reuse wins at events

A life-cycle analysis of reusable and single-use cups

Upstream

reuse wins at events

A life-cycle analysis of reusable and single-use cups

John Wentz, PhD, University of St. Thomas

This work was paid for by a grant from Upstream. The work was conducted by University of St. Thomas Associate Professor John Wentz, and University of St. Thomas Undergraduate Research Assistants Wayde Charging Hawk, Max Meves, Allie Paterson, and Zane Lundsgaard.

DESIGN: ERIN COVEY-SMITH
EDITORS: SAMANTHA SOMMER AND MATT PRINDIVILLE

Contents

Executive Summary

By Samantha Sommer, Director of Business Innovation & Matt Prindiville, CEO - Upstream

Over the past decade, the sports, entertainment, and live events industry has searched for alternatives to single-use plastic in food concessions. **As fans return to sporting arenas and concert-goers celebrate the return of music festivals, sustainability issues at events and venues are coming back into focus – specifically, the ever-present disposable plastic cup.**

Many attempts at solutions have been introduced, from bioplastic cups to reuse systems and now single-use aluminum. **But there has been no clear scientific consensus as to which options have the greatest environmental impact and which options have the least – until now.**

Upstream commissioned this life-cycle assessment to examine the environmental impacts of single-use and reusable cups made from different materials that are used in arena and stadium events within the United States during an average event tour season.

The goal of the report is to provide unbiased information and analysis to help venue managers, food concessionaires, and other industry leaders identify the most environmentally friendly options.

The materials, manufacture, transport and use phases of 16-ounce beverage cups made from polyethylene terephthalate (PET), polylactic acid (PLA), aluminum (Al), and reusable versions made of polypropylene (PP) and stainless steel (SS) were analyzed for energy consumption, carbon dioxide emissions, air acidification, water eutrophication and landfill impact.

Key Findings

1. **Reusable stainless steel and polypropylene cups dramatically outperform the single-use cup options across all environmental metrics. These are the most sustainable material options for events and venues.** In all use scenarios, stainless steel and polypropylene cups have the lowest impact compared to single-use cups if they are washed and used past the "break-even point" of six times. The break-even point is the number of times a reusable product must be used in order to exceed the environmental benefits of a comparable amount of disposables (e.g. after two uses, a stainless steel fork starts to accrue environmental benefits over a disposable plastic one). The more a reusable product or package is washed and reused past the break-even point, the more environmental benefits accumulate. Polypropylene cups can be washed and reused hundreds of times, and stainless steel cups thousands of times.
2. **If you're still using single-use cups, PET and PLA cups are better options for the climate.** At current recycling rates among single-use cups, polyethylene terephthalate (PET) had the lowest energy consumption and global warming potential, followed closely by polylactic acid (PLA).
3. **Single-use aluminum cups are the worst option for the climate by far.** Single-use aluminum cups used 47% more energy over their life-cycle and created 86% more carbon dioxide than other single-use plastic options.
4. **The use category – transportation and washing – for the reusable cups had a minor impact for all use cases** in comparison to single-use cups.
5. **The average stadium that hosts 300 events annually uses 5.4 million single-use cups – creating a whopping 63.75 tons of plastic waste.** If these were replaced with reusable polypropylene (PP) cups used 300 times and then discarded, that would generate less than one ton of waste. Reusable stainless steel cups used 300 times and then discarded would generate just 1.8 tons of waste.

Recommendations

1. **Venues and event companies should begin the process of shifting away from all single-use cups,** not just single-use plastic.
2. **Single-use aluminum cups are not a sustainable option when compared to other single-use cups or reusable cups,** even if most of the aluminum cups get collected for recycling. The average recycled content for aluminum cans is 73%, which we extrapolated to aluminum cups. Even in this scenario, roughly 27% is virgin aluminum, which is associated with five times more carbon pollution than recycled aluminum. Bauxite mining for aluminum releases perfluorocarbons that are 9,200 times more harmful for the climate than CO_2.
3. **Stainless steel is the preferred choice for all venues and events locations that allow it.** It can be used many more times than reusable plastic and is better for the environment and people all around.
4. **Venues and event companies can either a) create their own reusable cup systems, b) license 3rd party systems, or c) hire reuse companies to provide the service for them.** A number of reuse companies have developed proven, cost-effective systems for distributing, collecting and washing hundreds of thousands of cups per day. Integration into existing operations is often easier than anticipated, and customer data shows a high level of enthusiasm and participation for the new reuse systems.
5. **There are ways to save and make money from deploying reusable cup systems,** including: a) savings on disposables procurement, b) savings on waste management costs, c) savings on clean-up and litter, d) opportunities for brand partnerships and building brand loyalty, and e) opportunities for tech integration, special offers and valuable customer use data.

Background

The primary tool used to assess the environmental impacts for different types of materials is called life-cycle analyses or assessments (LCAs). Researchers plug in different assumptions regarding how the reusable packaging will be served (and collected, washed and reused) and compare the different upstream and downstream environmental impacts of each option.

For this report, the life-cycle inventories of each cup and use case were compiled using two software packages (GRANTA EduPackand Sustainability Eco Audit and Dassault Systems Solidworks) that were then compared with each other for redundancy. Use scenarios are built on conservative common and different component assumptions such as material mass, manufacturing processes, use cases, end-of-life management, and transportation.

The types of events that the analysis is designed around are those where a performing art group travels from city to city on a multi-stop tour. The arena sizes analyzed ranged from 8,000 seats to 60,000 seats and the number of events ranged from 12 to 90 events in a given tour season.

All cups within the study are assumed to have the same volumetric capacity of 16 ounces. In single-use scenarios, the cups were evaluated with varying levels of recycled content and post-consumer recycling, including up to 100% as a theoretical scenario and where all waste, recycling, and reusable cups within an arena are recovered or returned by event goers. In reusable scenarios, the cups are assumed to be retained by the venue after use and sent to an industrial washing facility for cleaning before being shipped and reused at the next event.

The materials, manufacture, transport and use phases of 16-ounce beverage cups made from PET, PLA, Al, PP and SS were analyzed for energy consumption, carbon dioxide emissions, air acidification, water eutrophication and landfill impact. The reuse of polypropylene and stainless steel were compared with single-uses of the other materials to determine break-even points based on the number of reuses.

Conclusion

With all the attention being paid to single-use plastic, venue owners and events companies are rightly looking to reduce their plastic footprint. Unfortunately, trading one single-use product for another generally means trading one set of environmental problems for others. For example, there may not be as much plastic in the ocean, but there is now more climate pollution, more deforestation, more mining for precious metals, or increased use of toxic chemicals.

But the good news is that reuse wins for the environment every time, and companies are innovating to create new reuse services to get us what we want and need without all the waste.

The events industry can be a leader in the new reuse economy by developing and deploying reusable cups systems. Your fans and employees will love it, and you will have taken a significant step toward zero waste, a healthier planet, and a bigger bottom line.

Introduction

Project Overview and Background

This analysis looks at the environmental impacts of beverage containers (cups) used in arena and stadium events within the United States during an event tour season. The goal is to provide unbiased information about energy use requirements and carbon dioxide emissions that accompany the use of different beverage containers so that venue managers and other industry leaders can identify the most environmentally friendly approach. The types of events that the analysis is designed around are those where a performing art group travels from city to city on a multi-stop tour. The arena sizes analyzed ranged from 8,000 seats to 60,000 seats and the number of events ranged from 12 events to 90 events. The beverage containers analyzed were single-use versions made of polyethylene terephthalate (PET), polylactic acid (PLA), aluminum (Al), and reusable versions made of polypropylene (PP) and stainless steel (SS).

In single-use scenarios the cups were evaluated with varying levels of recycled content and post-consumer recycling, including up to 100% as a theoretical scenario where all waste within an arena is recovered. In reuse scenarios the cups are assumed to be retained by the venue after use and sent to an industrial washing facility for cleaning before being reused at the next event.

A literature review was conducted of previous work that investigated similar use cases or life-cycle analysis of beverage containers independent of events. A summary and full references of these comparisons can be provided by contacting info@upstreamsolutions.org.

LCA Methodology

Life-cycle inventories of each cup and use case were compiled using two software packages that were then compared with each other for redundancy. The packages used were GRANTA EduPack 2020 Level 3 Sustainability Eco Audit and Dassault Systems Solidworks 2020-2021 Sustainability Module. Both software packages use material and process databases to create environmental impact outputs based on material mass, manufacturing processes, use scenarios and transportation. The use scenarios and assumptions used in the analysis are provided below.

USE SCENARIOS

Use scenarios have both common and different components. The common components are based on an assumption that all cups, regardless of material, will be manufactured in approximately the same location and transported using the same methods. It is recognized that there are inaccuracies within these common assumptions but since all materials receive the same treatment the inaccuracy is minimized.

COMMON ASSUMPTIONS

1. Cup manufacturing takes place in China
2. Ocean freight transports the cups to Los Angeles, 11,070 km
3. Freight trucking transports the cups to venue locations, 3,242 km
4. Industrial conveyor dishwashers are used for cup washing (25 cups per rack, 244 racks per hour, 1800 W, 0.62 gallons per rack)
5. Dish washing facility is 10 miles from venue.
6. Transport energy calculations are based on total mass of material being transported, higher mass cups require more energy to transport.
7. Reusable cups are 100% recovered after each event for washing. This may not be possible as some patrons may wish to retain their cups and take them home. However, a cup that is taken home is expected to have a neutral environmental effect because it is replacing another reusable cup at the home, rather than a single-use container.

CUP GEOMETRIES AND FEATURES

All cups within the study are assumed to have the same volumetric capacity of 16 oz. Cups currently in the market made of the different materials in the study were measured to determine appropriate masses. Single-use PET and PLA cups are commonly available and were measured at 10.7g and 14.4g, respectively for 16 oz. volume. Single-use aluminum cups are less predominant in the market, the Ball Aluminum Cup™ was used as the basis for analysis with a mass of 21g for 16 oz. volume, 3004 grade aluminum was used. Reusable PP cup measurements were based on 16 oz. samples with a mass of 47g. The wall thickness for the reusable cup was significantly larger than the single-use cups to provide a more robust and long-lasting product. The reusable stainless steel cup dimensions were based on reusable stainless steel pint cups with a mass of 89.26g; 304 grade AISI steel was used.

All plastic cups were analyzed as being manufactured using injection molding. Stainless steel and aluminum cups were analyzed as being rolled strip, sheet metal blanked (15.5% waste removal), and deep drawn to shape.

LCA Results for State of the United States Recycling Scenarios

The life-cycle analysis results presented in the following use scenarios compare the different cup materials based on current recycled content values and recycling rates for each material as given below:

Material	Recycled Content	Recycling Rate	References
PET	7.5%	28.9%	Container Recycling Institute, National Association for PET Container Resources (NAPCOR) 2018; American Chemistry Council and Association of Plastic Recyclers 2019.
Aluminum	73%	46.1%	Sphera/Ball Corp, 2020; The Aluminum Association, 2019
PLA	0%	0%	ILSR, 2014
PP	0%	17%	American Chemistry Council and Association of Plastic Recyclers, 2019.
Stainless Steel	71%	80%	Team Stainless, 2016

Table 1: Recycling assumptions for materials

18,000-Capacity Venue, 300 Sold Out Events Scenario

The life-cycle analysis results in this section are presented as an analysis of an 18,000-capacity venue with 300 sold out events, followed by a breakdown for impact of the material, manufacture, transportation, use, and disposal.

Figures 1-5 show a comparison of cup material impact for, respectively, energy consumption (MJ), carbon dioxide footprint (kg), air acidification (kg SO_2e), water eutrophication (kg PO_4e), and landfill use (ton). The number of uses of the reusable PP and SS cups is listed on the horizontal axis of the figures. Table 2 provides correlating data.

