-118%	-90%	-98%	-119%	-124%	-98%	-105%

REDUCED WEIGHT (21 GRAMS) FOR 16.9 OZ AND 20 OZ PREFORMS

As noted in the equivalent number of containers sensitivity analysis, the same preform can be used for 16.9 oz and 20 oz bottles. Producers are continually making efforts to reduce the weight of containers, since this reduces the costs and impacts across all life cycle stages; the lighter the bottle, the less material is required to make the bottle, reducing material production impacts, converting impacts, and disposal burdens, and a lighter bottle takes less energy to transport. Some 16.9 and 20 oz PET CSD bottles are changing to a 21 g preform. While this is only about a 1 gram reduction from the average weight used in the baseline results, it represents about a 5% reduction in bottle weight and weight-related impacts. The reduction in bottle weight does not affect the modeling of multipack packaging for the 16.9 oz bottles. Table 50 through Table 52 present total results and percent difference comparisons for 21 g 16.9 oz and 20 oz PET CSD bottles with 10% recycled content compared to aluminum and glass systems on the basis of 1,000 gallons of beverage. Results for system expansion methodology are shown in the top section of each table and cut-off results in the bottom section.

Table 50. Summary of Results for 21 g PET CSD Bottles and Other CSD Container Systems, 1,000 Gallon Basis

System Totals, System Expansion	Units	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	Glass, no label, 38% RC, 39.6% RR
Cumulative Energy Demand	MJ eq	12,804	10,485	22,197	21,848	16,355	16,045	38,781	37,914
Non-renewable Energy	MJ eq	12,358	10,094	16,904	16,662	13,451	13,236	33,941	33,646
Solid Waste	kg SW	141	114	381	372	280	272	1,698	1,682
Water Consumption	liter H2O	3,164	2,630	3,757	3,733	3,093	3,072	9,867	9,736
Global Warming Potential	kg CO2 eq	596	495	1,241	1,218	990	969	2,608	2,566
Acidification Potential	kg SO2 eq	2.12	1.79	6.87	6.70	5.54	5.39	14.6	14.4
Eutrophication Potential	kg N eq	0.11	0.090	0.19	0.19	0.14	0.14	0.68	0.67
Ozone Depletion Potential	kg CFC-11 eq	5.2E-05	4.4E-05	7.2E-06	7.2E-06	5.1E-06	5.0E-06	9.1E-06	8.5E-06
Smog Formation Potential	kg O3 eq	37.2	31.0	75.2	74.0	58.1	57.0	350	348

System Totals, Cut-off	Units	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC,
Cumulative Energy Demand	MJ eq	14,464	11,888	18,579	20,131	12,506	13,885	33,739	32,872
Non-renewable Energy	MJ eq	13,942	11,417	13,690	14,726	10,559	11,479	27,635	27,340
Solid Waste	kg SW	142	115	275	313	183	218	1,605	1,590
Water Consumption	liter H2O	2,978	2,472	3,460	3,539	2,819	2,888	7,559	7,428
Global Warming Potential	kg CO2 eq	629	523	951	1,050	729	817	2,201	2,159
Acidification Potential	kg SO2 eq	2.22	1.87	4.95	5.66	3.81	4.44	11.4	11.3
Eutrophication Potential	kg N eq	0.11	0.093	0.17	0.18	0.12	0.12	0.55	0.54
Ozone Depletion Potential	kg CFC-11 eq	6.5E-05	5.5E-05	7.2E-06	7.5E-06	4.6E-06	4.8E-06	1.0E-05	9.3E-06
Smog Formation Potential	kg O3 eq	40.1	33.6	61.2	66.2	45.1	49.5	271	270

Although the reduction in PET bottle weight decreases results for PET bottles compared to the baseline bottle weight scenario, there is little effect on comparative conclusions for PET bottles compared to aluminum and glass CSD containers. None of the system expansion conclusions change from the baseline results shown in Table 27. For the cut-off method, some comparisons of non-renewable energy for PET bottles and aluminum cans shift more favorably for the 21 g PET bottles. In addition, a solid waste comparison of 16.9 PET with 16 oz aluminum and a smog comparison of 20 oz PET with 16 oz aluminum both shift from inconclusive to lower for PET. In all cases the lighter PET CSD bottles still show higher ozone depletion results compared to aluminum and glass systems.

Table 51. Comparison of 21 g 16.9 oz PET CSD with Other CSD Containers, 1,000 Gallon Basis

Results, System Expansion	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Cumulative Energy Demand	10%	-54%	-52%	-24%	-22%	-101%	-99%
Non-renewable Energy	10%	-31%	-30%	-8%	-7%	-93%	-93%
Solid Waste	25%	-92%	-90%	-66%	-64%	-169%	-169%
Water Consumption	25%	-17%	-16%	2%	3%	-103%	-102%
Global Warming Potential	25%	-70%	-69%	-50%	-48%	-126%	-125%
Acidification Potential	25%	-106%	-104%	-89%	-87%	-149%	-149%
Eutrophication Potential	25%	-58%	-57%	-26%	-25%	-146%	-145%
Ozone Depletion Potential	25%	151%	151%	164%	165%	140%	144%
Smog Formation Potential	25%	-68%	-66%	-44%	-42%	-162%	-161%

Results, Cut-off	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Cumulative Energy Demand	10%	-25%	-33%	15%	4%	-80%	-78%
Non-renewable Energy	10%	2%	-5%	28%	19%	-66%	-65%
Solid Waste	25%	-64%	-76%	-26%	-42%	-168%	-167%
Water Consumption	25%	-15%	-17%	5%	3%	-87%	-86%
Global Warming Potential	25%	-41%	-50%	-15%	-26%	-111%	-110%
Acidification Potential	25%	-76%	-87%	-53%	-67%	-135%	-134%
Eutrophication Potential	25%	-46%	-51%	-7%	-13%	-134%	-132%
Ozone Depletion Potential	25%	160%	159%	174%	172%	147%	150%
Smog Formation Potential	25%	-42%	-49%	-12%	-21%	-148%	-148%

Table 52. Comparison of 21 g 20 oz PET CSD with Other CSD Containers, 1,000 Gallon Basis

Results, System Expansion	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Cumulative Energy Demand	10%	-72%	-70%	-44%	-42%	-115%	-113%
Non-renewable Energy	10%	-50%	-49%	-29%	-27%	-108%	-108%
Solid Waste	25%	-108%	-106%	-84%	-82%	-175%	-175%
Water Consumption	25%	-35%	-35%	-16%	-15%	-116%	-115%
Global Warming Potential	25%	-86%	-84%	-67%	-65%	-136%	-135%
Acidification Potential	25%	-117%	-116%	-102%	-100%	-156%	-156%
Eutrophication Potential	25%	-73%	-72%	-42%	-41%	-153%	-153%
Ozone Depletion Potential	25%	144%	144%	159%	159%	131%	135%
Smog Formation Potential	25%	-83%	-82%	-61%	-59%	-167%	-167%

Results, Cut-off	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Cumulative Energy Demand	10%	-44%	-51%	-5%	-15%	-96%	-94%
Non-renewable Energy	10%	-18%	-25%	8%	-1%	-83%	-82%
Solid Waste	25%	-82%	-93%	-46%	-62%	-173%	-173%
Water Consumption	25%	-33%	-35%	-13%	-16%	-101%	-100%
Global Warming Potential	25%	-58%	-67%	-33%	-44%	-123%	-122%
Acidification Potential	25%	-90%	-100%	-68%	-81%	-144%	-143%
Eutrophication Potential	25%	-61%	-66%	-23%	-29%	-142%	-141%
Ozone Depletion Potential	25%	154%	152%	169%	168%	139%	142%
Smog Formation Potential	25%	-58%	-65%	-29%	-38%	-156%	-156%

UPDATED DATA FOR ALUMINUM

As noted in the Data Sources section on Aluminum Can Manufacturing, the modeling of virgin and recycled aluminum used in the aluminum can systems are based on unit process data sets from a 2013 report by the Aluminum Association.[27] An updated report was published by the Aluminum Association in January 2022.[43] However, the updated report no longer publishes data at a unit process level, only at an aggregated cradle-to-material level, so it is not possible to update our detailed aluminum models or align modeling of background processes such as electricity generation to use the same corresponding data

43 Aluminum Association (2022). The Environmental Footprint of Semi-Finished Aluminum Products in North America. Accessed at https://www.aluminum.org/sites/default/files/2022-01/2022_Semi-Fab_LCA_Report.pdf

sets used in the PET and glass models. To check whether updated aluminum production data affects comparative conclusions for PET and aluminum containers, results were run replacing the detailed 2013 virgin and recycled aluminum models with the cradle-to-aluminum data in Tables 7-5 and 7-8 of the 2022 AA report, recognizing that the background modeling and data sets may not be directly comparable to corresponding data sets used in the PET and glass models (e.g., data used for modeling background electricity, process and transportation fuels, etc.). In addition, the 2022 AA tables include only a short list of cradle-to-gate emissions, while detailed LCA models for production of fuels and electricity include a much more extensive list of emissions.

Table 53 shows a comparison of the impacts for a 23% virgin/73% recycled aluminum mix using the detailed 2013 AA aluminum LCA and the cradle-to-gate results from the 2022 AA LCA, as well as life cycle results for 12 oz cans modeled with the older and newer aluminum data. The first set of columns in the table shows that aluminum can material results modeled with the 2022 cradle-to-aluminum data give somewhat higher results for energy, solid waste, and global warming potential, but lower results for acidification and smog formation, while results for water consumption and eutrophication potential differ by 5% or less. The biggest difference seen is much lower acidification results for the 2022 data. Acidification impacts are generally associated with fuel-related emissions, so the difference between the 2013 AA data (modeled using AA unit process data with ERG background data sets) and the 2022 AA aggregated cradle-to-aluminum results is likely related to differences in the background data sets used for fuels and electricity. The last two sets of columns in the table show that the differences in aluminum material data have a smaller effect when put in the perspective of the can life cycle results, since other aluminum can life stages such as can manufacturing energy, can transport, packaging, and disposal of cans that are not recycled are not affected by the change in aluminum data. The change in aluminum data does affect end-of-life can recycling results using system expansion modeling, however, since it affects the impacts for aluminum recycling and the virgin aluminum burdens for the difference between RC and RR.

Table 53. Comparison of Results for 2013 and 2022 Aluminum Data

	Results for 12 oz Can with 73% Recycled Content								
	Aluminum Content Only (per kg can material)			Can Life Cycle (Syst Exp) per 1,000 gal			Can Life Cycle (Cut Off) per 1,000 gal		
Impact	2013 Alum Data	2022 Alum Data	2022 % of 2013	With 2013 Alum	With 2022 Alum	2022 % of 2013	With 2013 Alum	With 2022 Alum	2022 % of 2013
Cumulative Energy Demand	31.6	37.1	118%	22,197	22,933	103%	18,579	19,329	104%
Non-renewable Energy	21.9	25.2	115%	16,904	17,050	101%	13,690	14,134	103%
Solid Waste	0.75	0.91	122%	381	411	108%	275	297	108%
Water Consumption	2.04	2.01	98%	3,757	3,796	101%	3,460	3,456	100%
Global Warming Potential	2.01	2.20	110%	1,241	1,247	101%	951	978	103%
Acidification Potential	0.014	0.0025	18%	6.87	3.68	54%	4.95	3.44	70%
Eutrophication Potential	1.8E-04	1.9E-04	105%	0.19	0.19	98%	0.17	0.18	101%
Smog Formation Potential	0.10	0.083	83%	75.2	67.0	89%	61.2	58.8	96%

Meaningful difference comparisons of PET bottles with 10% recycled content and aluminum cans modeled with the 2022 Aluminum Association cradle-to-aluminum data are provided in Table 54 through Table 58. As in other sensitivity tables, system expansion results are shown at the top of each table and cut-off results at the bottom. The results using the updated aluminum data show more favorable comparative conclusions for PET than comparisons of PET and aluminum systems modeled with 2013 aluminum data. It should be noted that one reason the comparisons of PET bottles with cans using 2022 aluminum data appear more favorable for PET is that the cradle-to-aluminum tables in the 2022 report did not include sufficient information to be able to evaluate ozone depletion results, which was the only metric where PET consistently showed higher results than aluminum systems modeled using 2013 data.

Table 54. Comparison of 16.9 oz PET CSD with Aluminum Cans Modeled with 2022 Data, 1,000 Gallon Basis

Results, System Expansion	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
Cumulative Energy Demand	10%	-53%	-51%	-24%	-22%
Non-renewable Energy	10%	-28%	-26%	-5%	-3%
Solid Waste	25%	-95%	-93%	-70%	-68%
Water Consumption	25%	-14%	-12%	6%	8%
Global Warming Potential	25%	-67%	-65%	-46%	-44%
Acidification Potential	25%	-50%	-50%	-20%	-20%
Eutrophication Potential	25%	-53%	-52%	-20%	-19%
Smog Formation Potential	25%	-53%	-53%	-27%	-26%

Results, Cut-off	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
Cumulative Energy Demand	10%	-25%	-32%	13%	4%
Non-renewable Energy	10%	3%	-3%	28%	22%
Solid Waste	25%	-67%	-79%	-32%	-49%
Water Consumption	25%	-10%	-13%	10%	7%
Global Warming Potential	25%	-39%	-47%	-14%	-23%
Acidification Potential	25%	-39%	-42%	-6%	-10%
Eutrophication Potential	25%	-43%	-47%	-3%	-9%
Smog Formation Potential	25%	-34%	-39%	-3%	-10%

Table 55. Comparison of 20 oz PET CSD with Aluminum Cans Modeled with 2022 Data, 1,000 Gallon Basis

Results, System Expansion	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
Cumulative Energy Demand	10%	-70%	-69%	-43%	-41%
Non-renewable Energy	10%	-47%	-45%	-25%	-23%
Solid Waste	25%	-110%	-108%	-87%	-85%
Water Consumption	25%	-31%	-29%	-12%	-10%
Global Warming Potential	25%	-82%	-80%	-63%	-61%
Acidification Potential	25%	-65%	-65%	-36%	-36%
Eutrophication Potential	25%	-67%	-67%	-36%	-35%
Smog Formation Potential	25%	-69%	-69%	-44%	-43%

Results, Cut-off	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
Cumulative Energy Demand	10%	-43%	-50%	-6%	-15%
Non-renewable Energy	10%	-17%	-22%	9%	2%
Solid Waste	25%	-84%	-96%	-51%	-67%
Water Consumption	25%	-28%	-31%	-8%	-11%
Global Warming Potential	25%	-56%	-64%	-31%	-41%
Acidification Potential	25%	-55%	-57%	-23%	-27%
Eutrophication Potential	25%	-58%	-62%	-19%	-25%
Smog Formation Potential	25%	-50%	-56%	-20%	-27%

Table 56. Comparison of 2L PET CSD with Aluminum Cans Modeled with 2022 Data, 1,000 Gallon Basis

Results, System Expansion	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
Cumulative Energy Demand	10%	-115%	-114%	-93%	-91%
Non-renewable Energy	10%	-96%	-95%	-78%	-76%
Solid Waste	25%	-143%	-142%	-128%	-126%
Water Consumption	25%	-85%	-83%	-68%	-66%
Global Warming Potential	25%	-123%	-122%	-108%	-107%
Acidification Potential	25%	-111%	-111%	-88%	-88%
Eutrophication Potential	25%	-110%	-110%	-85%	-84%
Smog Formation Potential	25%	-113%	-112%	-92%	-92%

Results, Cut-off	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
Cumulative Energy Demand	10%	-94%	-100%	-62%	-70%
Non-renewable Energy	10%	-72%	-77%	-48%	-55%
Solid Waste	25%	-125%	-133%	-99%	-112%
Water Consumption	25%	-83%	-85%	-65%	-67%
Global Warming Potential	25%	-103%	-109%	-83%	-91%
Acidification Potential	25%	-103%	-105%	-77%	-80%
Eutrophication Potential	25%	-103%	-106%	-71%	-76%
Smog Formation Potential	25%	-98%	-102%	-72%	-78%

Table 57. Comparison of Average Weight 500 ml PET Water Bottle with Aluminum Cans Modeled with 2022 Data, 1,000 Gallon Basis

Results, System Expansion	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
Cumulative Energy Demand	10%	-105%	-104%	-82%	-80%
Non-renewable Energy	10%	-85%	-84%	-66%	-64%
Solid Waste	25%	-136%	-135%	-119%	-117%
Water Consumption	25%	-74%	-72%	-56%	-54%
Global Warming Potential	25%	-117%	-115%	-101%	-99%
Acidification Potential	25%	-103%	-103%	-79%	-79%
Eutrophication Potential	25%	-104%	-103%	-77%	-76%
Smog Formation Potential	25%	-103%	-103%	-82%	-81%

Results, Cut-off	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
Cumulative Energy Demand	10%	-83%	-89%	-49%	-57%
Non-renewable Energy	10%	-59%	-64%	-35%	-41%
Solid Waste	25%	-116%	-125%	-88%	-102%
Water Consumption	25%	-70%	-72%	-52%	-54%
Global Warming Potential	25%	-96%	-102%	-74%	-82%
Acidification Potential	25%	-94%	-97%	-67%	-70%
Eutrophication Potential	25%	-96%	-99%	-62%	-68%
Smog Formation Potential	25%	-88%	-92%	-61%	-67%

Table 58. Comparison of Lightweight 500 ml PET Water Bottle with Aluminum Cans Modeled with 2022 Data, 1,000 Gallon Basis

Results, System Expansion	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
Cumulative Energy Demand	10%	-121%	-120%	-101%	-99%
Non-renewable Energy	10%	-104%	-102%	-86%	-85%
Solid Waste	25%	-148%	-147%	-133%	-132%
Water Consumption	25%	-95%	-94%	-79%	-78%
Global Warming Potential	25%	-132%	-131%	-119%	-117%
Acidification Potential	25%	-120%	-120%	-99%	-99%
Eutrophication Potential	25%	-120%	-120%	-96%	-96%
Smog Formation Potential	25%	-120%	-120%	-101%	-101%

Results, Cut-off	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
Cumulative Energy Demand	10%	-101%	-106%	-70%	-78%
Non-renewable Energy	10%	-79%	-84%	-57%	-63%
Solid Waste	25%	-131%	-139%	-107%	-119%
Water Consumption	25%	-92%	-93%	-75%	-77%
Global Warming Potential	25%	-114%	-119%	-95%	-102%
Acidification Potential	25%	-113%	-115%	-88%	-91%
Eutrophication Potential	25%	-113%	-116%	-83%	-88%
Smog Formation Potential	25%	-106%	-110%	-82%	-88%

NO RECYCLING OF PET WATER BOTTLE SHRINK FILM CASE PACKAGING

The baseline results for PET water bottle systems assume that film wrap used as packaging for cases of filled bottles is recycled at a rate of 10%, the U.S. recycling rate for plastic bags, sacks, and film.[23] However, this published recycling rate may largely be driven by industrial recycling of pallet film and recycling of plastic shopping bags. Although results for PET water bottle systems increase slightly when no film recycling is modeled, the sensitivity analysis results in Table 59 show that no comparative conclusions change for PET water bottles and aluminum can systems. Both PET water bottle systems (average weight and lightweight) still have lower results than aluminum systems for all impacts other than ozone depletion.

Table 59. Comparison of 500 ml PET Water Bottle Systems with No Film Recycling and Aluminum Can Systems, 1,000 Gallon Basis

		Comparison with Avg Wt PET System				Comparison with Lt Wt PET System			
	% Diff Threshold	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR
Results, System Expansion									
Cumulative Energy Demand	10%	-75%	-74%	-73%	-72%	-95%	-94%	-94%	-92%
Non-renewable Energy	10%	-54%	-60%	-59%	-66%	-73%	-79%	-78%	-84%
Solid Waste	25%	-110%	-108%	-108%	-106%	-126%	-125%	-125%	-123%
Water Consumption	25%	-41%	-40%	-50%	-49%	-66%	-65%	-74%	-73%
Global Warming Potential	25%	-91%	-90%	-96%	-94%	-110%	-109%	-115%	-113%
Acidification Potential	25%	-122%	-121%	-127%	-125%	-137%	-135%	-140%	-139%
Eutrophication Potential	25%	-78%	-77%	-74%	-73%	-98%	-97%	-94%	-93%
Ozone Depletion Potential	25%	138%	138%	141%	142%	120%	121%	124%	125%
Smog Formation Potential	25%	-86%	-84%	-88%	-86%	-105%	-103%	-107%	-105%
Results, Cut-off									
Cumulative Energy Demand	10%	-79%	-86%	-44%	-54%	-98%	-104%	-65%	-75%
Non-renewable Energy	10%	-56%	-71%	-31%	-49%	-77%	-91%	-54%	-71%
Solid Waste	25%	-111%	-119%	-79%	-93%	-126%	-134%	-98%	-111%
Water Consumption	25%	-70%	-72%	-52%	-54%	-92%	-94%	-75%	-77%
Global Warming Potential	25%	-93%	-101%	-71%	-81%	-112%	-118%	-92%	-101%
Acidification Potential	25%	-120%	-128%	-102%	-113%	-135%	-142%	-119%	-129%
Eutrophication Potential	25%	-96%	-99%	-62%	-67%	-113%	-116%	-82%	-87%
Ozone Depletion Potential	25%	132%	130%	153%	151%	113%	110%	139%	137%
Smog Formation Potential	25%	-91%	-97%	-65%	-73%	-109%	-114%	-86%	-93%

SENSITIVITY ON BOTTLE BILL RECYCLING RATES FOR ALL CONTAINERS

This sensitivity analysis examines the effect on results and comparative conclusions for PET, aluminum, and glass systems evaluated at the higher recycling rates achieved in deposit states. States with bottle bills have much higher recycling rates for aluminum (77% recycling rate in deposit states), PET (62%) and glass (64%), as documented in the 2020 Container Recycling Institute publication "2018 Beverage Market Data Analysis." Increased recycling rates would also lead to increases in the supply of recycled material available for use as recycled content in containers. However, due to uncertainties around how container recycled content may actually increase in response to higher recycling rates, this sensitivity analysis only looks at the end-of-life effects of increased recycling rates.

Comparisons of results for container systems at U.S. national average recycling rates and U.S. bottle bill average recycling rates are presented for system expansion and cut-off recycling methodology in Table 60 and Table 61, respectively. For system expansion, higher recycling rates not only reduce solid waste (and greenhouse gas emissions from the percent of disposed PET bottles managed by WTE combustion) but also increase avoided virgin material production credits. As a result, bottle bill results for system expansion show decreases in almost all impacts for the systems studied, as shown at the bottom of Table 60, with the exception of increased water consumption results for PET bottles, associated with washing recovered bottles for recycling. In contrast, cut-off results do not show much difference for higher recycling rates. In the cut-off method, containers recycled at end of life leave the system boundaries without recycling burdens or avoided virgin material credits, so higher recycling rates only reduce the amounts of containers disposed. This is why the comparison of average recycling results and bottle bill recycling results at the bottom of Table 61 mainly show changes in solid waste. For PET systems, the decreases in GWP and small increases in energy, water, and acidification are due to less PET being disposed by WTE combustion, reducing GHG emissions but also reducing credits for avoiding grid electricity displaced by energy recovered from WTE combustion.

In Table 62 through Table 66, system expansion comparisons for both recycling rate scenarios are shown in the top two sections of each table, and cut-off comparisons for both scenarios are shown in the bottom sections. Within each recycling methodology, comparing the color-coded results shows that very few comparative conclusions shift for systems compared at the higher bottle bill recycling rates versus the current average U.S. recycling rates.

Table 60. Summary of Results for CSD and Bottled Water Containers at U.S. Average Recycling Rates and Bottle Bill Recycling Rates, 1,000 Gallon Basis, System Expansion

Baseline Recycling Rates		29.1%	29.1%	29.1%	29.1%	29.1%	50.4%	50.4%	50.4%	50.4%	39.6%	39.6%
System Expansion Results, Baseline Recycling Rates	**Units**	**16.9 oz PET CSD, 10% RC**	**20 oz PET CSD, 10% RC**	**2L PET CSD, 10% RC**	**500 ml PET Water - Avg,**	**500 ml PET Water - Lt,**	**12 oz Al Can, 73% RC**	**12 oz Al Can, 62.3% RC**	**16 oz Al Can, 73% RC**	**16 oz Al Can, 62.3% RC**	**12 oz Glass, 38% RC**	**12 oz Glass, no label, 38% RC**
Cumulative Energy Demand	MJ	13,355	10,997	6,190	7,106	5,610	22,197	21,848	16,355	16,045	38,781	37,914
Non-renewable Energy	MJ	12,893	10,592	5,967	6,866	5,410	16,904	16,662	13,451	13,236	33,941	33,646
Solid Waste	kg	147	120	67.6	77.9	61.2	381	372	280	272	1,698	1,682
Water Consumption	liters	3,310	2,766	1,541	1,755	1,351	3,757	3,733	3,093	3,072	9,867	9,736
Global Warming Potential	kg CO2 eq	623	521	296	328	254	1,241	1,218	990	969	2,608	2,566
Acidification Potential	kg SO2 eq	2.21	1.87	1.05	1.18	0.92	6.87	6.70	5.54	5.39	14.6	14.4
Eutrophication Potential	kg N eq	0.11	0.094	0.055	0.060	0.047	0.19	0.19	0.14	0.14	0.68	0.67
Ozone Depletion Potential	kg CFC-11	5.5E-05	4.6E-05	2.7E-05	2.8E-05	2.1E-05	7.2E-06	7.2E-06	5.1E-06	5.0E-06	9.1E-06	8.5E-06
Smog Formation Potential	kg O3 eq	38.8	32.5	18.7	21.3	16.7	75.2	74.0	58.1	57.0	350	348

Bottle Bill Recycling Rates		62%	62%	62%	62%	62%	77%	77%	77%	77%	64%	64%
System Expansion Results, Bottle Bill Recycling Rates	**Units**	**16.9 oz PET CSD, 10% RC**	**20 oz PET CSD, 10% RC**	**2L PET CSD, 10% RC**	**500 ml PET Water - Avg,**	**500 ml PET Water - Lt,**	**12 oz Al Can, 73% RC**	**12 oz Al Can, 62.3% RC**	**16 oz Al Can, 73% RC**	**16 oz Al Can, 62.3% RC**	**12 oz Glass, 38% RC**	**12 oz Glass, no label, 38% RC**
Cumulative Energy Demand	MJ	10,486	8,581	4,870	5,694	4,533	17,752	17,403	12,408	12,098	37,064	36,197
Non-renewable Energy	MJ	9,989	8,147	4,630	5,436	4,320	14,002	13,760	10,874	10,659	32,224	31,929
Solid Waste	kg	95.0	76.1	43.3	52.3	41.8	232	223	147	140	1,190	1,175
Water Consumption	liters	3,446	2,882	1,613	1,826	1,401	3,554	3,531	2,913	2,892	9,570	9,439
Global Warming Potential	kg CO2 eq	519	433	247	276	215	954	930	735	714	2,385	2,343
Acidification Potential	kg SO2 eq	1.99	1.69	0.95	1.07	0.84	4.74	4.57	3.65	3.50	14.1	14.0
Eutrophication Potential	kg N eq	0.10	0.085	0.050	0.055	0.043	0.17	0.17	0.12	0.11	0.67	0.66
Ozone Depletion Potential	kg CFC-11	3.0E-05	2.5E-05	1.5E-05	1.5E-05	1.1E-05	6.5E-06	6.4E-06	4.4E-06	4.3E-06	7.9E-06	7.2E-06
Smog Formation Potential	kg O3 eq	32.5	27.2	15.8	18.2	14.4	60.5	59.2	45.0	43.9	343	341

Bottle Bill Rate Results as Percent of Baseline Results		**16.9 oz PET CSD, 10% RC**	**20 oz PET CSD, 10% RC**	**2L PET CSD, 10% RC**	**500 ml PET Water - Avg, 10% RC**	**500 ml PET Water - Lt, 10% RC**	**12 oz Al Can, 73% RC**	**12 oz Al Can, 62.3% RC**	**16 oz Al Can, 73% RC**	**16 oz Al Can, 62.3% RC**	**12 oz Glass, 38% RC**	**12 oz Glass, no label, 38% RC**
Cumulative Energy Demand	MJ	79%	78%	79%	80%	81%	80%	80%	76%	75%	96%	95%
Non-renewable Energy	MJ	77%	77%	78%	79%	80%	83%	83%	81%	81%	95%	95%
Solid Waste	kg	65%	64%	64%	67%	68%	61%	60%	53%	51%	70%	70%
Water Consumption	liters	104%	104%	105%	104%	104%	95%	95%	94%	94%	97%	97%
Global Warming Potential	kg CO2 eq	83%	83%	83%	84%	85%	77%	76%	74%	74%	91%	91%
Acidification Potential	kg SO2 eq	90%	90%	90%	91%	91%	69%	68%	66%	65%	97%	97%
Eutrophication Potential	kg N eq	90%	90%	91%	91%	91%	86%	86%	83%	83%	98%	98%
Ozone Depletion Potential	kg CFC-11	55%	55%	55%	55%	55%	89%	89%	87%	87%	86%	85%
Smog Formation Potential	kg O3 eq	84%	84%	84%	85%	86%	80%	80%	77%	77%	98%	98%

Table 61. Summary of Results for CSD and Bottled Water Containers at U.S. Average Recycling Rates and Bottle Bill Recycling Rates, 1,000 Gallon Basis, Cut-Off