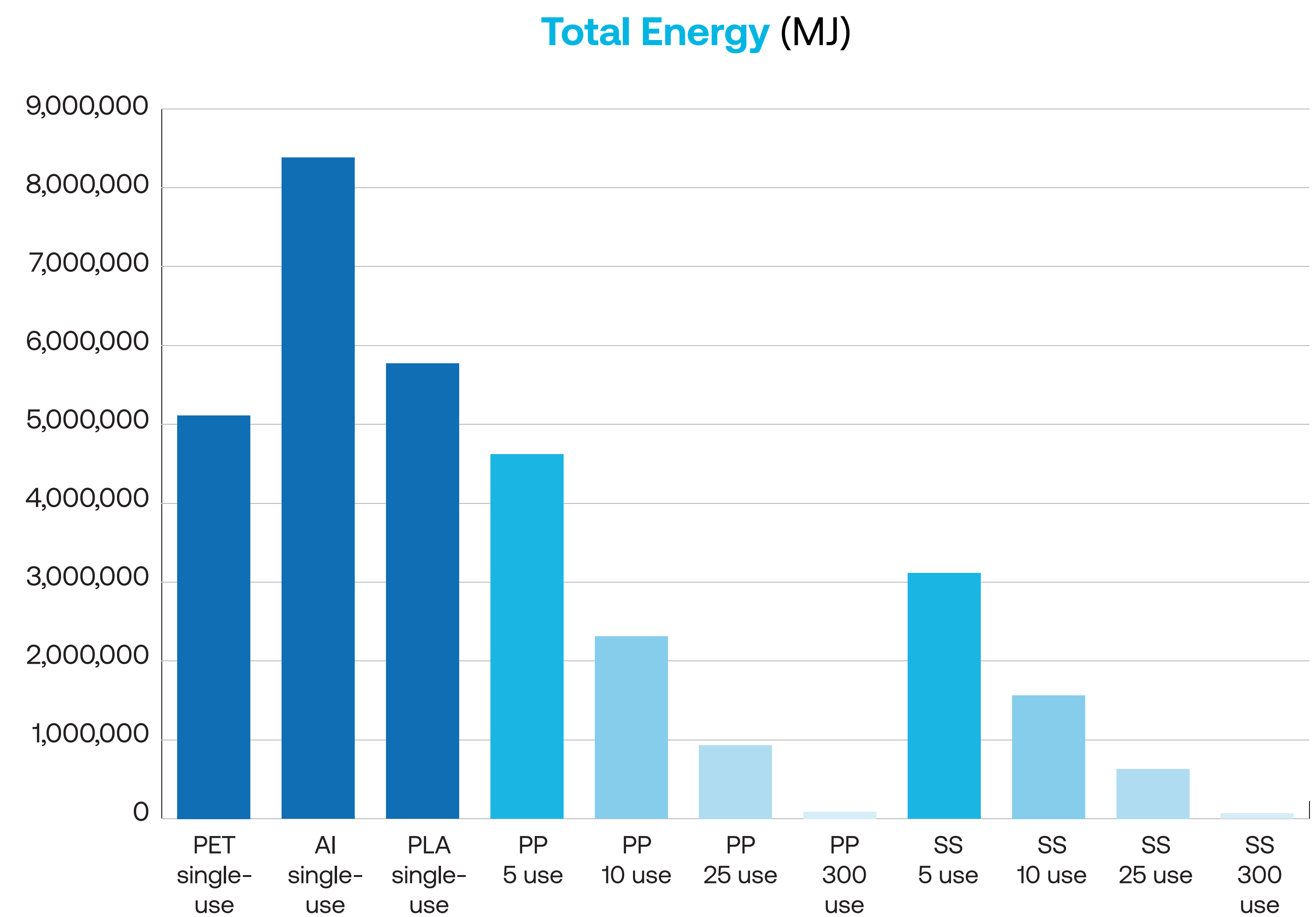


Figure 1: Total energy (MJ) for 18,000 venue, 300 events

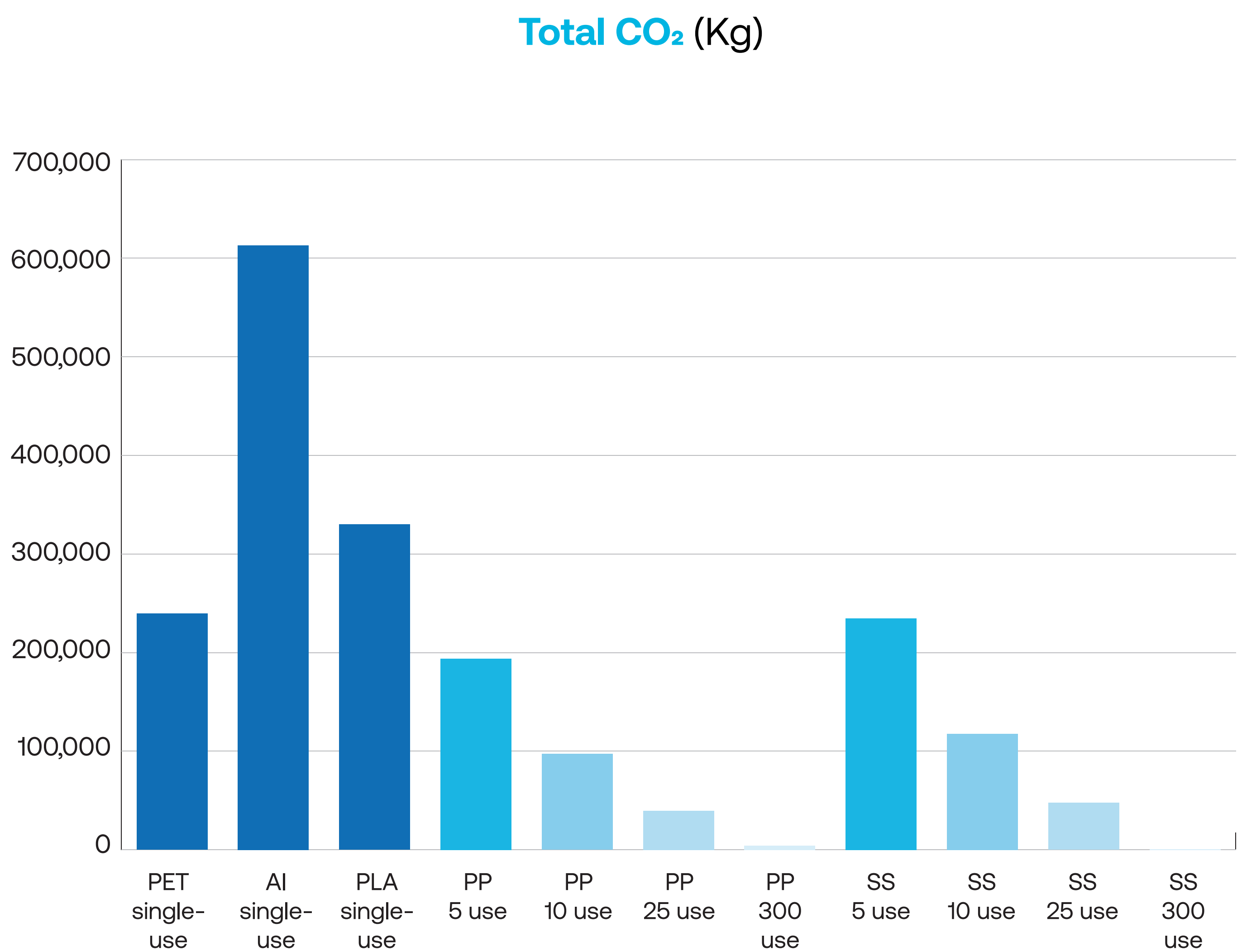


Figure 2: Total energy (MJ) for 18,000 venue, 300 events

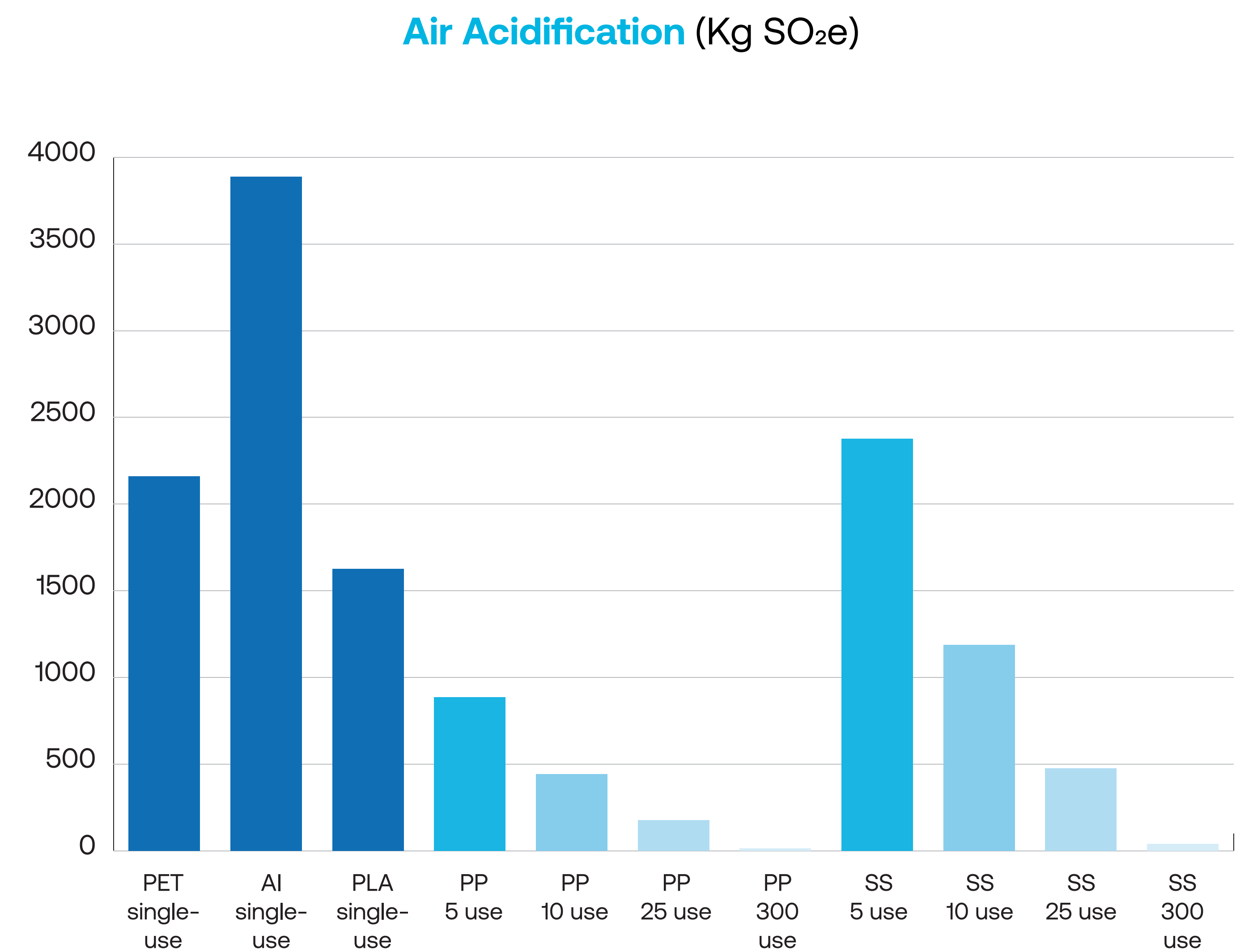


Figure 3: Air acidification (Kg SO_2e) for 18,000 venue, 300 events

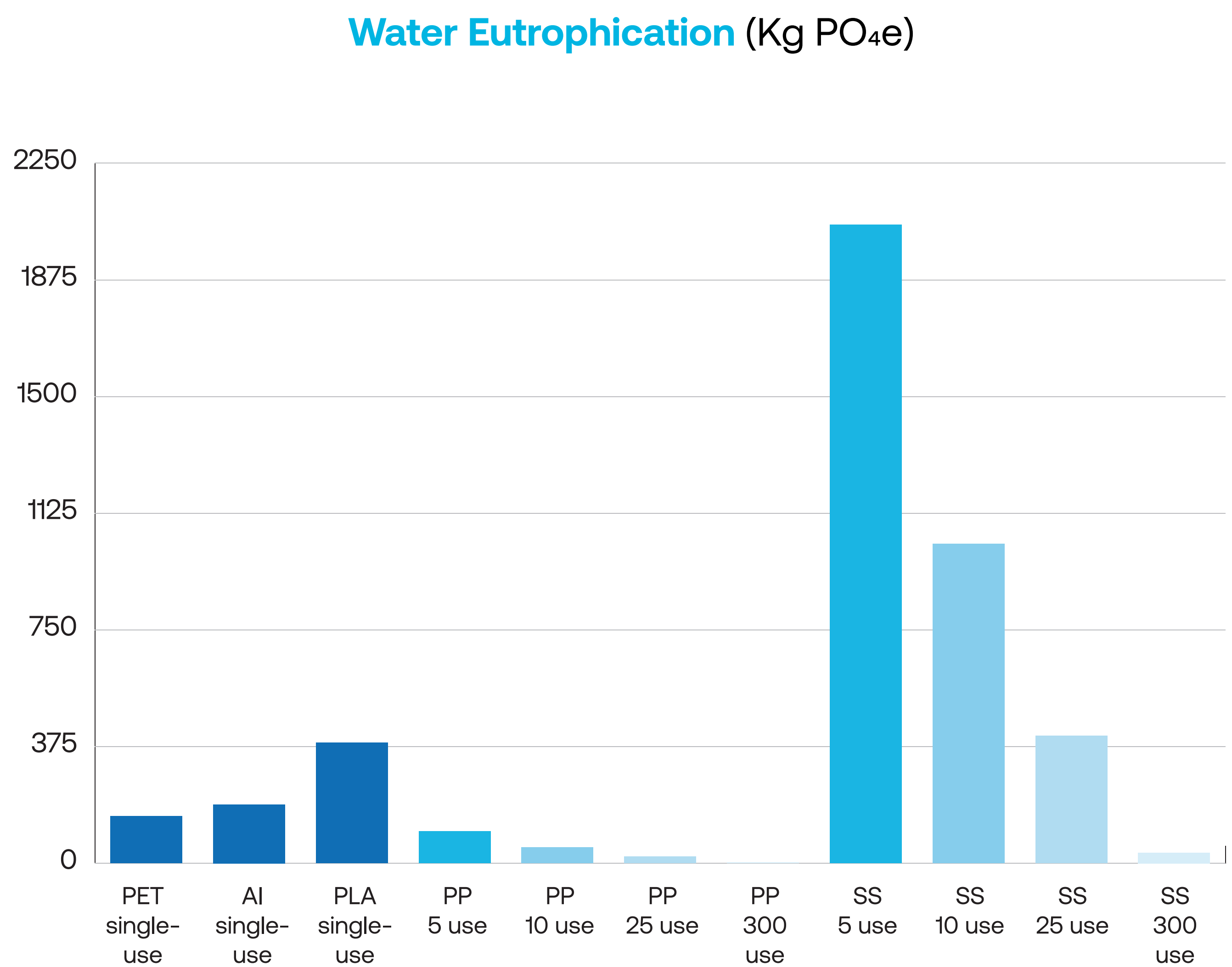


Figure 4: Water eutrophication (Kg PO_4e) for 18,000 venue, 300 events

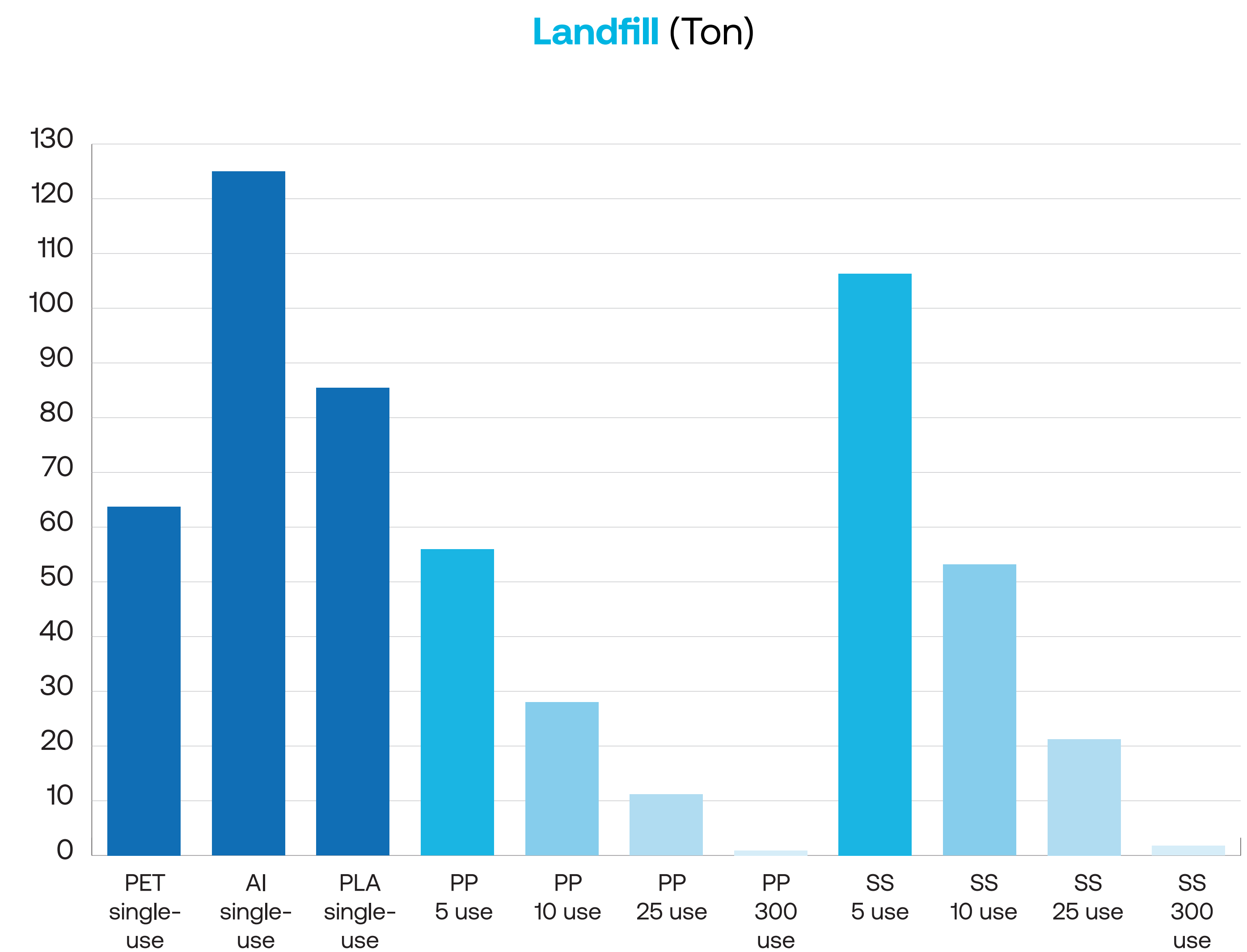


Figure 5: Landfill impact (tons) for 18,000 venue, 300 events

Material	Uses	Quantity	Energy (MJ)	CO_2 (kg)	SO_2e (kg)	PO_4e (kg)	Landfill (ton)
PET	1	5,400,000	5,113,000	239,500	2,160	151	63.75
Aluminum	1	5,400,000	8,380,000	613,000	3,888	189	125
PLA	1	5,400,000	5,770,000	330,000	1,627	387	85.42
PP	5	1,080,000	4,619,946	193,925	886	103	55.95
PP	10	540,000	2,311,189	97,274	443	51	27.98
PP	25	216,00	933,707	39,480	177	21	11.19
PP	300	18,000	89,261	4,212	15	2	0.93
Stainless	5	1,080,000	3,114,801	234,776	2,376	2,052	106.31
Stainless	10	540,000	1,566,652	117,618	1,188	1,026	53.15
Stainless	25	216,000	631,707	47,660	475	410	21.26
Stainless	300	18,000	70,140	1,437	40	34	1.77

Table 2: LCA impact comparison for 18,000 venue, 300 events

Breakeven Analysis for Reuse Scenarios

A breakeven analysis was conducted to determine how many uses of the PP and SS cups would be necessary to improve their impact beyond the single-use varieties. In Table 3 below, the breakeven value means that if the reusable cup was used that number or more times then it is preferable to the specified single-use cup. A lower number means that the reuse cup is more of a significant improvement over the single-use cup because it is anticipated that most cups will be reused many times.