Baseline Recycling Rates		29.1%	29.1%	29.1%	29.1%	29.1%	50.4%	50.4%	50.4%	50.4%	39.6%	39.6%
Cut-Off Results, Baseline Recycling Rates	**Units**	**16.9 oz PET CSD, 10% RC**	**20 oz PET CSD, 10% RC**	**2L PET CSD, 10% RC**	**500 ml PET Water - Avg,**	**500 ml PET Water - Lt,**	**12 oz Al Can, 73% RC**	**12 oz Al Can, 62.3% RC**	**16 oz Al Can, 73% RC**	**16 oz Al Can, 62.3% RC**	**12 oz Glass, 38% RC**	**12 oz Glass, no label, 38% RC**
Cumulative Energy Demand	MJ	15,077	12,458	6,965	8,014	6,350	18,579	20,131	12,506	13,885	33,739	32,872
Non-renewable Energy	MJ	14,542	11,974	6,689	7,724	6,096	13,690	14,726	10,559	11,479	27,635	27,340
Solid Waste	kg	148	121	68.1	78.5	61.7	275	313	183	218	1,605	1,590
Water Consumption	liters	3,112	2,597	1,435	1,658	1,285	3,460	3,539	2,819	2,888	7,559	7,428
Global Warming Potential	kg CO2 eq	657	550	311	346	269	951	1,050	729	817	2,201	2,159
Acidification Potential	kg SO2 eq	2.32	1.97	1.10	1.23	0.96	4.95	5.66	3.81	4.44	11.4	11.3
Eutrophication Potential	kg N eq	0.11	0.097	0.056	0.062	0.049	0.17	0.18	0.12	0.12	0.55	0.54
Ozone Depletion Potential	kg CFC-11	6.9E-05	5.9E-05	3.4E-05	3.5E-05	2.6E-05	7.2E-06	7.5E-06	4.6E-06	4.8E-06	1.0E-05	9.3E-06
Smog Formation Potential	kg O3 eq	41.9	35.2	20.2	22.9	18.0	61.2	66.2	45.1	49.5	271	270

Bottle Bill Recycling Rates		62%	62%	62%	62%	62%	77%	77%	77%	77%	64%	64%
Cut-Off Results, Bottle Bill Recycling Rates	**Units**	**16.9 oz PET CSD, 10% RC**	**20 oz PET CSD, 10% RC**	**2L PET CSD, 10% RC**	**500 ml PET Water - Avg,**	**500 ml PET Water - Lt,**	**12 oz Al Can, 73% RC**	**12 oz Al Can, 62.3% RC**	**16 oz Al Can, 73% RC**	**16 oz Al Can, 62.3% RC**	**12 oz Glass, 38% RC**	**12 oz Glass, no label, 38% RC**
Cumulative Energy Demand	MJ	15,186	12,549	7,014	8,067	6,391	18,552	20,104	12,482	13,861	33,654	32,787
Non-renewable Energy	MJ	14,641	12,057	6,733	7,773	6,134	13,663	14,699	10,535	11,455	27,551	27,255
Solid Waste	kg	98.3	79.0	45.0	54.0	43.2	239	277	151	186	1,063	1,048
Water Consumption	liters	3,171	2,646	1,462	1,687	1,307	3,459	3,537	2,818	2,887	7,555	7,424
Global Warming Potential	kg CO2 eq	634	530	301	334	260	949	1,048	727	815	2,194	2,152
Acidification Potential	kg SO2 eq	2.35	1.99	1.12	1.25	0.97	4.94	5.65	3.81	4.43	11.4	11.3
Eutrophication Potential	kg N eq	0.11	0.097	0.056	0.062	0.049	0.17	0.18	0.12	0.12	0.55	0.54
Ozone Depletion Potential	kg CFC-11	6.9E-05	5.9E-05	3.4E-05	3.5E-05	2.6E-05	7.2E-06	7.5E-06	4.6E-06	4.8E-06	9.9E-06	9.3E-06
Smog Formation Potential	kg O3 eq	41.8	35.1	20.1	22.9	18.0	60.8	65.8	44.8	49.2	270	268

Bottle Bill Rate Results as Percent of Baseline Results		**16.9 oz PET CSD, 10% RC**	**20 oz PET CSD, 10% RC**	**2L PET CSD, 10% RC**	**500 ml PET Water - Avg,**	**500 ml PET Water - Lt,**	**12 oz Al Can, 73% RC**	**12 oz Al Can, 62.3% RC**	**16 oz Al Can, 73% RC**	**16 oz Al Can, 62.3% RC**	**12 oz Glass, 38% RC**	**12 oz Glass, no label, 38% RC**
Cumulative Energy Demand	MJ	101%	101%	101%	101%	101%	100%	100%	100%	100%	100%	100%
Non-renewable Energy	MJ	101%	101%	101%	101%	101%	100%	100%	100%	100%	100%	100%
Solid Waste	kg	67%	65%	66%	69%	70%	87%	88%	83%	85%	66%	66%
Water Consumption	liters	102%	102%	102%	102%	102%	100%	100%	100%	100%	100%	100%
Global Warming Potential	kg CO2 eq	96%	96%	97%	97%	97%	100%	100%	100%	100%	100%	100%
Acidification Potential	kg SO2 eq	101%	101%	101%	101%	101%	100%	100%	100%	100%	100%	100%
Eutrophication Potential	kg N eq	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Ozone Depletion Potential	kg CFC-11	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Smog Formation Potential	kg O3 eq	100%	100%	100%	100%	100%	99%	99%	99%	99%	100%	100%

Table 62. Comparison of 16.9 oz PET CSD with Other CSD Containers at U.S. Average and Bottle Bill Recycling Rates, 1,000 gallon basis

System Expansion Results, Baseline Recycling Rates	% Diff Threshold	12 oz Al Can, 73% RC	12 oz Al Can, 62.3% RC	16 oz Al Can, 73% RC	16 oz Al Can, 62.3% RC	12 oz Glass, 38% RC	12 oz Glass, no label, 38% RC
Cumulative Energy Demand	10%	-50%	-48%	-20%	-18%	-98%	-96%
Non-renewable Energy	10%	-27%	-26%	-4%	-3%	-90%	-89%
Solid Waste	25%	-89%	-87%	-62%	-60%	-168%	-168%
Water Consumption	25%	-13%	-12%	7%	7%	-100%	-99%
Global Warming Potential	25%	-66%	-65%	-46%	-44%	-123%	-122%
Acidification Potential	25%	-103%	-101%	-86%	-84%	-147%	-147%
Eutrophication Potential	25%	-54%	-53%	-22%	-21%	-144%	-143%
Ozone Depletion Potential	25%	153%	154%	166%	166%	143%	146%
Smog Formation Potential	25%	-64%	-62%	-40%	-38%	-160%	-160%

System Expansion Results, Bottle Bill Recycling Rates	% Diff Threshold	12 oz Al Can, 73% RC	12 oz Al Can, 62.3% RC	16 oz Al Can, 73% RC	16 oz Al Can, 62.3% RC	12 oz Glass, 38% RC	12 oz Glass, no label, 38% RC
Cumulative Energy Demand	10%	-51%	-50%	-17%	-14%	-112%	-110%
Non-renewable Energy	10%	-33%	-32%	-8%	-6%	-105%	-105%
Solid Waste	25%	-84%	-81%	-43%	-38%	-170%	-170%
Water Consumption	25%	-3%	-2%	17%	17%	-94%	-93%
Global Warming Potential	25%	-59%	-57%	-34%	-32%	-128%	-127%
Acidification Potential	25%	-82%	-78%	-59%	-55%	-151%	-150%
Eutrophication Potential	25%	-50%	-49%	-14%	-13%	-148%	-147%
Ozone Depletion Potential	25%	129%	129%	149%	149%	117%	122%
Smog Formation Potential	25%	-60%	-58%	-32%	-30%	-165%	-165%

Cut-Off Results, Baseline Recycling Rates	% Diff Threshold	12 oz Al Can, 73% RC	12 oz Al Can, 62.3% RC	16 oz Al Can, 73% RC	16 oz Al Can, 62.3% RC	12 oz Glass, 38% RC	12 oz Glass, no label, 38% RC
Cumulative Energy Demand	10%	-21%	-29%	19%	8%	-76%	-74%
Non-renewable Energy	10%	6%	-1%	32%	24%	-62%	-61%
Solid Waste	25%	-60%	-72%	-21%	-38%	-166%	-166%
Water Consumption	25%	-11%	-13%	10%	7%	-83%	-82%
Global Warming Potential	25%	-37%	-46%	-10%	-22%	-108%	-107%
Acidification Potential	25%	-72%	-84%	-49%	-63%	-132%	-132%
Eutrophication Potential	25%	-42%	-47%	-3%	-9%	-131%	-130%
Ozone Depletion Potential	25%	162%	161%	175%	174%	149%	152%
Smog Formation Potential	25%	-38%	-45%	-7%	-17%	-147%	-146%

Cut-Off Results, Bottle Bill Recycling Rates	% Diff Threshold	12 oz Al Can, 73% RC	12 oz Al Can, 62.3% RC	16 oz Al Can, 73% RC	16 oz Al Can, 62.3% RC	12 oz Glass, 38% RC	12 oz Glass, no label, 38% RC
Cumulative Energy Demand	10%	-20%	-28%	20%	9%	-76%	-73%
Non-renewable Energy	10%	7%	0%	33%	24%	-61%	-60%
Solid Waste	25%	-83%	-95%	-42%	-61%	-166%	-166%
Water Consumption	25%	-9%	-11%	12%	9%	-82%	-80%
Global Warming Potential	25%	-40%	-49%	-14%	-25%	-110%	-109%
Acidification Potential	25%	-71%	-82%	-47%	-61%	-132%	-131%
Eutrophication Potential	25%	-42%	-47%	-2%	-9%	-131%	-130%
Ozone Depletion Potential	25%	162%	161%	175%	174%	150%	152%
Smog Formation Potential	25%	-37%	-45%	-7%	-16%	-146%	-146%

Table 63. Comparison of 20 oz PET CSD with Other CSD Containers at U.S. Average and Bottle Bill Recycling Rates, 1,000 gallon basis

System Expansion Results, Baseline Recycling Rates	% Diff Threshold	12 oz Al Can, 73% RC	12 oz Al Can, 62.3% RC	16 oz Al Can, 73% RC	16 oz Al Can, 62.3% RC	12 oz Glass, 38% RC	12 oz Glass, no label, 38% RC
Cumulative Energy Demand	10%	-67%	-66%	-39%	-37%	-112%	-110%
Non-renewable Energy	10%	-46%	-45%	-24%	-22%	-105%	-104%
Solid Waste	25%	-104%	-103%	-80%	-78%	-174%	-173%
Water Consumption	25%	-30%	-30%	-11%	-10%	-112%	-112%
Global Warming Potential	25%	-82%	-80%	-62%	-60%	-133%	-133%
Acidification Potential	25%	-114%	-113%	-99%	-97%	-154%	-154%
Eutrophication Potential	25%	-69%	-68%	-38%	-37%	-151%	-151%
Ozone Depletion Potential	25%	146%	146%	161%	161%	134%	138%
Smog Formation Potential	25%	-79%	-78%	-56%	-55%	-166%	-166%

System Expansion Results, Bottle Bill Recycling Rates	% Diff Threshold	12 oz Al Can, 73% RC	12 oz Al Can, 62.3% RC	16 oz Al Can, 73% RC	16 oz Al Can, 62.3% RC	12 oz Glass, 38% RC	12 oz Glass, no label, 38% RC
Cumulative Energy Demand	10%	-70%	-68%	-36%	-34%	-125%	-123%
Non-renewable Energy	10%	-53%	-51%	-29%	-27%	-119%	-119%
Solid Waste	25%	-101%	-98%	-64%	-59%	-176%	-176%
Water Consumption	25%	-21%	-20%	-1%	0%	-107%	-106%
Global Warming Potential	25%	-75%	-73%	-52%	-49%	-139%	-138%
Acidification Potential	25%	-95%	-92%	-73%	-70%	-157%	-157%
Eutrophication Potential	25%	-65%	-64%	-30%	-28%	-155%	-154%
Ozone Depletion Potential	25%	119%	120%	141%	142%	106%	112%
Smog Formation Potential	25%	-76%	-74%	-49%	-47%	-171%	-170%

Cut-Off Results, Baseline Recycling Rates	% Diff Threshold	12 oz Al Can, 73% RC	12 oz Al Can, 62.3% RC	16 oz Al Can, 73% RC	16 oz Al Can, 62.3% RC	12 oz Glass, 38% RC	12 oz Glass, no label, 38% RC
Cumulative Energy Demand	10%	-39%	-47%	0%	-11%	-92%	-90%
Non-renewable Energy	10%	-13%	-21%	13%	4%	-79%	-78%
Solid Waste	25%	-78%	-89%	-41%	-57%	-172%	-172%
Water Consumption	25%	-29%	-31%	-8%	-11%	-98%	-96%
Global Warming Potential	25%	-53%	-63%	-28%	-39%	-120%	-119%
Acidification Potential	25%	-86%	-97%	-64%	-77%	-141%	-141%
Eutrophication Potential	25%	-57%	-62%	-19%	-25%	-140%	-139%
Ozone Depletion Potential	25%	156%	155%	171%	169%	142%	145%
Smog Formation Potential	25%	-54%	-61%	-25%	-34%	-154%	-154%

Cut-Off Results, Bottle Bill Recycling Rates	% Diff Threshold	12 oz Al Can, 73% RC	12 oz Al Can, 62.3% RC	16 oz Al Can, 73% RC	16 oz Al Can, 62.3% RC	12 oz Glass, 38% RC	12 oz Glass, no label, 38% RC
Cumulative Energy Demand	10%	-39%	-46%	1%	-10%	-91%	-89%
Non-renewable Energy	10%	-12%	-20%	13%	5%	-78%	-77%
Solid Waste	25%	-100%	-111%	-63%	-81%	-172%	-172%
Water Consumption	25%	-27%	-29%	-6%	-9%	-96%	-95%
Global Warming Potential	25%	-57%	-66%	-31%	-42%	-122%	-121%
Acidification Potential	25%	-85%	-96%	-63%	-76%	-141%	-140%
Eutrophication Potential	25%	-57%	-62%	-18%	-25%	-140%	-139%
Ozone Depletion Potential	25%	156%	155%	171%	169%	142%	145%
Smog Formation Potential	25%	-54%	-61%	-24%	-33%	-154%	-154%

Table 64. Comparison of 2L PET CSD with Other CSD Containers at U.S. Average and Bottle Bill Recycling Rates, 1,000 gallon basis