Single-use Material	PP Energy Breakeven Uses	PP CO_2 Breakeven Uses	SS Energy Breakeven Uses	SS CO_2 Breakeven Uses
PET	5	5	4	5
Aluminum	3	2	2	2
PLA	5	3	4	4

Table 3: Number of uses for breakeven impact in current state of recycling

Energy And CO_2 Life-cycle Breakdown of Material Impact

In this section, each material is presented broken down by the relative impact of material, manufacture, transportation, use, and disposal. Single-use cups are assumed to have negligible use components. Reuse cups are assumed to be driven 20 miles round-trip by 40-ton truck to an industrial washing facility, where they are washed with industrial conveyor dishwashers (25 cups per rack, 244 racks per hour, 1800 W, 0.62 gallons per rack). End-of-life (EOL) is treated as a credit, or subtraction, from the total impact if post-use recycling is used. PLA, a bio-polymer, is designed for industrial composting instead of recycling, however at this time very little industrial composting infrastructure is operating in the United States and most PLA material that can be composted finds its way to the landfill instead. According to *State of Composting in the US: What, Why, Where & How* (Institute for Local Self-Reliance, 2014), only 2% of composting facilities take mixed organics such as used food ware waste; based on that, an assumption of landfilling is made for PLA products.

PET Energy Breakdown (MJ)

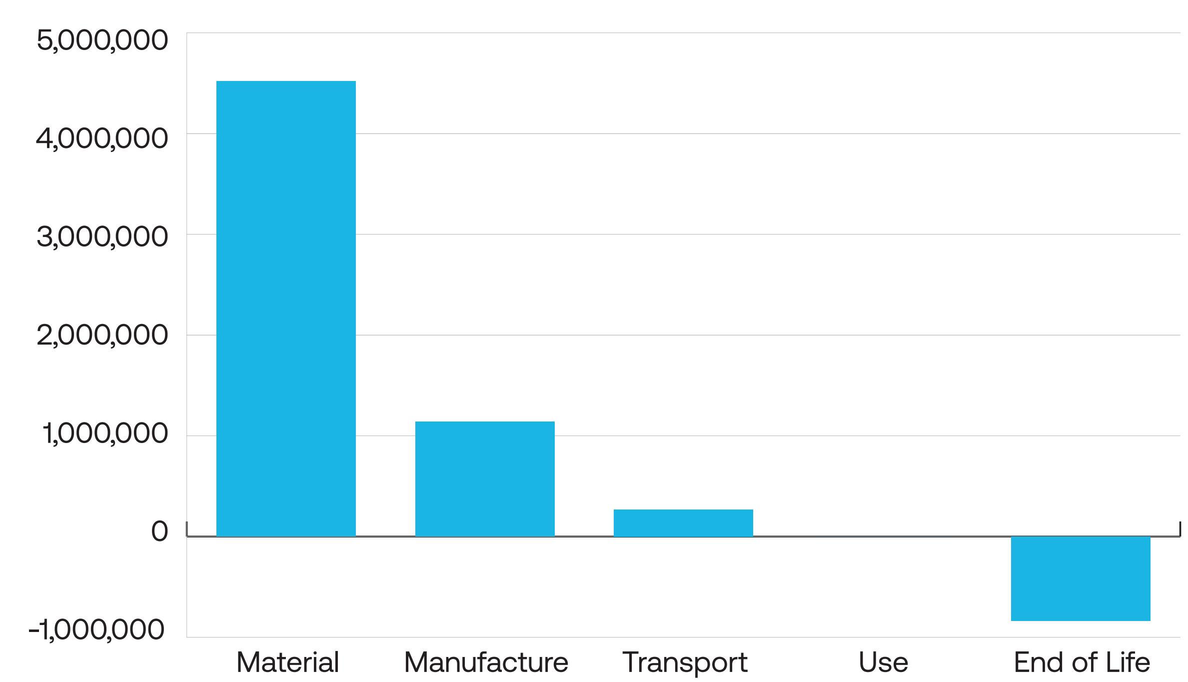


Figure 6: PET energy breakdown (MJ) for 18,000 venue, 300 events

PET CO_2 Breakdown (Kg)

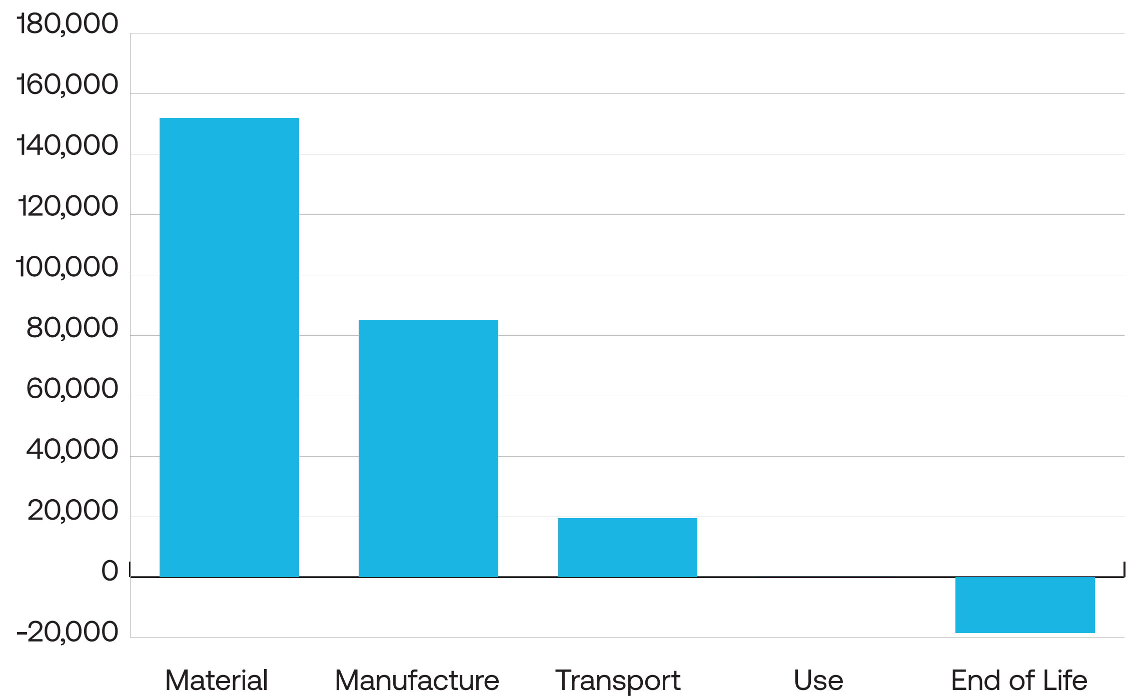


Figure 7: PET CO_2 breakdown (kg) for 18,000 venue, 300 events

Aluminum Energy Breakdown (MJ)

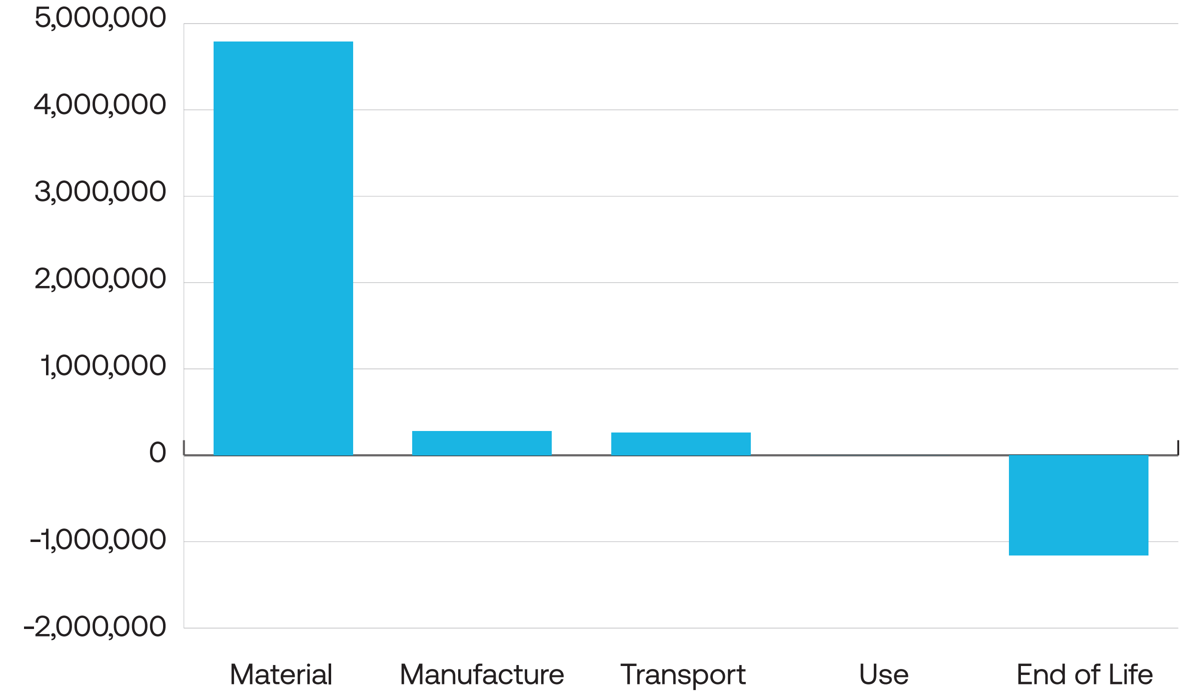


Figure 8: Aluminum energy breakdown (MJ) for 18,000 venue, 300 events

Aluminum CO_2 Breakdown (Kg)