System Expansion Results, Baseline Recycling Rates	% Diff Threshold	12 oz Al Can, 73% RC	12 oz Al Can, 62.3% RC	16 oz Al Can, 73% RC	16 oz Al Can, 62.3% RC	12 oz Glass, 38% RC	12 oz Glass, no label, 38% RC
Cumulative Energy Demand	10%	-113%	-112%	-90%	-89%	-145%	-144%
Non-renewable Energy	10%	-96%	-95%	-77%	-76%	-140%	-140%
Solid Waste	25%	-140%	-139%	-122%	-120%	-185%	-185%
Water Consumption	25%	-84%	-83%	-67%	-66%	-146%	-145%
Global Warming Potential	25%	-123%	-122%	-108%	-106%	-159%	-159%
Acidification Potential	25%	-147%	-146%	-136%	-135%	-173%	-173%
Eutrophication Potential	25%	-112%	-111%	-87%	-85%	-170%	-170%
Ozone Depletion Potential	25%	116%	117%	137%	138%	100%	105%
Smog Formation Potential	25%	-120%	-119%	-102%	-101%	-180%	-180%

System Expansion Results, Bottle Bill Recycling Rates	% Diff Threshold	12 oz Al Can, 73% RC	12 oz Al Can, 62.3% RC	16 oz Al Can, 73% RC	16 oz Al Can, 62.3% RC	12 oz Glass, 38% RC	12 oz Glass, no label, 38% RC
Cumulative Energy Demand	10%	-114%	-113%	-87%	-85%	-154%	-153%
Non-renewable Energy	10%	-101%	-99%	-81%	-79%	-150%	-149%
Solid Waste	25%	-137%	-135%	-109%	-105%	-186%	-186%
Water Consumption	25%	-75%	-75%	-57%	-57%	-142%	-142%
Global Warming Potential	25%	-118%	-116%	-99%	-97%	-162%	-162%
Acidification Potential	25%	-133%	-131%	-118%	-115%	-175%	-175%
Eutrophication Potential	25%	-108%	-107%	-79%	-78%	-172%	-172%
Ozone Depletion Potential	25%	79%	80%	109%	110%	62%	70%
Smog Formation Potential	25%	-117%	-116%	-96%	-94%	-182%	-182%

Cut-Off Results, Baseline Recycling Rates	% Diff Threshold	12 oz Al Can, 73% RC	12 oz Al Can, 62.3% RC	16 oz Al Can, 73% RC	16 oz Al Can, 62.3% RC	12 oz Glass, 38% RC	12 oz Glass, no label, 38% RC
Cumulative Energy Demand	10%	-91%	-97%	-57%	-66%	-132%	-130%
Non-renewable Energy	10%	-69%	-75%	-45%	-53%	-122%	-121%
Solid Waste	25%	-120%	-129%	-92%	-105%	-184%	-184%
Water Consumption	25%	-83%	-85%	-65%	-67%	-136%	-135%
Global Warming Potential	25%	-101%	-109%	-80%	-90%	-150%	-150%
Acidification Potential	25%	-127%	-135%	-110%	-120%	-165%	-164%
Eutrophication Potential	25%	-103%	-106%	-70%	-76%	-163%	-162%
Ozone Depletion Potential	25%	130%	128%	153%	150%	110%	115%
Smog Formation Potential	25%	-101%	-107%	-76%	-84%	-172%	-172%

Cut-Off Results, Bottle Bill Recycling Rates	% Diff Threshold	12 oz Al Can, 73% RC	12 oz Al Can, 62.3% RC	16 oz Al Can, 73% RC	16 oz Al Can, 62.3% RC	12 oz Glass, 38% RC	12 oz Glass, no label, 38% RC
Cumulative Energy Demand	10%	-90%	-97%	-56%	-66%	-131%	-130%
Non-renewable Energy	10%	-68%	-74%	-44%	-52%	-121%	-121%
Solid Waste	25%	-137%	-144%	-108%	-122%	-184%	-184%
Water Consumption	25%	-81%	-83%	-63%	-66%	-135%	-134%
Global Warming Potential	25%	-104%	-111%	-83%	-92%	-152%	-151%
Acidification Potential	25%	-126%	-134%	-109%	-119%	-164%	-164%
Eutrophication Potential	25%	-102%	-106%	-70%	-75%	-163%	-162%
Ozone Depletion Potential	25%	130%	128%	153%	151%	110%	115%
Smog Formation Potential	25%	-101%	-106%	-76%	-84%	-172%	-172%

Table 65. Comparison of Average Weight 500 ml PET Water Bottle with Aluminum Cans at U.S. Average and Bottle Bill Recycling Rates, 1,000 gallon basis

System Expansion Results, Baseline Recycling Rates	% Diff Threshold	12 oz Al Can, 73% RC	12 oz Al Can, 62.3% RC	16 oz Al Can, 73% RC	16 oz Al Can, 62.3% RC
Cumulative Energy Demand	10%	-103%	-102%	-79%	-77%
Non-renewable Energy	10%	-84%	-83%	-65%	-63%
Solid Waste	25%	-132%	-131%	-113%	-111%
Water Consumption	25%	-73%	-72%	-55%	-55%
Global Warming Potential	25%	-116%	-115%	-101%	-99%
Acidification Potential	25%	-142%	-140%	-130%	-128%
Eutrophication Potential	25%	-105%	-104%	-79%	-78%
Ozone Depletion Potential	25%	117%	118%	138%	139%
Smog Formation Potential	25%	-112%	-111%	-93%	-91%

System Expansion Results, Bottle Bill Recycling Rates	% Diff Threshold	12 oz Al Can, 73% RC	12 oz Al Can, 62.3% RC	16 oz Al Can, 73% RC	16 oz Al Can, 62.3% RC
Cumulative Energy Demand	10%	-103%	-101%	-74%	-72%
Non-renewable Energy	10%	-88%	-87%	-67%	-65%
Solid Waste	25%	-127%	-124%	-95%	-91%
Water Consumption	25%	-64%	-64%	-46%	-45%
Global Warming Potential	25%	-110%	-108%	-91%	-88%
Acidification Potential	25%	-127%	-124%	-110%	-107%
Eutrophication Potential	25%	-101%	-101%	-71%	-70%
Ozone Depletion Potential	25%	81%	82%	111%	111%
Smog Formation Potential	25%	-107%	-106%	-85%	-83%

Cut-Off Results, Baseline Recycling Rates	% Diff Threshold	12 oz Al Can, 73% RC	12 oz Al Can, 62.3% RC	16 oz Al Can, 73% RC	16 oz Al Can, 62.3% RC
Cumulative Energy Demand	10%	-79%	-86%	-44%	-54%
Non-renewable Energy	10%	-56%	-62%	-31%	-39%
Solid Waste	25%	-111%	-120%	-80%	-94%
Water Consumption	25%	-70%	-72%	-52%	-54%
Global Warming Potential	25%	-93%	-101%	-71%	-81%
Acidification Potential	25%	-120%	-128%	-102%	-113%
Eutrophication Potential	25%	-96%	-99%	-62%	-67%
Ozone Depletion Potential	25%	132%	130%	153%	151%
Smog Formation Potential	25%	-91%	-97%	-65%	-73%

Cut-Off Results, Bottle Bill Recycling Rates	% Diff Threshold	12 oz Al Can, 73% RC	12 oz Al Can, 62.3% RC	16 oz Al Can, 73% RC	16 oz Al Can, 62.3% RC
Cumulative Energy Demand	10%	-79%	-85%	-43%	-53%
Non-renewable Energy	10%	-55%	-62%	-30%	-38%
Solid Waste	25%	-126%	-135%	-95%	-110%
Water Consumption	25%	-69%	-71%	-50%	-52%
Global Warming Potential	25%	-96%	-103%	-74%	-84%
Acidification Potential	25%	-119%	-128%	-101%	-112%
Eutrophication Potential	25%	-95%	-99%	-61%	-67%
Ozone Depletion Potential	25%	132%	130%	153%	151%
Smog Formation Potential	25%	-91%	-97%	-65%	-73%

Table 66. Comparison of Lightweight 500 ml PET Water Bottle with Aluminum Cans at U.S. Average and Bottle Bill Recycling Rates, 1,000 gallon basis

System Expansion Results, Baseline Recycling Rates	% Diff Threshold	12 oz Al Can, 73% RC	12 oz Al Can, 62.3% RC	16 oz Al Can, 73% RC	16 oz Al Can, 62.3% RC
Cumulative Energy Demand	10%	-119%	-118%	-98%	-96%
Non-renewable Energy	10%	-103%	-102%	-85%	-84%
Solid Waste	25%	-145%	-144%	-128%	-127%
Water Consumption	25%	-94%	-94%	-78%	-78%
Global Warming Potential	25%	-132%	-131%	-118%	-117%
Acidification Potential	25%	-153%	-152%	-143%	-142%
Eutrophication Potential	25%	-121%	-121%	-98%	-97%
Ozone Depletion Potential	25%	96%	96%	121%	121%
Smog Formation Potential	25%	-127%	-126%	-111%	-109%

System Expansion Results, Bottle Bill Recycling Rates	% Diff Threshold	12 oz Al Can, 73% RC	12 oz Al Can, 62.3% RC	16 oz Al Can, 73% RC	16 oz Al Can, 62.3% RC
Cumulative Energy Demand	10%	-119%	-117%	-93%	-91%
Non-renewable Energy	10%	-106%	-104%	-86%	-85%
Solid Waste	25%	-139%	-137%	-112%	-108%
Water Consumption	25%	-87%	-86%	-70%	-69%
Global Warming Potential	25%	-126%	-125%	-109%	-107%
Acidification Potential	25%	-140%	-138%	-125%	-123%
Eutrophication Potential	25%	-118%	-117%	-91%	-90%
Ozone Depletion Potential	25%	55%	56%	89%	89%
Smog Formation Potential	25%	-123%	-122%	-103%	-101%

Cut-Off Results, Baseline Recycling Rates	% Diff Threshold	12 oz Al Can, 73% RC	12 oz Al Can, 62.3% RC	16 oz Al Can, 73% RC	16 oz Al Can, 62.3% RC
Cumulative Energy Demand	10%	-98%	-104%	-65%	-74%
Non-renewable Energy	10%	-77%	-83%	-54%	-61%
Solid Waste	25%	-127%	-134%	-99%	-112%
Water Consumption	25%	-92%	-93%	-75%	-77%
Global Warming Potential	25%	-112%	-119%	-92%	-101%
Acidification Potential	25%	-135%	-142%	-119%	-129%
Eutrophication Potential	25%	-113%	-116%	-82%	-87%
Ozone Depletion Potential	25%	113%	110%	139%	137%
Smog Formation Potential	25%	-109%	-114%	-86%	-93%

Cut-Off Results, Bottle Bill Recycling Rates	% Diff Threshold	12 oz Al Can, 73% RC	12 oz Al Can, 62.3% RC	16 oz Al Can, 73% RC	16 oz Al Can, 62.3% RC
Cumulative Energy Demand	10%	-98%	-104%	-65%	-74%
Non-renewable Energy	10%	-76%	-82%	-53%	-61%
Solid Waste	25%	-139%	-146%	-111%	-125%
Water Consumption	25%	-90%	-92%	-73%	-75%
Global Warming Potential	25%	-114%	-121%	-95%	-103%
Acidification Potential	25%	-134%	-141%	-118%	-128%
Eutrophication Potential	25%	-112%	-116%	-82%	-87%
Ozone Depletion Potential	25%	113%	110%	139%	137%
Smog Formation Potential	25%	-109%	-114%	-85%	-93%

APPENDIX A. CUT-OFF RESULTS BY STAGE

In this appendix, results by life cycle stage are presented for PET container systems with 10% recycled content and alternative containers, all evaluated using cut-off recycling methodology. The results use the same format as the baseline system expansion results presented in Table 18 through Table 25 and Figure 3 through Figure 10 of the main report.

Compared to the baseline system expansion results in the report, the change in recycling methodology affects the results for each life cycle stage that includes recycling, including the following lines in the tables and figures:

- Container EOL
- LC Closure (for PET bottles and glass bottles)
- LC Multipack (where relevant)
- LC Tier Sheets

The results for “LC Label” for PET and glass bottles are not affected by the change in recycling methodology since no end-of-life recycling is modeled for these components.

Comparative conclusions based on cut-off recycling methodology are discussed in the sensitivity analysis on cut-off recycling methodology in the main report and are not repeated here.

Table 67. Total Energy Demand (MJ) for Beverage Container Systems, 1,000 Gallon Basis, Cut-off Recycling

Life Cycle Stage	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Raw material	9,464	8,033	4,697	4,796	3,520	4,710	6,262	4,182	5,561	20,448	20,448
Converting	3,005	2,624	1,451	1,536	1,127	8,483	8,483	7,533	7,533	0	0
Transp empty to filler	83.2	87.4	112	51.9	51.6	221	221	213	213	2,453	2,453
Transp filled to DC	17.4	14.6	8.28	9.45	7.37	20.2	20.2	11.4	11.4	221	221
Transp filled to store	17.4	31.4	8.28	9.45	7.37	20.2	20.2	23.7	23.7	221	221
Container EOL	-189	-161	-93.9	-95.9	-70.3	50.3	50.3	44.7	44.7	209	209
LC Closure	1,785	1,424	405	711	711	0	0	0	0	626	626
LC Label	209	166	222	151	151	0	0	0	0	867	
LC Multipack	448	0	0	698	698	4,398	4,398	0	0	8,203	8,203
LC Tier Sheets	236	238	155	148	148	676	676	498	498	492	492
Total	**15,077**	**12,458**	**6,965**	**8,014**	**6,350**	**18,579**	**20,131**	**12,506**	**13,885**	**33,739**	**32,872**
Expended Energy	**8,119**	**6,842**	**3,834**	**4,273**	**3,363**	**17,126**	**18,672**	**12,306**	**13,679**	**30,764**	**30,764**
Expended % of Total	53.8%	54.9%	55.0%	53.3%	53.0%	92.2%	92.8%	98.4%	98.5%	91.2%	93.6%
Non-renewable Energy	**14,542**	**11,974**	**6,689**	**7,724**	**6,096**	**13,690**	**14,726**	**10,559**	**11,479**	**27,635**	**27,340**
% of Total	96.5%	96.1%	96.0%	96.4%	96.0%	73.7%	73.1%	84.4%	82.7%	81.9%	83.2%

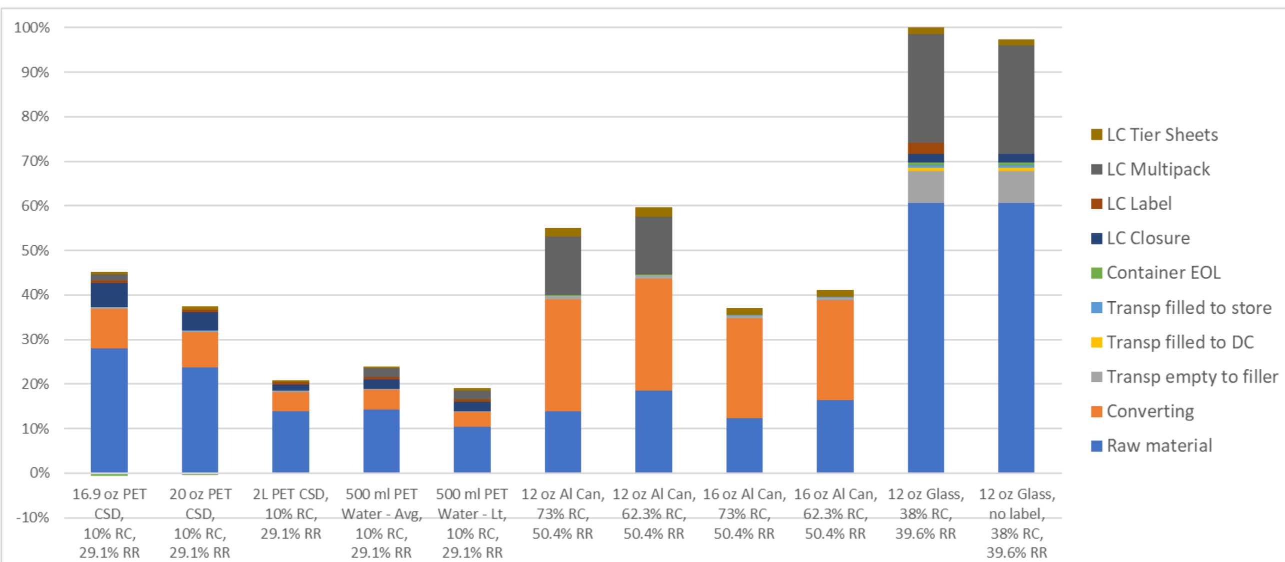

Figure 11. Total Energy Demand (MJ) for Beverage Container Systems, 1,000 Gallon Basis, Cut-off Recycling

Table 68. Solid Wastes (kg) for Beverage Container Systems, 1,000 Gallon Basis, Cut-off Recycling

Life Cycle Stage	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Raw material	14.5	12.3	7.19	7.35	5.39	101	140	89.9	124	91.7	91.7
Converting	14.9	13.0	7.11	7.44	5.46	35.3	35.3	31.4	31.4	0	0
Transp empty to filler	0.086	0.091	0.12	0.054	0.054	0.23	0.23	0.22	0.22	2.23	2.23
Transp filled to DC	0.016	0.013	0.0075	0.0086	0.0067	0.021	0.021	0.012	0.012	0.20	0.20
Transp filled to store	0.016	0.029	0.0075	0.0086	0.0067	0.021	0.021	0.022	0.022	0.20	0.20
Container EOL	95.5	81.0	47.4	48.4	35.5	67.3	67.3	59.8	59.8	1,342	1,342
LC Closure	14.4	11.5	3.27	5.74	5.74	0	0	0	0	24.9	24.9
LC Label	2.29	1.82	2.43	1.65	1.65	0	0	0	0	15.5	
LC Multipack	5.13	0	0	7.27	7.27	67.8	67.8	0	0	126	126
LC Tier Sheets	0.93	0.94	0.61	0.58	0.58	2.68	2.68	1.97	1.97	1.95	1.95
Total	**148**	**121**	**68.1**	**78.5**	**61.7**	**275**	**313**	**183**	**218**	**1,605**	**1,590**

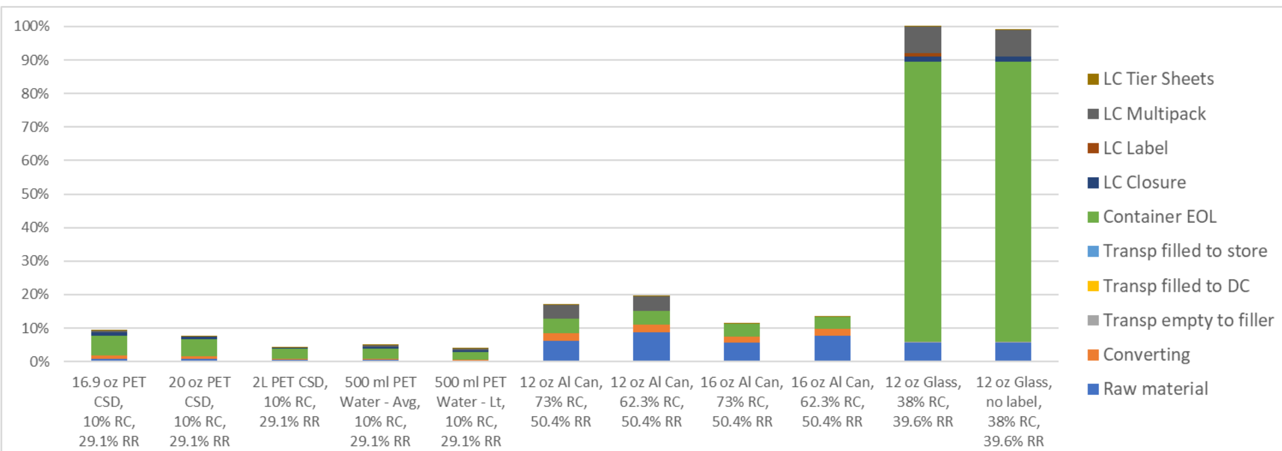

Figure 12. Solid Wastes (kg) for Beverage Container Systems, 1,000 Gallon Basis, Cut-off Recycling

Table 69. Water Consumption (liters) for Beverage Container Systems, 1,000 Gallon Basis, Cut-off Recycling

Life Cycle Stage	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Raw material	1,352	1,148	671	685	503	277	355	246	316	6,619	6,619
Converting	1,446	1,248	696	771	566	2,837	2,837	2,519	2,519	0	0
Transp empty to filler	4.10	4.30	5.50	2.55	2.54	10.9	10.9	10.5	10.5	95.3	95.3
Transp filled to DC	0.67	0.57	0.32	0.37	0.29	0.99	0.99	0.56	0.56	8.58	8.58
Transp filled to store	0.67	1.22	0.32	0.37	0.29	0.99	0.99	0.92	0.92	8.58	8.58
Container EOL	-106	-89.7	-52.5	-53.6	-39.3	2.48	2.48	2.20	2.20	10.3	10.3
LC Closure	301	240	68.3	120	120	0	0	0	0	130	130
LC Label	32.1	25.4	34.1	23.1	23.1	0	0	0	0	131	
LC Multipack	62.1	0	0	97.6	97.6	277	277	0	0	517	517
LC Tier Sheets	18.7	18.8	12.3	11.7	11.7	53.6	53.6	39.5	39.5	39.0	39.0
Total	**3,112**	**2,597**	**1,435**	**1,658**	**1,285**	**3,460**	**3,539**	**2,819**	**2,888**	**7,559**	**7,428**

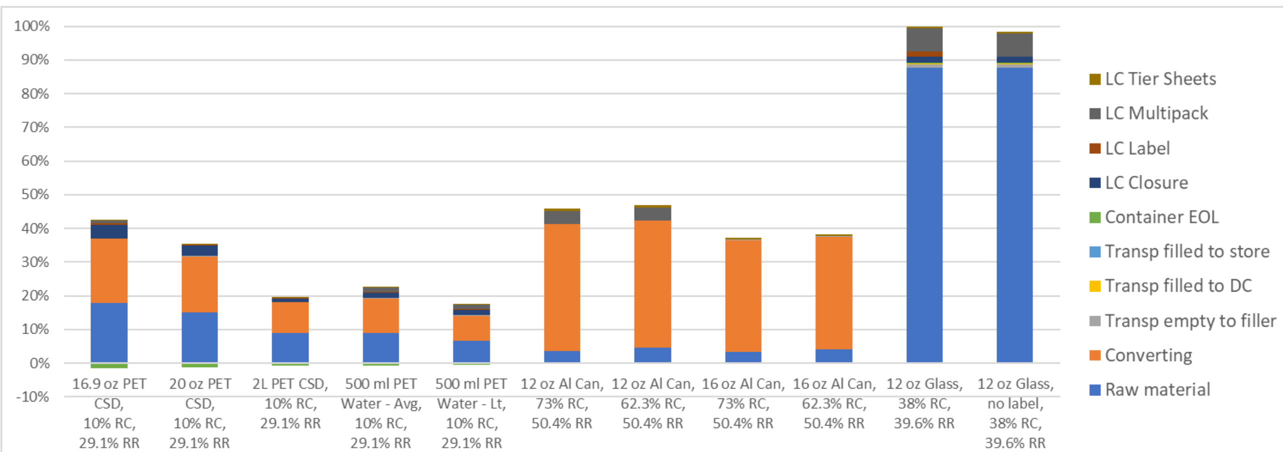

Figure 13. Water Consumption (liters) for Beverage Container Systems, 1,000 Gallon Basis, Cut-off Recycling

Table 70. Global Warming Potential (kg CO_2 eq) for Beverage Container Systems, 1,000 Gallon Basis, Cut-off Recycling

Life Cycle Stage	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Raw material	348	295	173	176	129	297	396	264	352	1,605	1,605
Converting	174	152	84.2	89.6	65.8	490	490	435	435	0	0
Transp empty to filler	6.47	6.80	8.69	4.04	4.01	17.2	17.2	16.6	16.6	192	192
Transp filled to DC	1.36	1.15	0.65	0.74	0.58	1.57	1.57	0.89	0.89	17.3	17.3
Transp filled to store	1.36	2.47	0.65	0.74	0.58	1.57	1.57	1.87	1.87	17.3	17.3
Container EOL	44.6	37.8	22.1	22.6	16.6	3.91	3.91	3.47	3.47	16.2	16.2
LC Closure	57.1	45.5	13.0	22.7	22.7	0	0	0	0	61.5	61.5
LC Label	6.78	5.37	7.20	4.87	4.87	0	0	0	0	41.9	
LC Multipack	14.3	0	0	21.8	21.8	130	130	0	0	242	242
LC Tier Sheets	3.57	3.60	2.35	2.23	2.23	10.2	10.2	7.54	7.54	7.44	7.44
Total	**657**	**550**	**311**	**346**	**269**	**951**	**1,050**	**729**	**817**	**2,201**	**2,159**

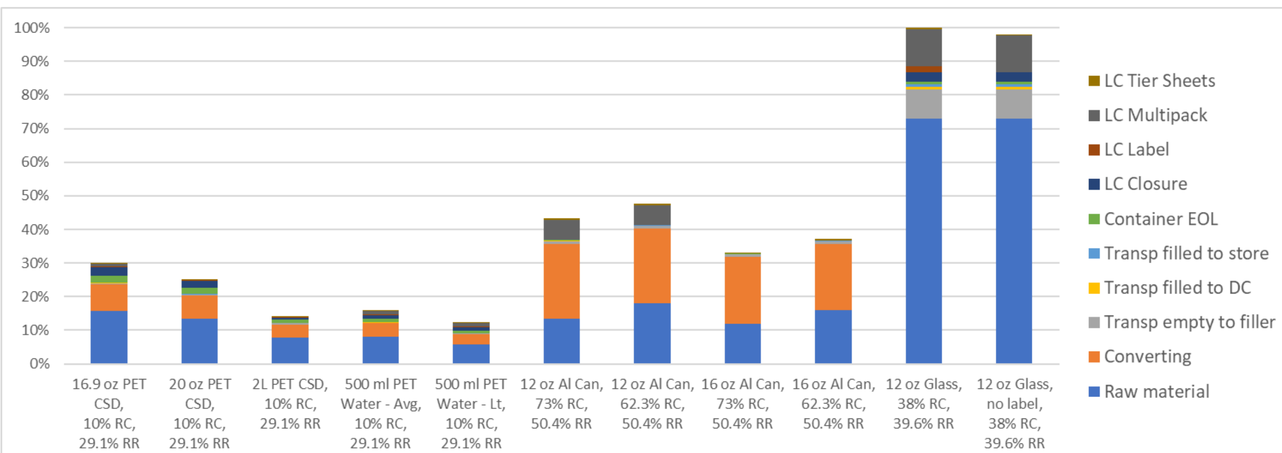

Figure 14. Global Warming Potential (kg CO_2 eq) for Beverage Container Systems, 1,000 Gallon Basis, Cut-off Recycling

Table 71. Acidification Potential (kg SO_2 eq) for Beverage Container Systems, 1,000 Gallon Basis, Cut-off Recycling

Life Cycle Stage	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Raw material	1.10	0.94	0.55	0.56	0.41	1.94	2.64	1.72	2.34	9.02	9.02
Converting	0.89	0.78	0.43	0.48	0.35	2.10	2.10	1.86	1.86	0	0
Transp empty to filler	0.020	0.021	0.027	0.012	0.012	0.053	0.053	0.051	0.051	0.58	0.58
Transp filled to DC	0.0041	0.0035	0.0020	0.0022	0.0017	0.0048	0.0048	0.0027	0.0027	0.052	0.052
Transp filled to store	0.0041	0.0061	0.0020	0.0022	0.0017	0.0048	0.0048	0.0046	0.0046	0.052	0.052
Container EOL	-0.050	-0.042	-0.025	-0.025	-0.019	0.019	0.019	0.017	0.017	0.081	0.081
LC Closure	0.22	0.17	0.049	0.087	0.087	0	0	0	0	0.21	0.21
LC Label	0.020	0.016	0.021	0.014	0.014	0	0	0	0	0.11	
LC Multipack	0.037	0	0	0.058	0.058	0.62	0.62	0	0	1.16	1.16
LC Tier Sheets	0.076	0.076	0.050	0.047	0.047	0.22	0.22	0.16	0.16	0.16	0.16
Total	**2.32**	**1.97**	**1.10**	**1.23**	**0.96**	**4.95**	**5.66**	**3.81**	**4.44**	**11.4**	**11.3**

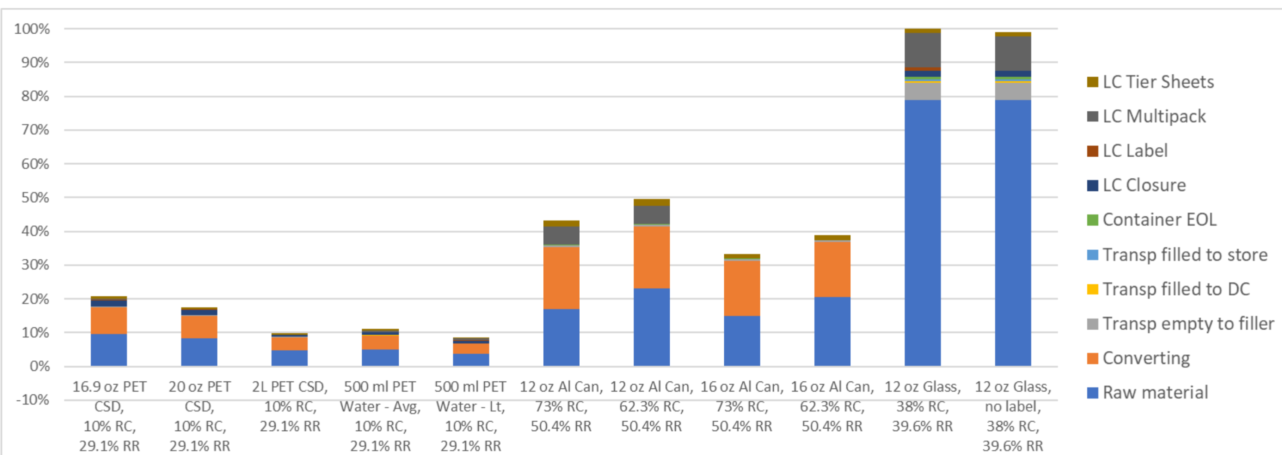

Figure 15. Acidification Potential (kg SO_2 eq) for Beverage Container Systems, 1,000 Gallon Basis, Cut-off Recycling