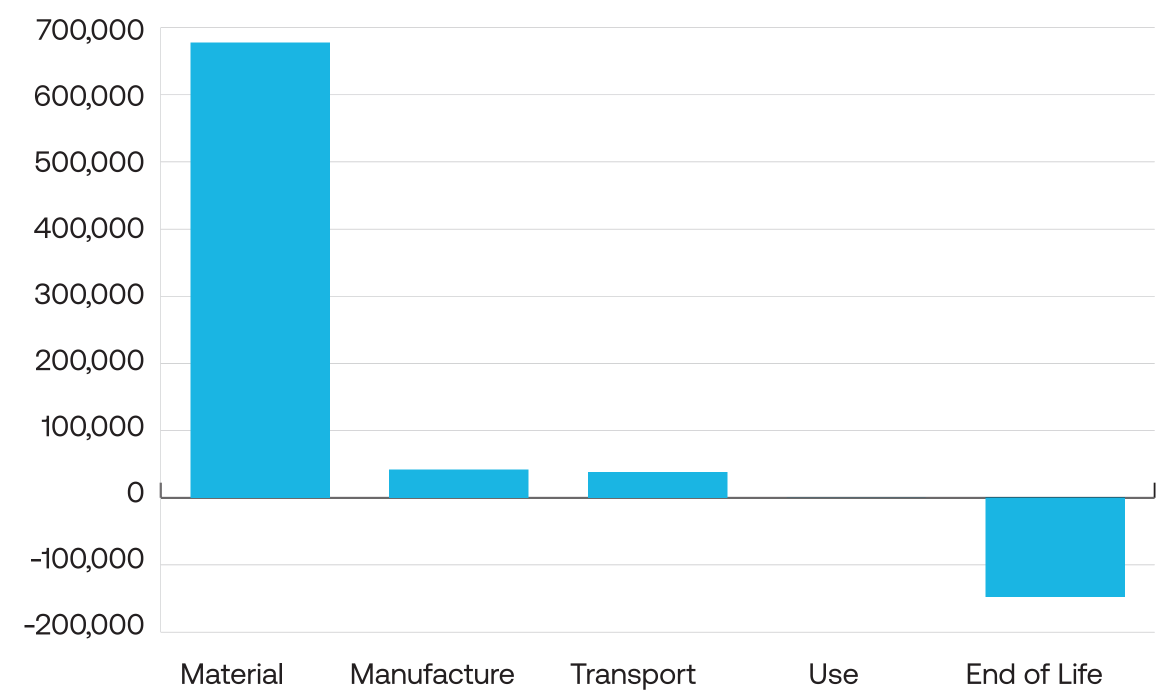
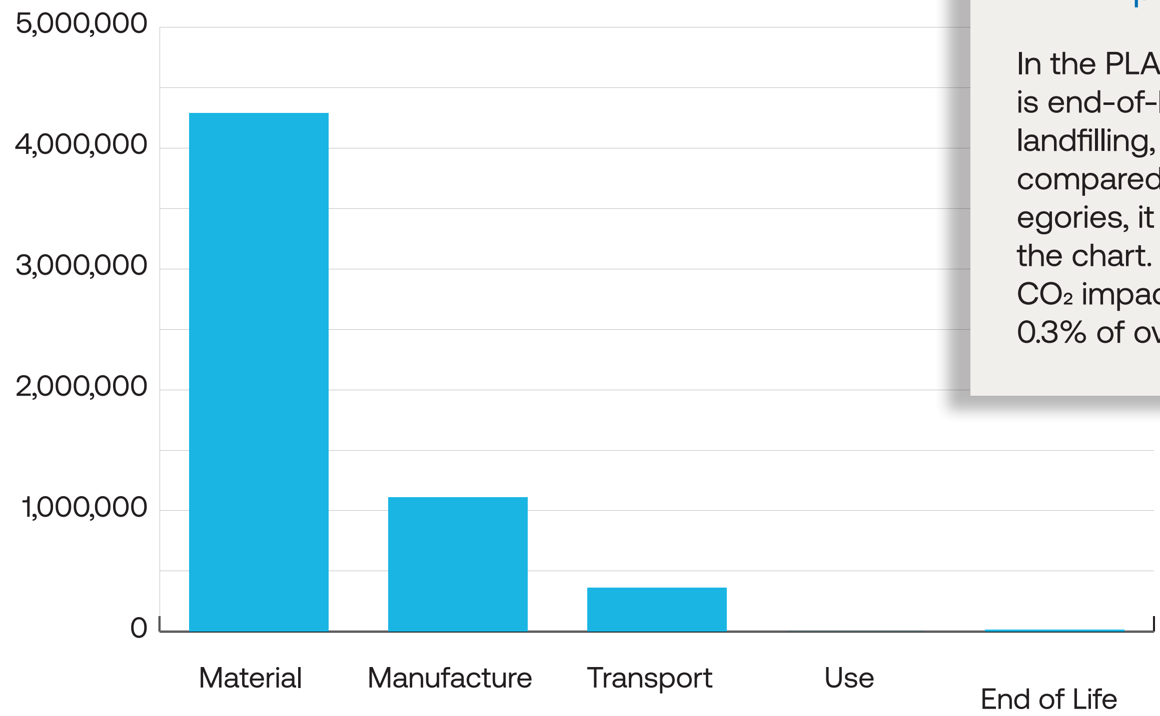


Figure 9: PET CO_2 breakdown (kg) for 18,000 venue, 300 events

PLA Energy Breakdown (MJ)



PLA Impact Breakdown

In the PLA analysis, there is end-of-life impact from landfilling, but it is so small compared to the other categories, it does not show on the chart. In both energy and CO_2 impact, it accounts for 0.3% of overall impact.

Figure 10: PLA energy breakdown (MJ) for 18,000 venue, 300 events

PLA CO_2 Breakdown (Kg)

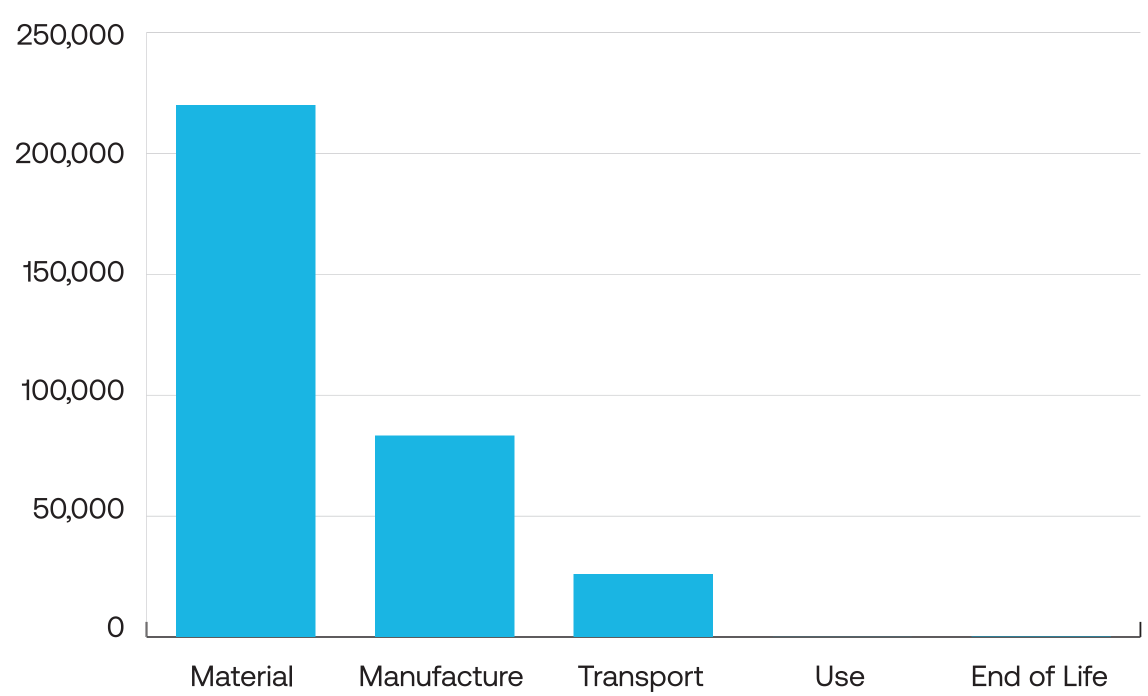


Figure 11: PET CO_2 breakdown (kg) for 18,000 venue, 300 events

Polypropylene Impact Breakdown

Polypropylene is a reuse scenario, so it does carry a use impact due to driving back and forth from the washing facility and the act of washing itself. To show the varying impact of use with reuse number both the 10 use scenario and the 300 use scenario are provided. It can be seen that as reuse increases the total impact significantly reduces and the use impact increases relative to the other categories.

PP 10 Use Energy Breakdown (MJ)

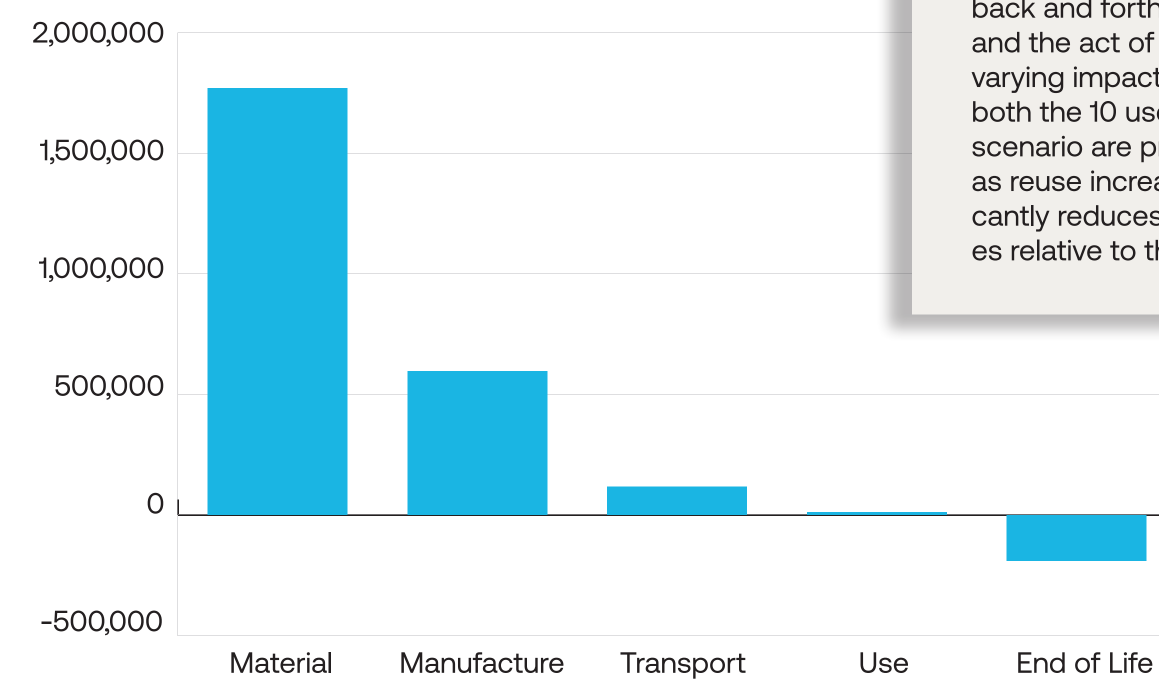


Figure 12: PP energy breakdown (MJ), 10 uses, 18,000 capacity, 300 events

PP 300 Use Energy Breakdown (MJ)

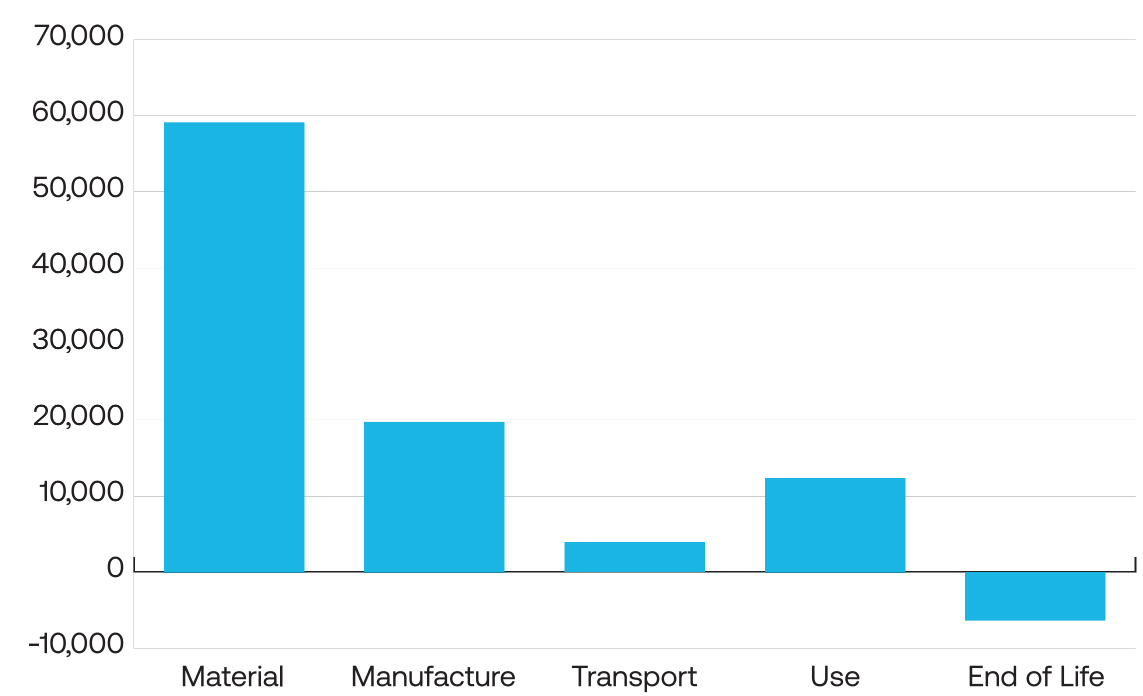


Figure 13: PP energy breakdown (MJ), 300 uses, 18,000 capacity, 300 events

PP 10 Use CO_2 Breakdown (Kg)