Table 72. Eutrophication Potential (kg N eq) for Beverage Container Systems, 1,000 Gallon Basis, Cut-off Recycling

Life Cycle Stage	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Raw material	0.072	0.061	0.036	0.036	0.027	0.036	0.045	0.032	0.040	0.39	0.39
Converting	0.020	0.018	0.010	0.012	0.0088	0.069	0.069	0.061	0.061	0	0
Transp empty to filler	0.0012	0.0013	0.0016	7.6E-04	7.6E-04	0.0033	0.0033	0.0031	0.0031	0.037	0.037
Transp filled to DC	2.6E-04	2.2E-04	1.2E-04	1.4E-04	1.1E-04	3.0E-04	3.0E-04	1.7E-04	1.7E-04	0.0033	0.0033
Transp filled to store	2.6E-04	3.9E-04	1.2E-04	1.4E-04	1.1E-04	3.0E-04	3.0E-04	3.0E-04	3.0E-04	0.0033	0.0033
Container EOL	3.7E-04	3.2E-04	1.9E-04	1.9E-04	1.4E-04	0.0012	0.0012	0.0011	0.0011	0.0050	0.0050
LC Closure	0.0085	0.0068	0.0019	0.0034	0.0034	0	0	0	0	0.0041	0.0041
LC Label	8.3E-04	6.6E-04	8.8E-04	6.0E-04	6.0E-04	0	0	0	0	0.013	
LC Multipack	0.0018	0	0	0.0027	0.0027	0.039	0.039	0	0	0.073	0.073
LC Tier Sheets	0.0091	0.0091	0.0060	0.0057	0.0057	0.026	0.026	0.019	0.019	0.019	0.019
Total	**0.11**	**0.097**	**0.056**	**0.062**	**0.049**	**0.17**	**0.18**	**0.12**	**0.12**	**0.55**	**0.54**

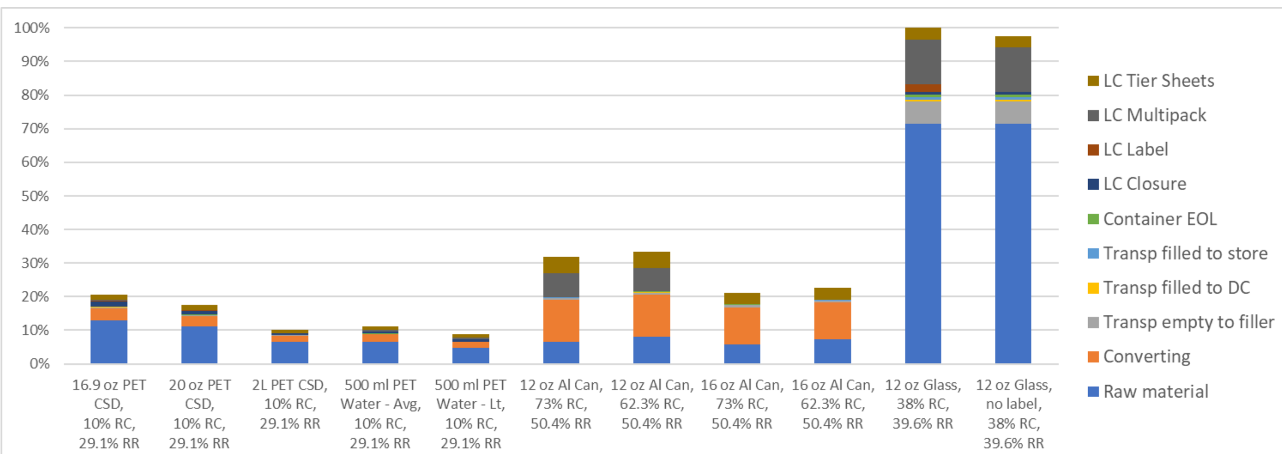

Figure 16. Eutrophication Potential (kg N eq) for Beverage Container Systems, 1,000 Gallon Basis, Cut-off Recycling

Table 73. Ozone Depletion Potential (kg CFC-11 eq) for Beverage Container Systems, 1,000 Gallon Basis, Cut-off Recycling

Life Cycle Stage	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Raw material	6.8E-05	5.7E-05	3.4E-05	3.4E-05	2.5E-05	2.1E-06	2.3E-06	1.8E-06	2.1E-06	3.7E-06	3.7E-06
Converting	4.0E-08	3.3E-08	2.2E-08	2.8E-08	2.0E-08	8.0E-07	8.0E-07	7.1E-07	7.1E-07	0	0
Transp empty to filler	1.7E-08	1.8E-08	2.3E-08	1.1E-08	1.1E-08	4.6E-08	4.6E-08	4.5E-08	4.5E-08	5.3E-07	5.3E-07
Transp filled to DC	3.7E-09	3.2E-09	1.8E-09	2.0E-09	1.6E-09	4.2E-09	4.2E-09	2.4E-09	2.4E-09	4.8E-08	4.8E-08
Transp filled to store	3.7E-09	6.8E-09	1.8E-09	2.0E-09	1.6E-09	4.2E-09	4.2E-09	5.1E-09	5.1E-09	4.8E-08	4.8E-08
Container EOL	2.0E-08	1.7E-08	9.9E-09	1.0E-08	7.4E-09	1.1E-08	1.1E-08	9.4E-09	9.4E-09	4.4E-08	4.4E-08
LC Closure	6.9E-08	5.5E-08	1.6E-08	2.7E-08	2.7E-08	0	0	0	0	2.4E-08	2.4E-08
LC Label	4.8E-09	3.8E-09	5.1E-09	3.4E-09	3.4E-09	0	0	0	0	6.4E-07	
LC Multipack	8.0E-09	0	0	1.2E-08	1.2E-08	1.6E-06	1.6E-06	0	0	2.9E-06	2.9E-06
LC Tier Sheets	9.6E-07	9.7E-07	6.3E-07	6.0E-07	6.0E-07	2.7E-06	2.7E-06	2.0E-06	2.0E-06	2.0E-06	2.0E-06
Total	**6.9E-05**	**5.9E-05**	**3.4E-05**	**3.5E-05**	**2.6E-05**	**7.2E-06**	**7.5E-06**	**4.6E-06**	**4.8E-06**	**1.0E-05**	**9.3E-06**

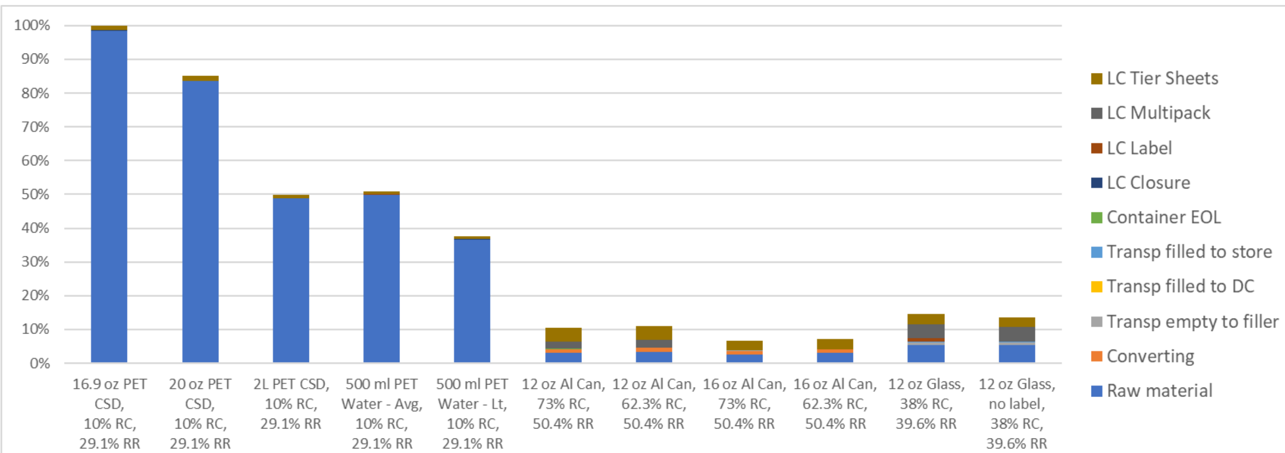

Figure 17. Ozone Depletion Potential (kg CFC-11 eq) for Beverage Container Systems, 1,000 Gallon Basis, Cut-off Recycling

Table 74. Photochemical Smog Formation Potential (kg O_3 eq) for Beverage Container Systems, 1,000 Gallon Basis, Cut-off Recycling

Life Cycle Stage	16.9 oz PET CSD, 10% RC, 29.1% RR	20 oz PET CSD, 10% RC, 29.1% RR	2L PET CSD, 10% RC, 29.1% RR	500 ml PET Water - Avg, 10% RC, 29.1% RR	500 ml PET Water - Lt, 10% RC, 29.1% RR	12 oz Al Can, 73% RC, 50.4% RR	12 oz Al Can, 62.3% RC, 50.4% RR	16 oz Al Can, 73% RC, 50.4% RR	16 oz Al Can, 62.3% RC, 50.4% RR	12 oz Glass, 38% RC, 39.6% RR	12 oz Glass, no label, 38% RC, 39.6% RR
Raw material	23.1	19.6	11.5	11.7	8.59	15.2	20.2	13.5	17.9	219	219
Converting	11.1	9.69	5.53	6.65	4.88	30.5	30.5	27.1	27.1	0	0
Transp empty to filler	0.69	0.73	0.93	0.43	0.43	1.84	1.84	1.77	1.77	20.8	20.8
Transp filled to DC	0.15	0.12	0.070	0.080	0.062	0.17	0.17	0.095	0.095	1.87	1.87
Transp filled to store	0.15	0.22	0.070	0.080	0.062	0.17	0.17	0.17	0.17	1.87	1.87
Container EOL	0.24	0.20	0.12	0.12	0.089	0.67	0.67	0.60	0.60	2.86	2.86
LC Closure	4.22	3.37	0.96	1.68	1.68	0	0	0	0	2.28	2.28
LC Label	0.42	0.33	0.44	0.30	0.30	0	0	0	0	1.68	
LC Multipack	0.87	0	0	1.35	1.35	10.1	10.1	0	0	18.9	18.9
LC Tier Sheets	0.88	0.88	0.58	0.55	0.55	2.51	2.51	1.85	1.85	1.83	1.83
Total	**41.9**	**35.2**	**20.2**	**22.9**	**18.0**	**61.2**	**66.2**	**45.1**	**49.5**	**271**	**270**

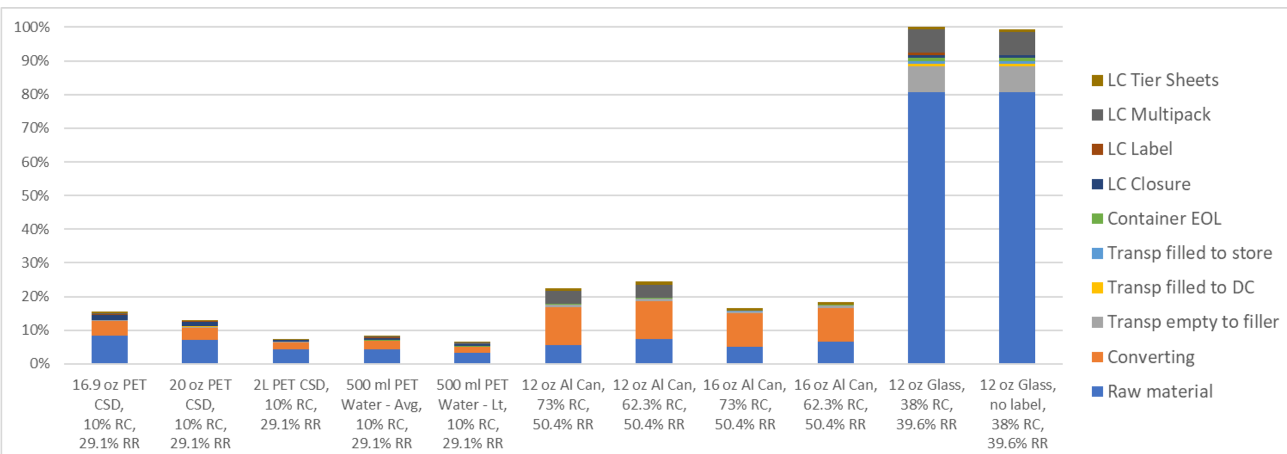

Figure 18. Smog Formation Potential (kg O_3 eq) for Beverage Container Systems, 1,000 Gallon Basis, Cut-off Recycling

APPENDIX B. PEER REVIEW REPORT AND ERG RESPONSES

This appendix presents the peer review panel's approval letter, as well as the panel's detailed comments on the draft report and ERG's responses.

ERG provided initial feedback to the panel on proposed responses in November 2022, which are included in the detailed panel report, along with interim panel feedback, ERG's final responses, and the panel's final approval of each issue.

- Red text is used for ERG responses, and blue text is used for panel responses.
- For cases where the panel's response to ERG's proposed approach closed the issue, the panel's approval is noted in blue text.
- For cases where the panel approved ERG responses that stated that additional information or sensitivities would be added to the study, the panel's approval of the proposed approach is noted in blue, but "pending approval of added material" is added, and the panel's final approval after reviewing the added material is noted in blue.

February 4, 2023

Franklin Associates, a Division of ERG
561 Virginia Road – Suite 300
Building 4
Concord, MA 01742

Subject: Peer Review Panel Conclusion--"Life Cycle Assessment of Predominant U.S. Beverage Container Systems for Carbonated Soft Drinks and Domestic Still Water"

To Whom It May Concern:

The Panel reviewed and commented on a draft version of Franklin Associates' report for NAPCOR, entitled --"Life Cycle Assessment of Predominant U.S. Beverage Container Systems for Carbonated Soft Drinks and Domestic Still Water," then subsequently reviewed Franklin Associates' revisions in response to its comments. The Panel finds Franklin Associates' final report to be reasonable and consistent with both ISO standards and current LCA practice. The Panel concludes that the revised final report meets ISO 14040/14044 guidelines for its intended use.