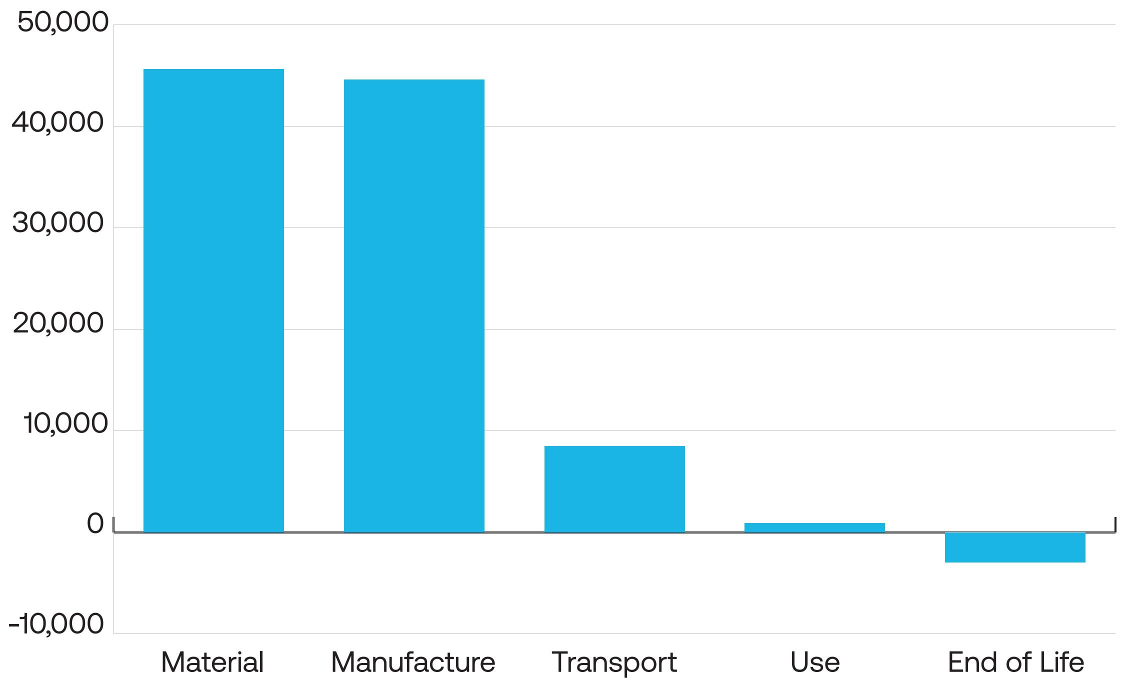


Figure 14: PP CO_2 breakdown (kg), 10 uses, 18,000 capacity, 300 events

PP 300 Use CO_2 Breakdown (Kg)

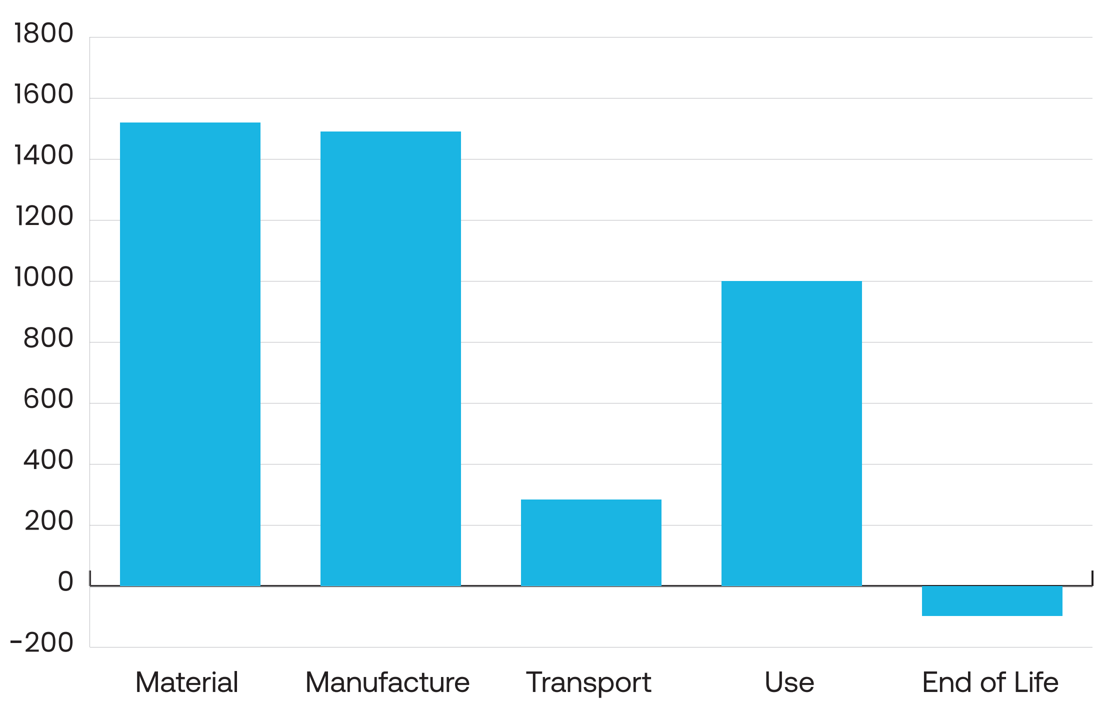


Figure 15: PP CO_2 breakdown (kg), 300 uses, 18,000 capacity, 300 events

Stainless Steel Impact Breakdown

Similar to polypropylene, stainless steel is a reuse scenario, so it carries a use impact due to driving back and forth from the washing facility and the act of washing itself. To show the varying impact of use with reuse number both the 10 use scenario and the 300 use scenario are provided. A similar impact to that of the PP cup is shown, although the high recycling rate of stainless steel leads to a much more significant end of life credit.

SS 10 Use Energy Breakdown (MJ)

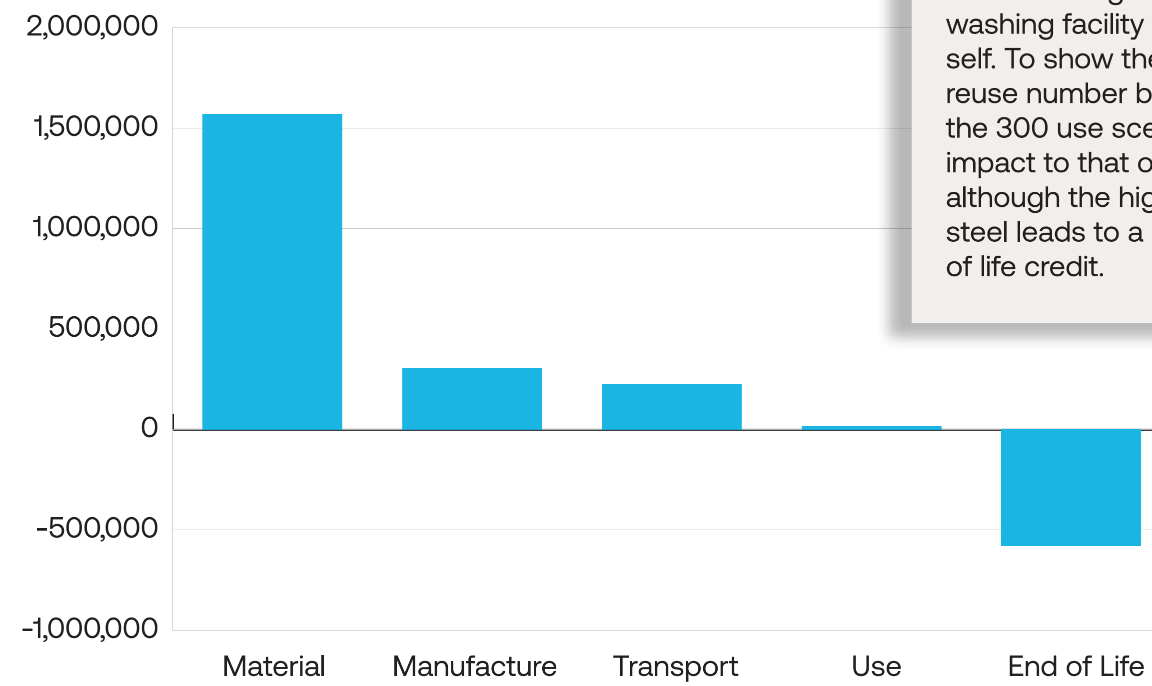


Figure 16: SS energy breakdown (MJ), 10 uses, 18,000 capacity, 300 events

SS 300 Use Energy Breakdown (MJ)

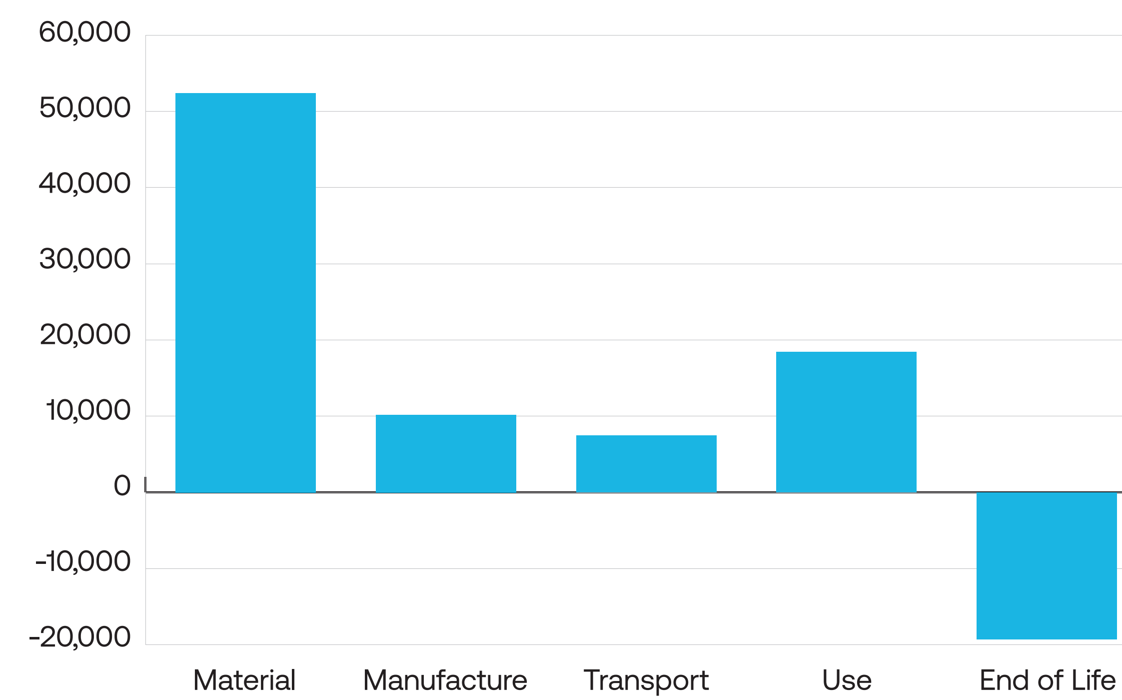


Figure 17: SS energy breakdown (MJ), 300 uses, 18,000 capacity, 300 events

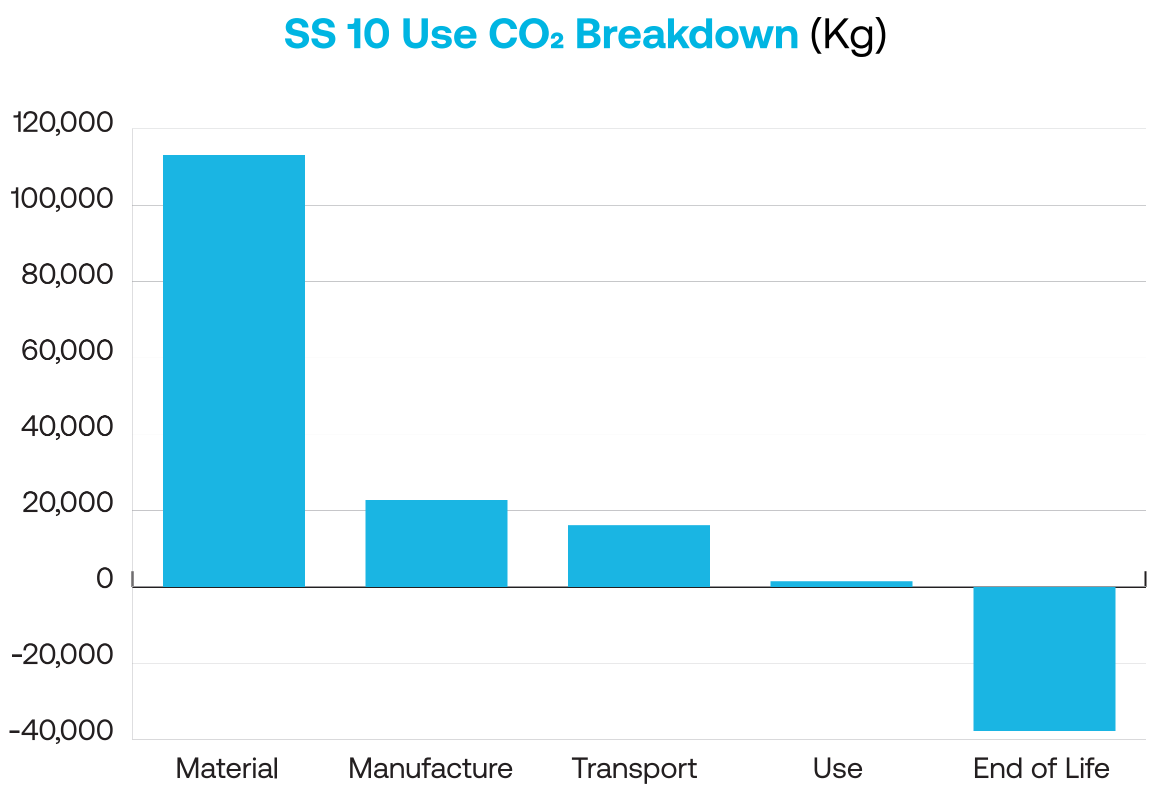


Figure 18: SS CO_2 breakdown (kg), 10 uses, 18,000 capacity, 300 events

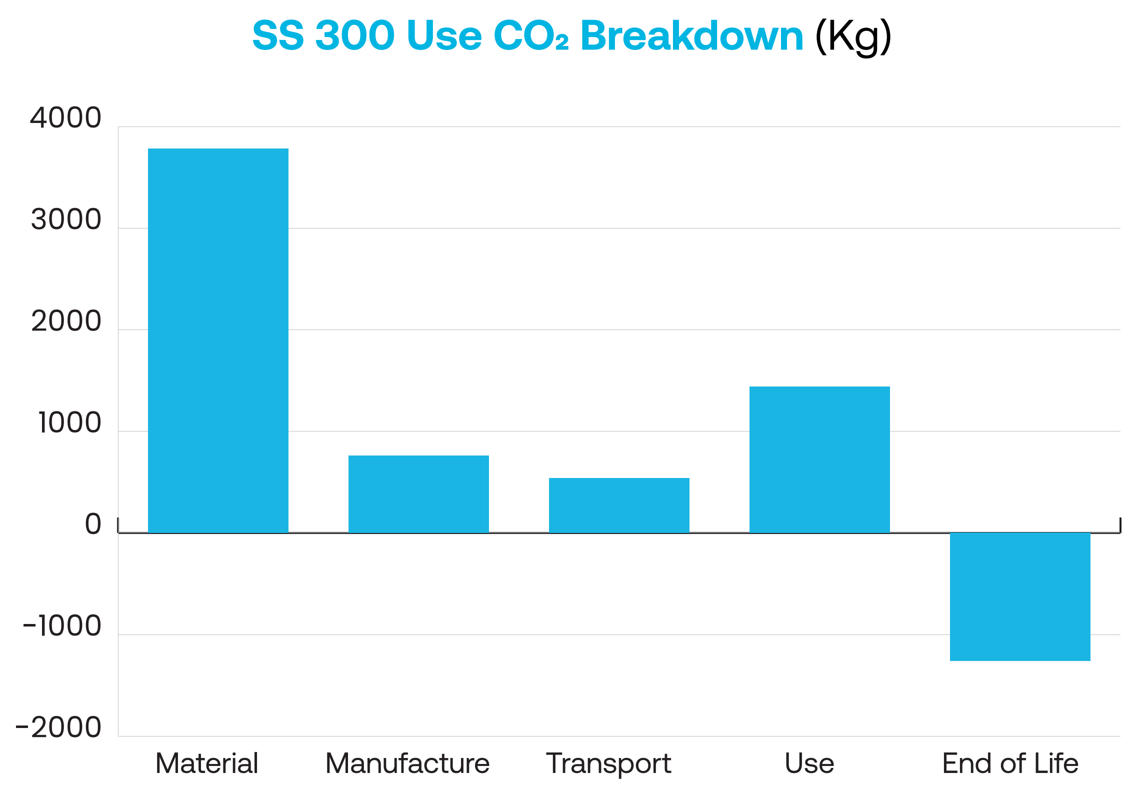


Figure 19: SS CO_2 breakdown (kg), 300 uses, 18,000 capacity, 300 events

LCA Results for Optimal Recycling Scenarios

While the previous analysis looked at the current average state of recycling and use, it is possible to make products with higher levels of recyclable materials and also to enforce a theoretical universal recycling within a venue. The following analysis of three different event scenarios anticipates a "best case" for each material, even if that case is not currently the norm. This also allows a finer distinction to be drawn for a maximum number of reuses necessary to breakeven with single-use cups.

The life-cycle analysis results are presented by use scenario so that comparisons within use scenarios can be made. After those data sets there is an analysis of the relative importance of venue size and number of events on reuse scenarios.

Scenario One Results: 50 sold out events at 8,000 capacity

The figures and table on the following pages provide a comparison of the total energy consumption and total carbon dioxide emissions respective from best case scenario usage and recycling rates for each material. In this analysis, maximum recycling rates are presented for each material. The recycling rates are presented in Table 4, which also provides the data shown graphically in Figs. 1 and 2.

While it is recognized that the 100% recycling rates are unachievably optimistic, they are used in this case because reducing the recycling rates to more typical numbers would not change the relative performance of the materials but would instead create an even larger gap between the cups that are reused and the single-use cups. Therefore, the results presented show the most conservative relationship between the materials.

Scenario One: Total Energy (MJ)

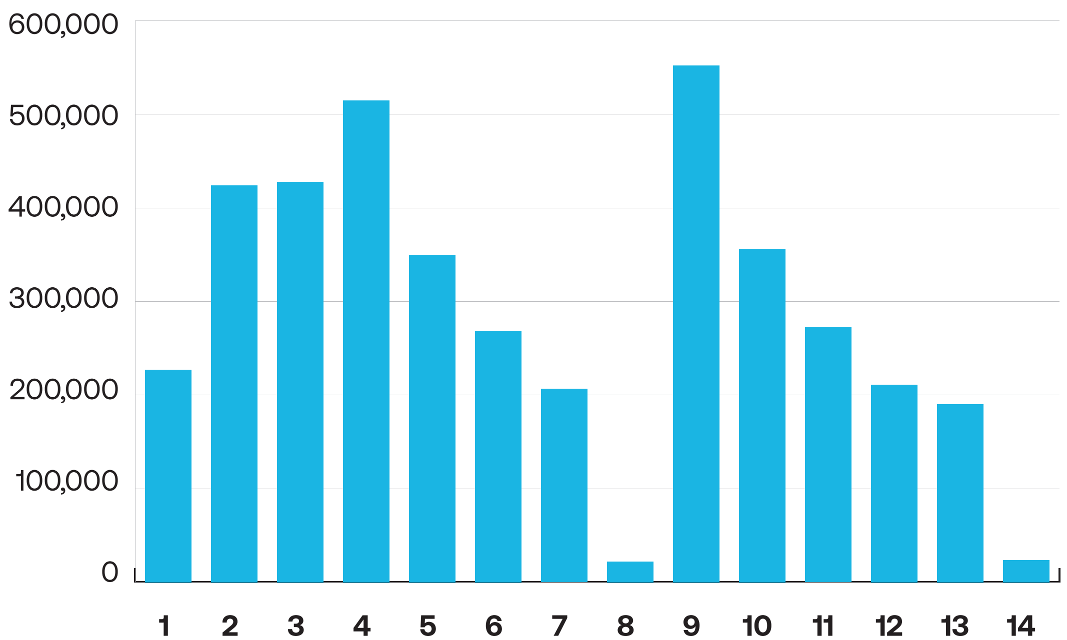


Figure 20: Total energy for 8,000 capacity, 50 events

Scenario One: Total CO_2 (Kg)

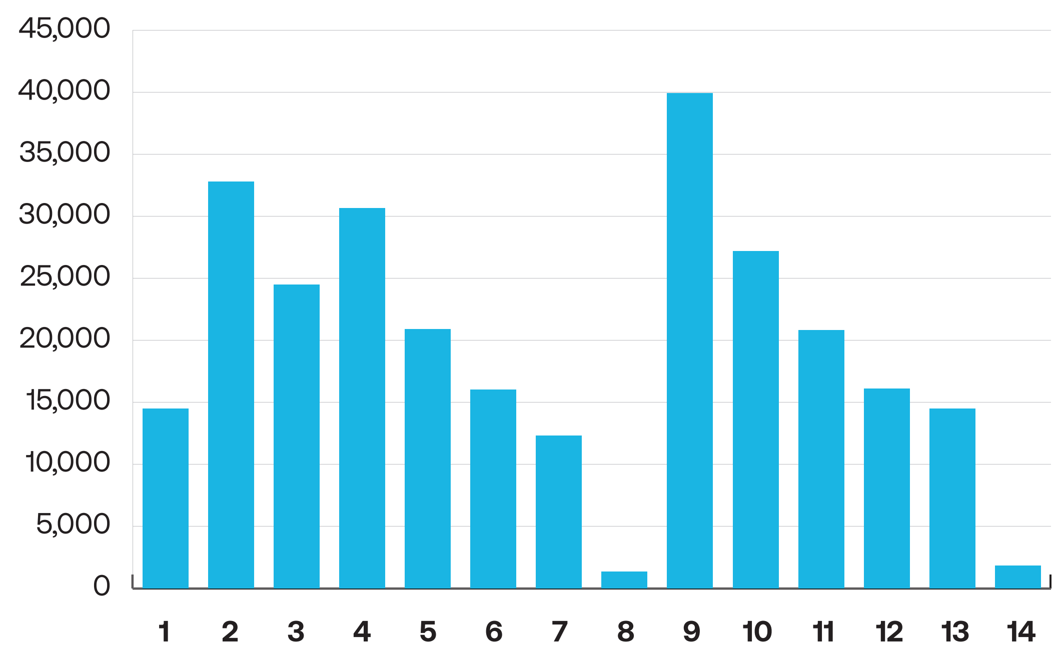


Figure 21: Total CO_2 for 8,000 capacity, 50 events

x-axis key

1	2	3	4	5	6	7	8	9	10	11	12	13	14
PET single-use	Al single-use	PLA single-use	PP 2 uses	PP 3 uses	PP 4 uses	PP 5 uses	PP 50 uses	SS 2 uses	SS 3 uses	SS 4 uses	SS 5 uses	SS 6 uses	SS 50 uses

From Table 4 and Figs. 20 and 21, it can be seen that the lowest energy and global warming impact for this scenario comes from a polypropylene cup that is re-used throughout the total number of events, meaning that there are only 8,000 made and they are washed 49 times. In both the SS and PP analysis the impact of number of reuses shows with the more times the cup is reused the better. Among the single-use cups, the PET cup has the lowest energy and GWP impact. The aluminum and PLA cups have similar energy consumption, but the PLA has a lower carbon dioxide output. There is not a difference within the significance of the data for energy consumed.

SCENARIO ONE BREAKEVEN POINTS

A breakeven analysis was conducted to determine how many uses of the PP and SS cups would be necessary to improve their impact beyond the single-use varieties in Scenario One. In Table 5 on the following page, the breakeven value means that if the reusable cup was used that number or more times then it is preferable to the specified single-use cup.

Material	Quantity	% Recycled Content	% Recycled Post Event	Total Energy (MJ)	Total CO_2 (kg)
PET single-use	400,000	20	100	227,000	14,490
Al single-use	400,000	100	100	424,000	32,800
PLA single-use	400,000	0	0	428,000	24,500
PP 2 uses	200,000	50	100	514,832	30,655
PP 3 uses	136,000	50	100	350,098	20,909
PP 4 uses	104,00	50	100	268,232	16,041
PP 5 uses	80,000	50	100	206,565	12,328
PP 50 uses	8,000	50	100	22,018	1,356
SS 2 uses	200,000	100	100	552,394	39,915
SS 3 uses	136,00	100	100	356,098	27,199
SS 4 uses	104,000	100	100	272,232	20,811
SS 5 uses	80,000	100	100	211,286	16,085
SS 6 uses	72,000	100	100	190,510	14,508
SS 50 uses	8,000	100	100	23,633	1,817

Table 4: Material values for 8,000 capacity, 50 events

Single-use Material	PP energy breakeven uses	PP CO_2 breakeven uses	SS energy breakeven uses	SS CO_2 breakeven uses
PET	5	5	5	6
Aluminum	3	2	3	3
PLA	3	3	3	4

Table 5: Breakeven analysis for Scenario One

Scenario Two Results: 90 sold out events at 18,000 capacity

Like Scenario One, the following figures and table provide a comparison of the total energy consumption and total carbon dioxide emissions respective from best case scenario usage and recycling rates for each material.

In this analysis, maximum recycling rates are presented for each material. The recycling rates are presented in Table 6, which also provides the data shown graphically in Figs. 22 and 23.

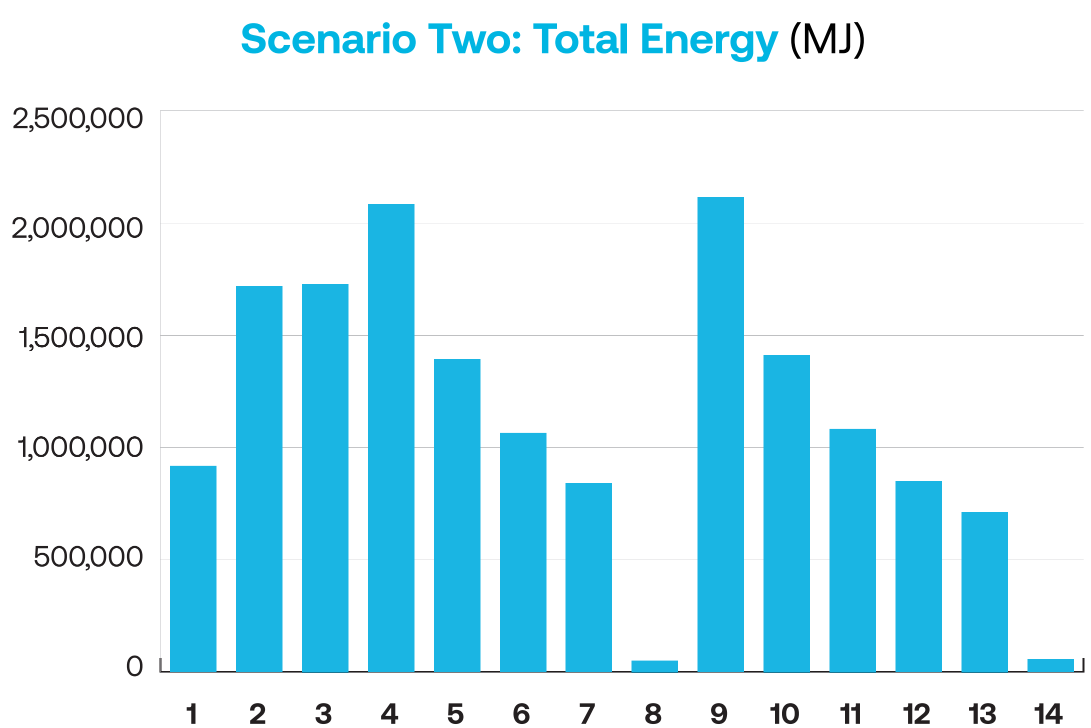


Figure 22: Total energy for 18,000 capacity, 90 events

x-axis key

1	2	3	4	5	6	7	8	9	10	11	12	13	14
PET single-use	Al single-use	PLA single-use	PP 2 uses	PP 3 uses	PP 4 uses	PP 5 uses	PP 90 uses	SS 2 uses	SS 3 uses	SS 4 uses	SS 5 uses	SS 6 uses	SS 90 uses