Sincerely,

Peer Review Panel Members:

Dr. Greg Keoleian
Director, Center for Sustainable Systems
Professor, Civil and Environmental Engineering
co-Coordinator, Engineering Sustainable Systems Program
University of Michigan

Dr. Susan Selke
Professor Emeritus, School of Packaging
Michigan State University

Beth Quay (Chair)
Private Consultant (USA)

PEER REVIEW

of

LIFE CYCLE ASSESSMENT OF BEVERAGE CONTAINER SYSTEMS FOR CARBONATED SOFT DRINKS AND DOMESTIC STILL WATER

Prepared for

The National Association for PET Container Resources (NAPCOR)
and
Franklin Associates, A Division of ERG (ERG)

by

Dr. Greg Keoleian
Director, Center for Sustainable Systems
Professor, Civil and Environmental Engineering
co-Coordinator, Engineering Sustainable Systems Program
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Dr. Susan Selke
Professor Emeritus, School of Packaging
Michigan State University

Beth Quay (Chair)
Private Consultant

August 17, 2022

SUMMARY

At the request of Franklin Associates, the peer review panel evaluated Franklin's cradle-to-grave life cycle assessment (LCA) of nine beverage container systems used for carbonated soft drink (CSD) and still water delivery on the basis of 1,000 gallons of delivered beverage:

- PET bottles
  - 500 ml domestic still water bottle sold as 24-packs shrink-wrapped in plastic film
    - Light weight (8.22 g bottle)
    - Mid-weight (11.2 g bottle)
  - 16.9 oz CSD bottle sold as 6 packs with plastic film ring holders
  - 20 oz CSD bottle sold as individual bottles
  - 2 liter CSD bottle sold as individual bottles
- Aluminum can (used for CSD or water)
  - 12 oz can sold in paperboard boxes holding 12 cans
  - 16 oz can sold as individual bottles
- Glass bottle (used for CSD)
  - 12 oz bottle sold in paperboard carriers holding 4 bottles

Franklin performed a life cycle inventory and impact assessment for each container system across a range of categories: energy demand (total, non-renewable, and expended); solid waste by weight; water consumption; and global warming (GWP), acidification, eutrophication, ozone depletion, and photochemical smog formation potentials.

Each system was evaluated for a baseline scenario of recycling rate (RR) and recycled content (RC) as follows, using a system expansion methodology:

- PET bottles—29.1% RR and 10% RC
- Aluminum cans—50.4% RR and both 73% and 62.3% RC
- Glass bottles—39.6% RR and 40% RC

Sensitivity analyses were then performed for the alternative cut-off recycling allocation methodology, PET bottle recycled content increased to 25% and 50%, PET bottle preform reduced from 22 g to 21g, aluminum cans modeled with the updated January 2022 Aluminum Association data, and equivalent number of containers. However, primary and secondary aluminum production were modeled using older 2013 data.

To ensure the analysis had been conducted in a manner consistent with ISO standards for LCA, the panel of 3 external experts independent of the study was asked to review the draft LCA report against the following criteria:

- Does the goal unambiguously state the intended application and reasons for the study and the intended audience and use of the study and whether the results will be used in comparative assertions to be disclosed to the public?
- Does the scope clearly describe the product system to be studied, the function and system boundaries; the functional unit, system boundaries, and allocation procedures; the LCIA

methodology and impacts to be analyzed, the data quality requirements and the assumptions, limitations and value choices of the study?

- Is the methodology consistent with ISO 14040/14044?
- Has the study conformed to the defined objectives, scope, and boundaries, including any revisions made following the initial goal and scope review?
- Are the assumptions used clearly identified and reasonable?
- Are the sources of data clearly identified and representative in relation to the goal of the study?
- Is the report complete, consistent, and transparent?
- Are the conclusions appropriate based on the data and analysis? Do the interpretations reflect the limitations identified and reflect the goal of the study?

In addition, consistent with the report's being used for comparative assertions for public disclosure, the panel was asked to apply 4 additional tests in the study:

- Does the LCIA employ a sufficiently comprehensive set of category indicators?
- Is the comparison conducted category indicator by category indicator with no weighting of indicators?
- Are the category indicators scientifically/technically valid, environmentally relevant, and internationally accepted?
- Is there sufficient analysis of the sensitivity of the LCIA results?

The calculations, assumptions employed, and data analysis methods are, with some minor exceptions, clear and consistent with ISO 14040 series documents. Generally, the sources of data are clearly identified and representative. Although the reviewers did not replicate calculations, the analyses yielded results that seemed reasonable, based on the assumptions. In general, the panel found the study to meet the high professional standards that life cycle assessment practitioners have come to expect from Franklin Associates.

More detailed responses to each of the questions listed above are given below, including some important issues and concerns which were identified by the panel.

Does the goal unambiguously state the intended application and reasons for the study and the intended audience and use of the study and whether the results will be used in comparative assertions to be disclosed to the public?

Yes, the Executive Summary clearly states the goal is "to provide NAPCOR and its members with information to understand and communicate environmental impacts for PET containers and how they compare with competing beverage containers..." Chapter 1 of the report further states, "NAPCOR wishes to be able to use this study to share comparative results for PET and competing container systems with members and external parties."

Does the scope clearly describe the product system to be studied, the function and system boundaries; the functional unit, system boundaries, and allocation procedures; the LCIA methodology and impacts to be analyzed, the data quality requirements and the assumptions, limitations and value choices of the study?

Yes, the report clearly describes the functional unit (1000 gallons of delivered beverage), system boundaries, allocation procedures, LCIA methodology and impacts, data quality requirements, assumptions, limitations, and value choices.

Is the methodology consistent with ISO 14040/14044?

This study generally follows ISO 14040/14044 guidelines. Objectives, scope, and boundaries are identified, as well as most assumptions.

Two methods were used to model material recycling which is consistent with ISO 14044. For the base case analysis the study used a systems expansion approach to model recycling of container material from the end-of-life management stage. ISO 14044 indicates that if alternative allocation approaches seem applicable, then they should be tested to investigate whether they can impact findings. The cut-off approach defined by US EPA was used in the analysis as an appropriate alternative allocation method and demonstrated robustness of the results.

With the systems expansion methodology, the system boundaries are expanded to include recycling processes for containers recovered for recycling, and the system is credited with avoiding virgin material production if the system's recycling rate (RR) exceeds the system's use of recycled content (RC). Therefore, the results are sensitive to the RR and RC parameters used.

The entire analysis is fundamentally sound. However, a few areas for improvement are identified in the sections below.

Has the study conformed to the defined objectives, scope, and boundaries, including any revisions made following the initial goal and scope review?

Yes, the study has conformed to the defined objectives, scope, and boundaries. No revisions to initial goal and scope were indicated.

Are the assumptions used clearly identified and reasonable?

In general, the assumptions used are clearly identified and reasonable.

However, the assumption for adjusting the recycled content modeling for aluminum is not well founded. Page 7, para. 5 states, "However, since at least some of the material in the postindustrial scrap is likely to be material that has not yet had a useful life in a finished product, an additional scenario is run modeling the postindustrial scrap recycled content as a 50/50 mix of virgin and postconsumer aluminum." The use of the postindustrial scrap also reduces the amount of bauxite extraction and primary aluminum production, so it is not clear why it doesn't receive the same credit as postconsumer scrap.

The concern with treating postindustrial scrap the same as postconsumer scrap is the uncertainty around whether virgin material burdens for non-postconsumer aluminum content in postindustrial scrap is accounted for. Since it is unknown how much of the aluminum in the postindustrial scrap is postconsumer aluminum that has had a previous use in a finished product and how much of the postindustrial scrap is virgin aluminum that has not yet been used in a finished product, it is unknown whether virgin production burdens for non-postconsumer content of the postindustrial scrap have been accounted for. In the methodology used in this study, virgin material production burdens are charged to the system that first uses the material as part of a finished product. If postindustrial scrap is treated the same as postconsumer scrap, the virgin material production burdens for any non-postconsumer content in the postindustrial scrap would not be picked up by either the system producing the scrap or the system using the scrap, so the virgin production burdens for that portion of the postindustrial scrap would never be accounted for. Since the Aluminum Association can report had no information on the mix of virgin and postconsumer content in the postindustrial scrap used in the cans, the 50/50 mix scenario was included to address the potential gap in accounting for virgin production burdens for non-postconsumer content of postindustrial scrap when the can is the first finished product in which that material is used. For these reasons, we prefer to keep both sets of recycled content results in the report.

Panel is satisfied with the proposed response.

Are the sources of data clearly identified and representative in relation to the goal of the study?

ISO 14040, Section 5.1.2.3 states, "The data quality requirements should address:

- time-related coverage;
- geographical coverage;
- technology coverage;
- precision, completeness and representativeness of the data;
- consistency and reproducibility of the methods used throughout the LCA;
- sources of the data and their representativeness;
- uncertainty of the information."

The study authors have clearly identified data sources, which appear to be generally reliable. The majority of the data used is from North American databases, such as industry sources and Franklin Associates' private database. Data is sourced from similar and relatively recent time periods.

However, the panel does have some concerns about the data used.

- A particular concern is the use of a 10% recycling rate for all multipack components for PET beverage containers (plastic), and 15.3% for Al cans and glass (paperboard). The report clearly states that the rates for the plastic components are based on the US EPA recycling rate for "film bags, wraps, and sacks," and for paperboard on the US EPA recycling rate in 2018 for "all types of paperboard packaging other than corrugated." However, the plastic recycling rate is likely much lower than is actually the case, and the paperboard rate is incorrect; it is the 2017 rate (the 2018 rate is 20.8%). The "film bags, wraps, and sacks" rate includes recycling of pallet stretch wrap and of merchandise bags (grocery sacks, etc.). Pallet stretch wrap is recycled at a much higher rate than other plastic film, and grocery sacks are very likely recycled at a higher rate than other film plastics. The recycling of plastic ring connectors, which are not targeted in most collection programs for film plastics, is likely extremely small, and the recycling rate for the bundling film is quite likely to be lower than the rate for bags and sacks. At the very least, a recycling rate of 0% for these components should be considered in the sensitivity analysis.

We agree that the plastic recycling rate used likely overstates the rate for plastic rings and will revise the recycling rate for plastic rings to 0 as a more realistic estimate. Plastic overwrap is collected at the same drop-off locations that collect plastic bags, but no data was found on how much of the material collected at these locations is bags versus overwrap or other types of clean film. We prefer to continue to use the 10% recycling rate for film overwrap in the main results but will run a sensitivity analysis on a 0% recycling rate for film multipacks for PET water bottles to see if any comparative conclusions are affected.

Panel is satisfied with the proposed response (pending approval of added material).

We continued to use the 10% recycling rate for film overwrap in the main results and added a sensitivity analysis on a 0% recycling rate for film multipacks for PET water bottles to see if any comparative conclusions were affected. The sensitivity showed that no conclusions regarding PET water bottles and aluminum cans changed with 0% recycling of film multipacks.

Panel is satisfied with the response.

In the case of paperboard, the EPA rate includes components such as "bags and sacks" that historically were recycled at a rate higher than folding cartons, and wrapping papers and other paper packaging that historically were recycled at a lower rate. Historically, the folding carton subcategory is considerably larger in total amount than the other subcategories, but it is difficult to determine whether using the EPA average understates the actual recycling rate for these large, easily identifiable containers or not. Certainly, using the 2017 rate is not appropriate, especially considering that it was much lower than the 2016 or previous rates, or the 2018 rate. Again, examining other rates using sensitivity analysis is recommended. Since these are relatively minor components, the differences are likely to be small, but this should be done. If nothing else, the rate for paperboard must be corrected.

We appreciate the panel catching the error in the paperboard recycling rate and will revise the results to reflect the higher 2018 rate. If updating the paperboard recycling rate to 20.8% ends up changing any comparative conclusions for PET bottles and 12 oz cans, we may run more sensitivity analysis on paperboard recycling at other rates.

Panel is satisfied with the proposed response (pending approval of added material).

Results have been to reflect the higher 2018 rate. Since no comparative conclusions were affected, no additional sensitivity analysis was added.

Panel is satisfied with the response.

- This study used Production of primary and secondary aluminum data from the Aluminum Association's 2013 report and indicated that an updated Aluminum Association 2022 data could not be used because it was not reported at a unit process level. The study did check whether updated aluminum production data affects comparative conclusions: "Although the 2022 virgin aluminum results (using cradle-to-gate data in Table 7-5 of the AA 2022 report) are somewhat lower than the virgin aluminum results modeled using AA 2013 unit process data, the 2022 recycled aluminum results (using cradle-to-gate data in Table 7-9 of the AA 2022 report) are higher than the results for recycled aluminum from our modeling based on unit process data in the AA 2013 report." The percentage differences (higher and lower) should be reported here and depending on the level this may prompt a note in the conclusion section about the robustness of the results.

More information on the aluminum comparisons is being added.

Panel is satisfied with the proposed response (pending approval of added material).

The original description has been replaced with a table showing a comparison of older and newer aluminum data both on a per kg basis, as well as in the perspective of the can life cycle, and a revised description has been provided.

Panel is satisfied with the response.

- Page 19, para. 3 states, "The results presented in this report use the average weight of each container type based on samples of leading beverage brands purchased and weighed by ERG." However, no information is given on the sampling plan:

  - Number of samples taken,
  - Geographic area from which they were sourced,
  - Brands selected, and
  - How random sampling was assured.

  Since container weight significantly impacts LCI results, this information needs to be included in the report.

More information on the sampling is being added to the report.

Panel is satisfied with the proposed response (pending approval of added material).

Sample information has been added to the report.

Panel is satisfied with the response.

- The discussion of PET bottle manufacturing (page 26) indicates a "mix" of offsite and onsite preform manufacture in bottle making, and offsite and onsite bottle making and filling. However, no percentages are provided in either case. Unless this information is proprietary, it should be provided.

  We have followed up with the data providers to better characterize the mix of offsite and onsite bottle making and filling and will provide an expanded description in the report. In the follow up correspondence with the bottle producers about this, they provided some additional information that affected the weighted average transportation calculations. Preform transport increased somewhat, and empty bottle transport decreased. The PET bottle results in the report are being updated accordingly.

  Panel is satisfied with the proposed response (pending approval of added material).

  The PET bottle results in the report have been updated. Because of the differences in information reported by the different fillers, there was concern that showing percentages could disclose confidential information; therefore, it was not possible to add information on percentages. However, a table showing the weighted average distances based on the mix of onsite and offsite operations and distances reported by the data providers has been added.

  Panel is satisfied with the response.

- According to Table 2, the unbleached paperboard multipack contributes a significant amount of weight to the 12-oz aluminum can system: 7.27g per 12.7-oz container. Yet the report gives no information on the age of the paperboard data used in the analysis. Page 25, bullet 3 simply states, "Coated and uncoated unbleached paperboard used in beverage multipacks and tier sheets: Franklin Associates private database." Since the multipack contributes such a significant amount to the 12-oz can system and only has a 15.3% recycling rate, the report needs to provide more detail about the paperboard data used in the analysis. Also, due to the potential impact of the multipack on the 12-az aluminum can system, a sensitivity analysis of paperboard light weighting should be considered.