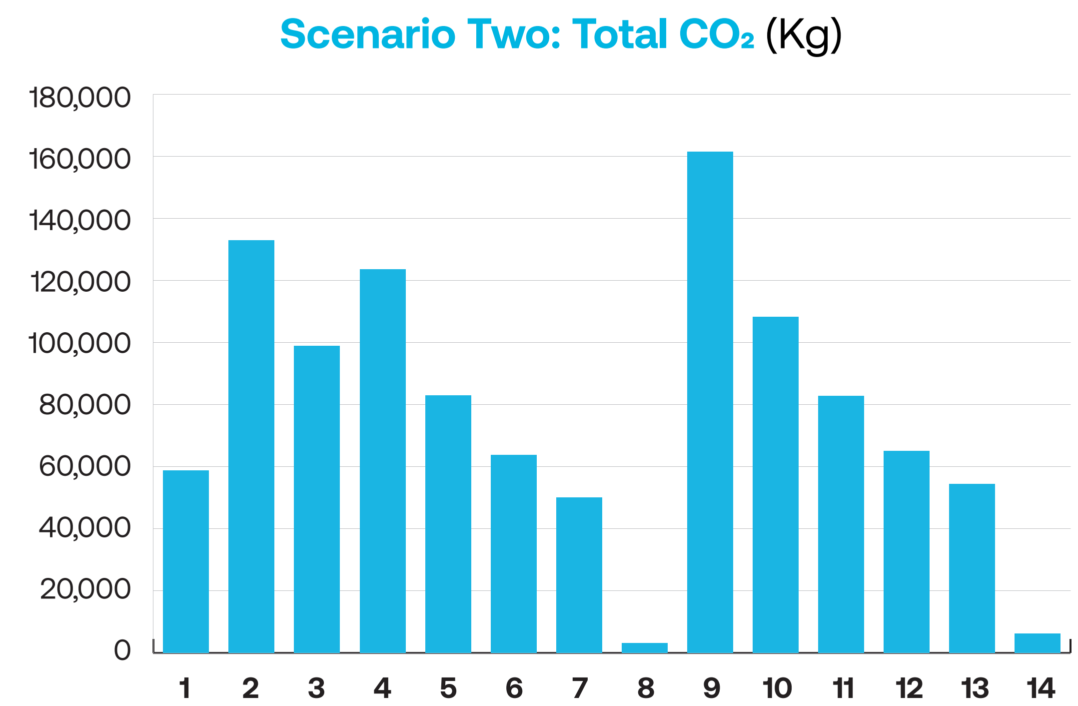


Figure 23: Total CO_2 for 18,000 capacity, 90 events

Material	Quantity	% Recycled Content	% Recycled Post Event	Total Energy (MJ)	Total CO_2 (kg)
PET single-use	1,620,000	20	100	919,000	58,700
Al single-use	1,620,000	100	100	1,720,000	133,000
PLA single-use	1,620,000	0	0	1,730,000	99,000
PP 2 uses	810,000	50	100	2,084,989	123,549
PP 3 uses	540,000	50	100	1,394,979	82,951
PP 4 uses	414,000	50	100	1,065,446	63,709
PP 5 uses	324,000	50	100	51,680	3,196
SS 2 uses	810,000	100	100	2,115,265	161,413
SS 3 uses	540,000	100	100	1,413,979	108,331
SS 4 uses	414,000	100	100	1,084,446	82,869
SS 5 uses	324,000	100	100	849,969	65,011
SS 6 uses	270,000	100	100	712,763	54,485
SS 50 uses	18,000	100	100	57,305	6,171

Table 6: Material values for 18,000 capacity, 90 events

From Table 6 and Figs. 22 and 23, it can be seen that the lowest energy and global warming impact for this scenario comes from a polypropylene cup that is re-used throughout the year, meaning that there are only 18,000 made, and they are washed 89 times. The remaining results are consistent with the results from Scenario One, with only the magnitude of energy and GWP going up along with the additional number of cups being used.

SCENARIO TWO BREAKEVEN POINTS

A breakeven analysis was conducted to determine how many uses of the PP and SS cups would be necessary to improve their impact beyond the single-use varieties in Scenario Two. In Table 7 below, the breakeven value means that if the reusable cup was used that number or more times then it is preferable to the specified single-use cup.

Single-use Material	PP energy breakeven uses	PP CO_2 breakeven uses	SS energy breakeven uses	SS CO_2 breakeven uses
PET	5	5	5	6
Aluminum	3	2	3	3
PLA	3	3	3	4

Table 7: Breakeven analysis for Scenario Two

Scenario Three Results: 12 sold out events at 60,000 capacity

Like Scenarios One and Two, the following figures and table provide a comparison of the total energy consumption and total carbon dioxide emissions respective from best case scenario usage and recycling rates for each material.

In this analysis, maximum recycling rates are presented for each material. The recycling rates are presented in Table 8, which also provides the data shown graphically in Figs. 24 and 25.

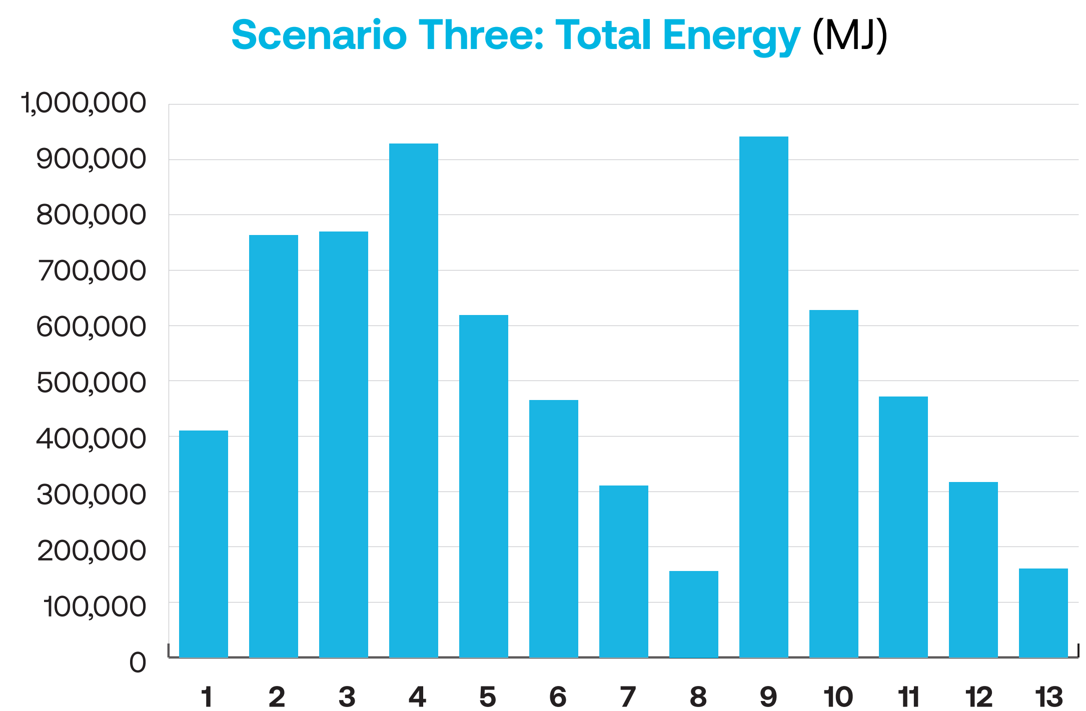


Figure 24: Total energy for 60,000 capacity, 12 events

x-axis key

1	2	3	4	5	6	7	8	9	10	11	12	13
PET single-use	Al single-use	PLA single-use	PP 2 uses	PP 3 uses	PP 4 uses	PP 6 uses	PP 12 uses	SS 2 uses	SS 3 uses	SS 4 uses	SS 6 uses	SS 12 uses

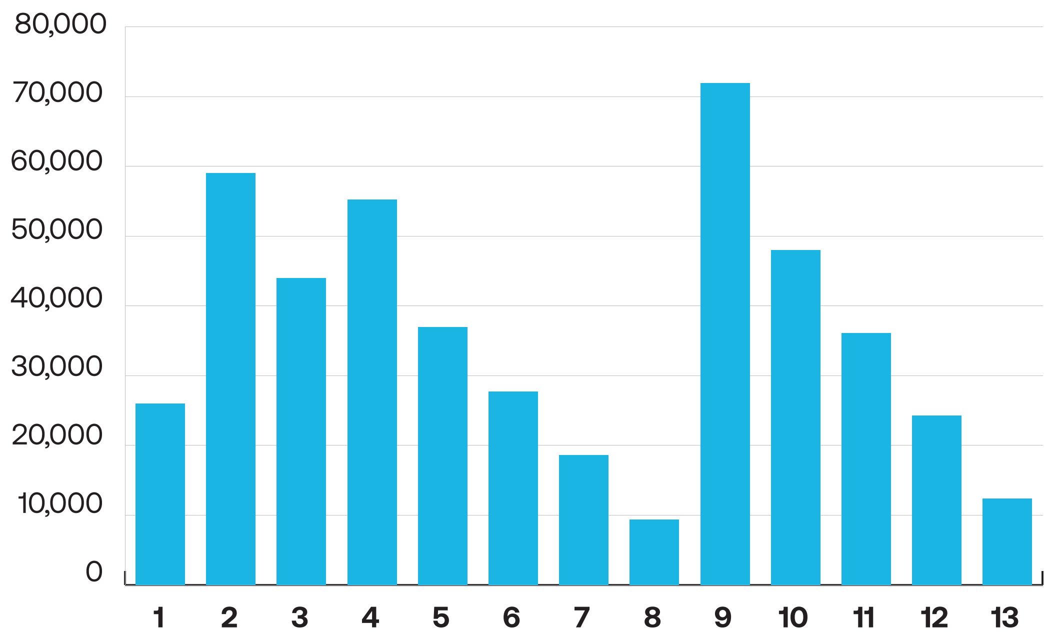


Figure 25: Total CO_2 for 60,000 capacity, 12 events
Refer to x-axis key on page 31

Material	Quantity	% Recycled Content	% Recycled Post Event	Total Energy (MJ)	Total CO_2 (kg)
PET single-use	720,000	20	100	410,000	26,010
Al single-use	720,000	100	100	763,000	59,000
PLA single-use	720,000	0	0	770,000	44,000
PP 2 uses	360,000	50	100	928,498	55,245
PP 3 uses	240,000	50	100	618,998	36,920
PP 4 uses	180,000	50	100	465,248	27,712
PP 6 uses	120,000	50	100	310,497	18,595
PP 12 uses	60,000	50	100	156,397	9,360
SS 2 uses	360,000	100	100	941,510	71,908
SS 3 uses	240,000	100	100	627,998	47,980
SS 4 uses	180,000	100	100	471,248	36,102
SS 6 uses	120,000	100	100	317,183	24,247
SS 12 uses	60,000	100	100	160,183	12,347

Table 8: Material values for 60,000 capacity, 12 events

Scenario Three results are consistent with the results from the first two scenarios, with only the magnitude of energy and GWP going up along with the additional number of cups being used.

SCENARIO THREE BREAKEVEN POINTS

A breakeven analysis was conducted to determine how many uses of the PP and SS cups would be necessary to improve their impact beyond the single-use varieties in Scenario Three.

In Table 9 below, the breakeven value means that if the reusable cup was used that number or more times then it is preferable to the specified single-use cup.

Single-use Material	PP energy breakeven uses	PP CO_2 breakeven uses	SS energy breakeven uses	SS CO_2 breakeven uses
PET	6	6	6	6
Aluminum	3	2	3	3
PLA	3	3	3	4

Table 9: Breakeven analysis for Scenario Two

Impact of Venue Size and Number of Events

To determine the relative influence of venue size and the number of events on the environmental footprint a comparison study was conducted. Three scenarios were compared in terms of energy consumption for four materials: PET, Al using 100% recycled content, PP used 6 times, and SS used 6 times.

By comparing the impacts from each scenario, it can be shown which has the greater environmental impact from cups, larger capacity venues or more events. The scenarios are outlined in Table 10, and results shown in Fig. 26.

From Fig. 26 there is a larger increase in energy consumption when comparing Scenario 1A to 1C than when comparing 1A to 1B. Since 1A and 1B share the same capacity but increase number of events and 1A and 1C share the same number of events but increase capacity, the larger impact is shown to be an increase of venue capacity.

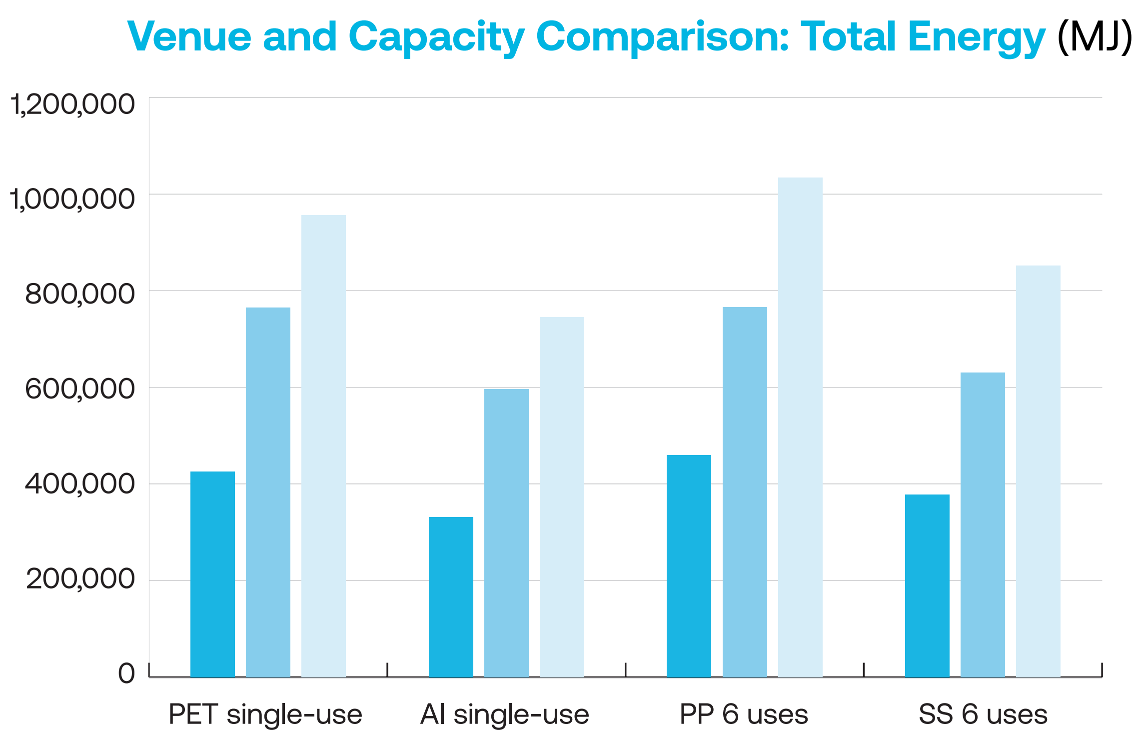


Figure 26: Total energy for venue and capacity comparison

Scenario	Capacity	Events
1A	8000	50
1B	8000	90
1C	18,000	50

Table 10: Scenario definitions

Material Recycling Sensitivity Analysis

The data and conclusions presented in the previous section was done so for a "best case" recycled material content. A best case of 100% recycled content or 100% post-use recycling is not realistic in most scenarios, with overall recycling rates in the United States ranging from 2% to 72% depending on the state and a number of factors, according to a recent report by Eunomia and Ball Corporation (*The 50 States of Recycling*, March 2021).