  Since no recent published data on U.S. unbleached paperboard (and coated paperboard used in cartons) was found during the data collection phase of the project we used data from our database. More information on the age of the data is being added to the report.

  Panel is satisfied with the proposed response (pending approval of added material).

  Information has been added.

  Panel is satisfied with the response.

  Regarding light weighting, these types of paperboard multipacks have been around for long enough that it is likely that the weight has been optimized to the minimum required to still safely transport the weight of the filled beverage containers. This is supported by the fact that carton samples weighed from several different soft drink brands were very similar in weight (heaviest sample was less than 2% heavier than the lightest sample). Therefore, we feel that a lightweighting sensitivity is not necessary.

Panel is satisfied with the proposed response.

- It's very surprising that a steel crown was modeled for the glass bottle system, since the soft drink industry has moved away from crowns—except for special markets—due to their lack of tamper evidence.

Eight of the nine glass bottle samples for the study, including all samples from the largest soft drink brands, had steel crowns. Only one bottle, from a small independent brand, had a twist-off aluminum cap, so the crowns were considered the most representative closure.

Panel is satisfied with the proposed response.

- Further, the study assumed PET bottle closures were recycled but the steel crowns for glass bottles were not. HDPE closures for PET bottles can be problematic to recycle (https://www.scientificamerican.com/article/recycling-plastic-bottle-caps/), and while steel crowns have limited recycling rates, they are being separated magnetically and collected in some municipalities. The panel recommends considering the base case for both caps to not be recycled and then model another case with recycling.

Data collected from PET reclaimers for an LCA conducted for APR on recycled resins indicated that closures are recovered from incoming bales of PET bottles and recycled, so modeling recycling of closures is believed to be accurate. Unlike the HDPE screw tops on PET bottles, steel crowns are not reattachable and were not modeled as being recycled due to (1) consumers disposing of crowns separately from bottles and (2) small size of crowns causing losses during transport/unloading/sorting at MRF. Even if crowns were recycled, the closure life cycle makes only a small contribution to overall results for the glass bottle system, so crown recycling would not affect overall conclusions for comparisons of glass and PET bottle systems.

While the panel wouldn't expect all plastic closures to be recycled, it is known that some metal caps are recycled. Recyclers have also indicated that plastic caps, while recyclable, are often lost because of their small size. The panel notes it is always better to be conservative with assumptions that would appear to be biased in favor of the client.

The data from the APR study on recycled resins indicated that the ratio of cap versus PET bottle material recovered at PET reclaimers was consistent with the range of cap-to-bottle weight ratios for the PET bottles in this study, so modeling recycling of PET bottle closures at the same rate as PET bottles is believed to be accurate. Additional description has been added to the report. To avoid potential bias against glass bottle systems, steel crown recycling was added to the glass bottle system results. Since no definitive data on steel crown recycling was found, an estimate of 25% was used.

Panel is satisfied with the response.

- If the 16.9-oz and 20-oz PET CSD bottles are blown from the same preform, why does Table 1 list a 22.1 g weight for the 16.9-oz bottle and 22.2 g for the 20-oz bottle?

  There were small differences in preform weights reported by different data providers for each bottle. The very small difference in average sample weights in Table 1 most likely means that the 16.9 oz and 20 oz bottles sampled represent different mixes of bottle producers with slightly different preform weights. A small difference is also seen in the production-weighted "Data Provider" weights in Table 10 due to small differences in individual producer preforms and different production shares by producer for 16.9 oz and 20 oz bottles.

  The panel recommends this explanation be included in the final report.

  This explanation has been added to the report.

- Glass bottles included a coated bleached paper label. While true for glass beer bottles, many carbonated beverages such as products of The Coca-Cola Company don't use paper labels for glass bottles.

  Yes, some bottle samples included graphics printed directly on the bottle. However, no data were available on the weights of ink directly printed on the glass bottles or on the impacts of the inks used or the bottle direct printing and ink curing process. Since labels were included for PET bottles, a paper label was modeled in order to include labeling for the glass bottle system. The paper label contributed 2% or less to all results for the glass bottle system, other than eutrophication, where the paper label contribution was about 7% of the total eutrophication impacts.

  Again, the panel notes it is always better to be conservative with assumptions that would appear to be biased in favor of the client.

  Glass bottle system results without a paper label have been added to the report. (Correction to previous response: the paper label contribution of 7% is for ozone depletion results, not eutrophication.)

  Panel is satisfied with the response.

- In the discussion of transport steps for PET, it is stated that weighted average distances were used, and that these were "between 150 and 200 miles." This implies that different distances were used for different sizes; further, no actual values are provided. Unless there are proprietary reasons that this data cannot be provided, a table indicating which distances were used for which sizes should be provided. If this cannot be done, at a minimum it should be clearly stated whether or not different distances were used for different bottle sizes and weights.

  Different distances were used for the different bottles, based on the distances reported by the participating bottle manufacturers and the production-weighted mix from each manufacturer for each bottle. As noted previously, the bottle transport data has been revised and results are being updated, and additional information is being added to the PET bottle transportation writeup.

  Panel is satisfied with the proposed response (pending approval of added material).

The bottle transport data has been revised, including addition of a table showing the weighted average transportation distances for each PET bottle size, and PET results have been updated for the revised transportation.

Panel is satisfied with the response.

- The first bullet on page 26 states, "Electricity used in all processes: US average mix of fuels for 2018 from US EPA eGRID database." The report should indicate that the upstream (precombustion) impacts for these fuels was also modeled.
  This will be added to the report.

  Panel is satisfied with the proposed response.

  Added.

Is the report complete, consistent, and transparent?

The report is generally complete, consistent and transparent. The calculations employed were, in general, clearly and carefully described. However, it should be noted that panel members were not provided comprehensive appendices with more detailed data and descriptions of the material inventories. Therefore, it was somewhat difficult for them to provide a thorough review of the study results.

Yet the panel does have some suggestions/recommendations to improve transparency and consistency, which are listed below, while others are included in the discussion of sensitivity.

- It would be useful, in discussion of recycled content for PET bottles, to explicitly state that the data for recycling is specific to recycling PET into food-grade resin, and includes solid-stating. The report only indicates (p. 74) "mechanical recycling." PET recycling systems obviously differ, and using a system that produces food-grade resin is the appropriate choice, but it is not made clear. An explicit statement to this effect could help avoid criticisms that might otherwise arise.
  This will be added to the report.

  Panel is satisfied with the proposed response.

  Description of the mechanically recycled PET as solid-stated food-grade resin has been added to the report.

- The first bullet on page 8, para. 2, states, "Life cycle inventory (LCI) metrics: Total energy demand, expended energy (total energy minus energy content of resources extracted as feedstocks for container materials), …" Expended energy is not generally reported as an indicator of environmental sustainability performance. PET bottles are made from fossil-based resources, and processes to convert recovered PET at end-of-life into fuels or electricity through pyrolysis and combustion will result in CO_2 emissions. Consequently, the

panel wouldn't recommend including this metric in the Executive Summary. It is useful to see the energy content of the materials broken out as part of total primary energy for PET but not reported as a separate result metric. It could be shown in bar graphs of total primary energy and/or reported separately in an appendix.
We will remove expended energy from the Executive Summary as suggested, but keep it in the energy results presented and discussed in Chapter 2 of the report.

Panel is satisfied with the proposed response (pending approval of added material).

Expended energy has been removed from the Executive Summary tables as suggested (as well as in the sensitivity tables in the report), but the section discussing expended energy has been retained in the energy results presented and discussed in Chapter 2 of the report.

Panel is satisfied with the response.

- The report seems to imply the container systems studied have the greatest market share. However, no numbers are ever given, just general statements like "a much smaller share of sales volume." Including a chart which shows market share by container type would strengthen the report. This chart would also help the reader understand why only 8.22g and 11.2g 500-ml water bottles were included in the study, though the report states, "…weights range from less than 10 grams to over 20 grams per 500 ml bottle."
  Market share information is being added to the report. The heavier PET water bottle weights referenced in the sentence are for premium brands, usually imported. These were excluded from the study, as noted later in the same paragraph.

  Panel is satisfied with the proposed response (pending approval of added material).

  Market share information has been added to the report.

  Panel is satisfied with the response.

- The white-to-red shading in the report tables is misleading. While a standard mechanism to indicate relative differences in numbers, the numbers in these charts should be compared based on significant differences, as done in the green-gray-red highlighted tables in Chapter 3. For transparency, the green-gray-red highlighting should be applied to numbers in the current white-to-red charts.
  The green-gray-red highlighting is based on significant difference comparisons between individual PET bottles and individual competing container systems. Since the tables referenced show results for all PET bottles and all competing containers, the color coding cannot be applied in these tables. There are a couple of options for addressing this comment: (1) We could add language explaining that the white-to-red shading in these tables is used to directionally identify systems that have the highest overall results for each results category but the shading should not be interpreted as designating significant differences between systems, and direct the reader to the meaningful difference tables in Chapters 2 and 3, or (2) Remove the white-to-red shading in the Executive Summary tables. The second option would

make it visually more difficult for the reader to identify the systems that have directionally higher results.

The panel desires option 2—removal of the white-to-red shading—to be implemented in the final report.

The white-to-red shading that was used in the Executive Summary tables and other tables in the report to identify systems with directionally higher results for competing systems has been removed to avoid any confusion between directional differences and differences that are large enough to be considered meaningful. Note that the white-to-red shading in tables presenting results by life cycle stage (in Chapter 2 and Appendix A) was retained, as the shading in these tables is used to identify the largest contributors within individual systems, not comparisons across different systems.

Panel is satisfied with the response.

- Comparing containers on an equivalent number of bottles basis (with the exception of 2L PET), in addition to the functional unit of amount of delivered beverage, is a useful approach, to be commended.

- Since the Executive Summary is sometimes issued as a standalone document, a few selections from later chapters need to be included in it, which are now missing:
  NAPCOR has stated that they will not release the Executive Summary as a standalone document; however, we can make the suggested additions to the Executive Summary.

  Panel desires the suggested additions to be made to the Executive Summary.

  The suggested additions have been made to the Executive Summary.

  - Definition of significant differences, which is outlined under "Meaningful Differences in Results" on page 57, para. 1. Currently…
    - conclusive and inconclusive differences are mentioned in the Summary on page 10, para. 1, bullets 1 and 3 but the logic behind them isn't.
    - "not significantly different" is stated on page 11, para. 3, but not explained.

    Both have been added.
  - Definition of the "Delivery" endpoint, which is explained on page 29, para. 3, ""Two-liter PET bottles and single-serve containers sold in multipacks (16.9 oz CSD in PET, 500 ml water in PET, 12 oz aluminum cans, 12 oz glass bottles) were modeled as transported to grocery stores on semi trucks, while larger single-serve containers sold individually (20 oz CSD in PET, 16 oz aluminum cans) were modeled as transported to convenience stores on single-unit delivery trucks." Added.
  - Explanation that the 50% RC scenario for PET bottles is a 2030 goal, which is relatively far into the future, and the 25% RC goal is 2025 California goal.
    Added in recycled content sensitivity section.
  - More detail on how the 62.3% aluminum can RC was calculated, as explained on page 34, para. 1. Added.

- Results of the January 2022 Aluminum Association data comparison with the data used in this analysis, since readers will probably question how this new data differs. Added.

The panel is satisfied with the additions.

- One environmental metric that is difficult to evaluate related to end-of-life solid waste is plastic marine debris. While not possible to quantify within the scope of this study, plastic marine debris should be identified as a potential environmental impact in the report.
A discussion of marine debris will be added to the report.

  Panel is satisfied with the proposed response (pending approval of added material).

  A paragraph on litter and marine debris has been added in the section "Inventory and Impact Assessment Results Categories".

  The panel is satisfied with the addition.

- Please clarify what the "single-service delivery trucks" are that are mentioned on page 29, para. 3.
This has been corrected to "single-unit delivery trucks."

  Panel is satisfied with the proposed response.

Are the conclusions appropriate based on the data and analysis? Do the interpretations reflect the limitations identified and reflect the goal of the study?

Conclusions are appropriate, and reflect the limitations and goal of the study. Some additional recommendations are listed under the discussion of sensitivity.

Does the LCIA employ a sufficiently comprehensive set of category indicators?

The category indicators are sufficiently comprehensive and well accepted by the international life cycle assessment community.

Is the comparison conducted category indicator by category indicator with no weighting of indicators?

No weighting of indicators is conducted in this study.

Are the category indicators scientifically/technically valid, environmentally relevant, and internationally accepted?

Category indicators are valid, relevant, and accepted.

Is there sufficient analysis of the sensitivity of the LCIA results?

While sensitivity analysis has been performed and results discussed, some additional analyses are suggested.

- For primary containers, because of the importance of recycled content and recycling rate and their interrelationship—especially using the system expansion methodology that is primary in this analysis—it would be useful to consider additional scenarios, specifically:

  - 0% recycled content for PET bottles. While 10% is the industry average, many bottles have less; 25% and 50% are examined, but 0% is not.
    A sensitivity analysis on 0% recycled content PET bottles will be added.

    Panel is satisfied with the proposed response (pending approval of added material).

    0% recycled content PET bottles have been added to the recycled content sensitivity in Chapter 3 (and Executive Summary).

    Panel is satisfied with the response.

  - Higher recycling rates for all container types, since only the U.S. average rates are considered. There is obvious interest in increasing these rates; so it would be very useful to see what impact higher rates would have. In particular, comparing PET, Al and glass at identical recycling rates would provide interesting information. This could approximate the case, for example, if a national deposit law were instituted.
    In deposit states, recycling rates for PET, aluminum, and glass containers are higher than in non-deposit states, but the recycling rates are not the same across all container types, so it does not seem realistic or useful to model a future scenario where all container recycling rates are the same. Furthermore, when modeling future recycling rate scenarios, projections would need to be made about how increases in recycling rates would or would not affect recycled content for the different container systems. A future higher recycling scenario was considered in the project scoping stage but for these reasons was considered too uncertain to produce useful results for this analysis.

    The panel feels this needs more attention. States with bottle bills have much higher rates for aluminum (77% recycling rate in deposit states), PET (62%) and glass (64%). See "2018 Beverage Market Data Analysis", Container Recycling Institute, 2020. Even if not modeled this should be referenced in the report as it is a major opportunity to achieve higher recycling rates.

A sensitivity analysis using the bottle bill recycling rates has been added to the report.

Panel is satisfied with the response.

- For secondary packaging, as mentioned earlier it would be helpful to consider…

  - a recycling rate of 0% for plastic components,

  10% recycling rate for 16.9 oz PET CSD plastic ring holders has been changed to 0%, and sensitivity analysis has been added for 0% recycling of plastic film packaging for PET water bottles.

  - a higher recycling rate for paperboard components,

  This has been corrected from 15.3% to 20.8% throughout the report and results have been updated.

  - and paperboard component light weighting.

  Earlier response provided a rationale for not considering this and was approved by panel.
  Panel is satisfied with the proposed response.