As mentioned in the earlier section, the "best case" was used because it provides be best possible scenario for single-use cups and if reusable cups are already an improvement over the best recycling case of all single-use cups then decreasing the recycling rates to lower values will just make that improvement more significant.

The following analysis provides the impact of using recycled materials in the cups at different rates and shows how that drives energy consumption and GWP. Values provided are for 1000 cups to provide a round number for easy extrapolation to additional comparisons as desired. Transportation of the new cups is not included in the comparisons because all recycled content varieties of the same material will have the same mass and distance transported.

For each material two tables are presented. The first table shows only the impact of recycled content on energy use and GWP. The second table also provides End of Life Potential (EoLP); this is a value that the recycling of an item after use is assumed to reduce future environmental impact because it reduces future need for virgin material. However, it is dependent on the recycling infrastructure to bring to fruition. The EoLP is analyzed for a 0% recycled content because appropriate calculation of actual impact cannot account for energy and CO_2 savings in both using recycled materials and also in the elimination of future materials – because those future materials are already accounted for by recycled material usage.

PLA is not analyzed in this section as it is designed for industrial composting rather than direct recycling. Industrial composting rates are extremely low with only 2% of composting sites taking mixed organic foodware (Institute for Local Self-Reliance, 2014).

PET

In Table 11, the sensitivity of using 0% or 15% of recycled content is provided. Table 6 provides end of life potential reductions as associated with recycling rates of 0%, 50%, and 100%.

Recycled Content	Energy (MJ)	CO_2 (kg)
0%	1,100	45
15%	1,010	43

Table 11: PET recycled content sensitivity, 1,000 cups

Recycling Rate	Initial Energy (MJ)	EoLP Energy (MJ)	Sum Energy (MJ)	Initial CO_2 (kg)	EoLP CO_2 (kg)	Sum CO_2 (kg)
0%	1,100	0	1,100	45	0	45
50%	1,100	-290	810	45	-6	39
100%	1,100	-579	521	45	-13	33

Table 12: PET recycling rate sensitivity, 1,000 cups, 0% recycled content

Aluminum

In Table 13, the sensitivity of using 0%, 50% or 100% of recycled content is provided. Table 14 provides end of life potential reductions as associated with recycling rates of 0%, 50%, and 100%. Aluminum shows the largest sensitivity to recycling as making cups with 100% recycled aluminum uses only 20% the amount of energy and 24% the CO_2 emissions as making them from virgin aluminum.

Recycled Content	Energy (MJ)	CO_2 (kg)
0%	4,350	290
50%	2,620	180
100%	893	70

Table 13: Aluminum recycled content sensitivity, 1,000 cups

Recycling Rate	Initial Energy (MJ)	EoLP Energy (MJ)	Sum Energy (MJ)	Initial CO_2 (kg)	EoLP CO_2 (kg)	Sum CO_2 (kg)
0%	4,350	0	4,350	290	0	290
50%	4,350	-1,730	2,620	290	-110	180
100%	4,350	-3,450	910	290	-220	71

Table 14: Aluminum recycling rate sensitivity, 1,000 cups, 0% recycled content

Polypropylene

In Table 15, the sensitivity of using 0% or 50% of recycled content is provided. 50% is the upper end of what is practice for using recycled PP in new PP products. Table 16 provides end of life potential reductions as associated with recycling rates of 0%, 50%, and 100%.

Recycled Content	Energy (MJ)	CO_2 (kg)
0%	4,400	168
50%	3,360	152

Table 15: Polypropylene recycled content sensitivity, 1,000 cups

Recycling Rate	Initial Energy (MJ)	EoLP Energy (MJ)	Sum Energy (MJ)	Initial CO_2 (kg)	EoLP CO_2 (kg)	Sum CO_2 (kg)
0%	4,400	0	4,400	168	0	290
50%	4,400	-1,040	3,360	168	-16	152
100%	4,400	-2,070	2,330	168	-32	136

Table 16: Polypropylene recycling rate sensitivity, 1,000 cups, 0% recycled content

Stainless Steel (AISI 304)

In Table 17, the sensitivity of using 0%, 50% or 100% of recycled content is provided for stainless steel 304. Table 18 provides end of life potential reductions as associated with recycling rates of 0%, 50%, and 100%.

Recycled Content	Energy (MJ)	CO_2 (kg)
0%	6,640	456
50%	4,320	306
100%	2,010	155

Table 17: Stainless steel recycled content sensitivity, 1,000 cups

Recycling Rate	Initial Energy (MJ)	EoLP Energy (MJ)	Sum Energy (MJ)	Initial CO_2 (kg)	EoLP CO_2 (kg)	Sum CO_2 (kg)
0%	6,640	0	6,640	456	0	456
50%	6,640	-2,320	4,320	456	-151	305
100%	6,640	-4,630	2,010	456	-301	155

Table 18: Stainless steel recycling rate sensitivity, 1,000 cups, 0% recycled content

Software Data Verification

The data that has been presented for Scenarios 1, 2 and 3 is from GRANTA EduPack using their Sustainability Level 3 Eco Audit. All uses of software packages for LCA come with the accompanying assumptions that the values used to create the software databases are similar to those values being used within the specific product manufacture, transportation and use that are being analyzed. This use of general data for specific cases always provides a margin of error within the results that should be recognized. In the case of this analysis a margin of error of 20% is suggested as reasonable.

To provide more confidence in the data and conclusions, the analysis was independently conducted on another LCA software package, Solidworks Sustainability Module. The Solidworks module lacks some of the sensitivity of the GRANTA EduPack software so it is not appropriate to expect exact match up of results. However, since the object of this research work it to determine relative environmental impact, seeing the same ordering of materials in terms of energy consumption and GWP provides a level of confidence in the results.

To provide an example of the comparison, the energy and GWP of a single cup is presented. As might be expected, the environmental impact of the cups designed for reuse is larger than a single-use cup due to the extra material and processing necessary to produce it.

Table 19 provides the comparisons of the two software packages for individual cups, independent of use scenarios, and Figs. 27 and 28 show the same material graphically. PLA is not present in the analysis because it is not covered in the Solidworks material database.

There is generally very good agreement both in magnitude of energy consumption and GWP and in the order in which the impact is seen. This provides verification of the data provided in the first part of the report.

	Energy (MJ)			Carbon Footprint (kg CO_2)		
	Solidworks	Granta Edupack	Error %	Solidworks	Granta Edupack	Error %
PET	1.91	2.06	6.96%	.10	0..09	8.2%
Al	3.90	4.19	6.92%	.32	0.33	1.85%
PP	5.00	4.62	7.6%	0.23	0.18	19.65%
SS	5.10	6.19	17.61%	0.47	0.43	8.69%

Table 19: Software comparison

Individual Cup Energy Comparison by Software (MJ)

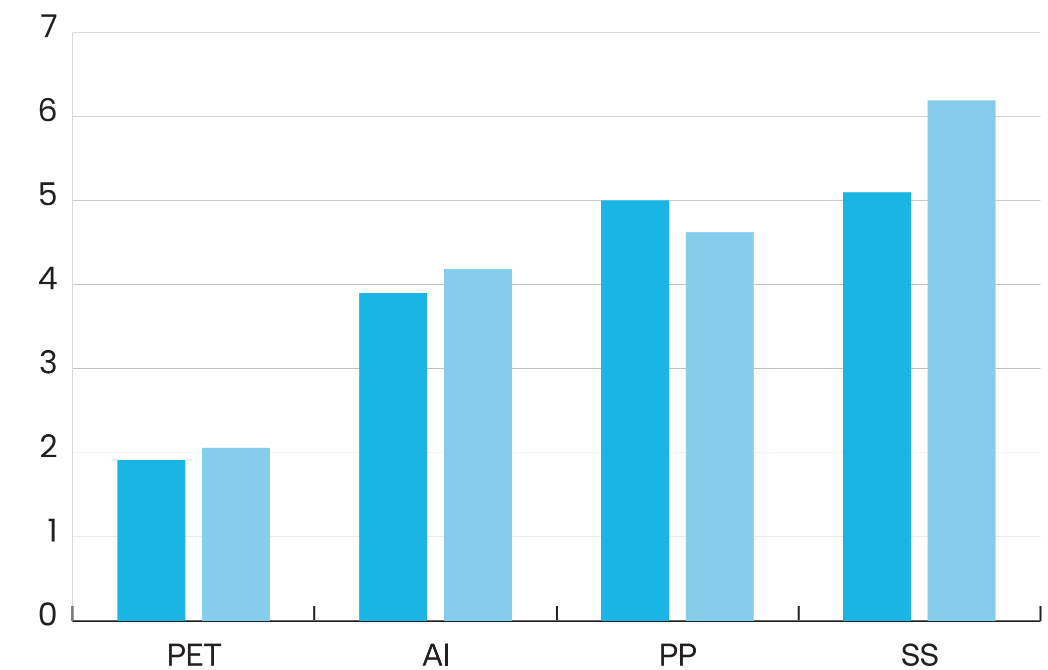


Figure 27: Comparison of software for individual cup total energy (MJ)

Solidworks EduPack

Individual Cup CO_2 Comparison by Software (Kg)

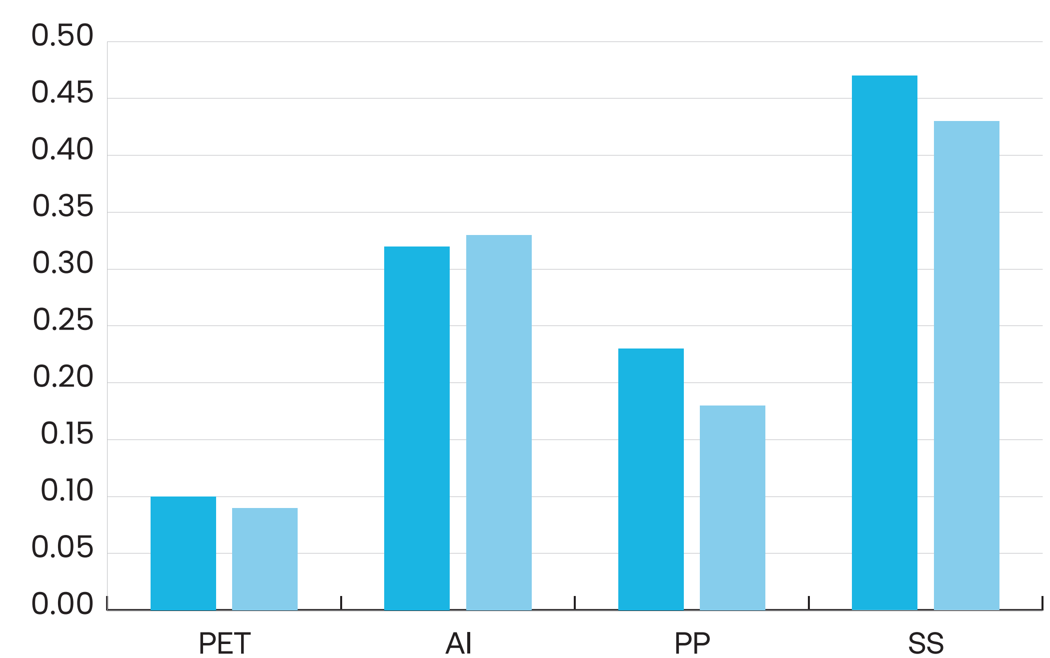


Figure 28: Comparison of software for individual cup total energy (MJ)

Conclusions

The materials, manufacture, transport and use phases of 16 oz beverage cups made from PET, Aluminum 3004, PLA, PP, and Stainless Steel 304 were analyzed for energy consumption, carbon dioxide emissions, air acidification, water eutrophication and landfill impact. The reuse of PP and SS were compared with single-uses of the other materials to determine breakeven points based on number of reuses. Additionally, recycling rate sensitivity and multiple software data verification were conducted.

The primary conclusions include:

- In all use scenarios a PP cup has the lowest impact compared to single-use cups if it can be used at least six times in optimal recycling and five times at current rates.
- In all use scenarios a SS cup has a lower impact compared to single-use cups if used at least six times in optimal recycling and five times at current rates.
- At current recycling rates, among single-use cups PET had the lowest energy consumption and GWP, followed closely by PLA. Aluminum single-use cups used 47% more energy over their life-cycle and created 86% more CO_2 than PET and PLA options.
- The use category, transportation and washing, for the reusable cups had a minor impact for all use cases except maximum uses of PP and SS cups.

Cited References

2018 United States National Postconsumer Plastic Bottle Recycling Report, The Association of Plastic Recyclers, American Chemistry Council, 2019.

Report on Postconsumer PET Container Recycling Activity in 2017, NAPCOR, The Association of Plastic Recyclers, 2018.

Beverage Packaging, A Comparative Life-cycle Assessment, Sphera, Ball Corporation, 2020.

The Aluminum Can Advantage: Sustainability Key Performance Indicators, The Aluminum Association, Can Manufacturers Institute, 2020.

The Global Life-cycle of Stainless Steels, Team Stainless, 2016.

State of Composting in the US: What, Why, Where & How, Institute for Local Self-Reliance, 2014.

50 States of Recycling, Eunomia, Ball Corporation, 2021.

Upstream