A Comparative Life Cycle Assessment of Compostable and Reusable Takeout Clamshells at the University of California, Berkeley

Monica F. Harnoto

ABSTRACT

Compostable and reusable products create environmental footprints in different impact categories. While both products theoretically reduce waste, their disparate life cycles incur different trade-offs. Consequently, it is often difficult to directly evaluate these products and select the most sustainable option. One example of this situation is compostable and reusable takeout clamshells. My research question attempts to discover which type of container, compostable bagasse or reusable polypropylene, is more sustainable for Cal Dining at the University of California, Berkeley. To evaluate sustainability, I looked at four impact categories: greenhouse gas contribution, energy consumption, material waste, and water consumption. My results showed that reusable containers require 15 uses to equal the greenhouse gas contribution, energy consumption, and material waste impact of the equivalent number of compostable clamshells. However, the water consumption for reusable clamshells remained greater than the compostable clamshells in all situations. I concluded that Cal Dining should use reusable clamshells over compostable clamshells.

KEYWORDS

Cal Dining, sustainability, bagasse containers, polypropylene containers, to-go

INTRODUCTION

The United States generates more garbage than any other nation in the world (Hoornweg and Bhada-Tata 2012). In 2010, the U.S. produced 230 million Mg of municipal solid waste (MSW), amounting to a national waste production average of 2.01 kg/person/day (EPA 2011). This daily per capita rate is nearly 70% more than the international average of 1.2 kg/person/day (Hoornweg and Bhada-Tata 2012). Moreover, trends suggest that the U.S. will produce more garbage in the future given a growing population (U.S. Census Bureau 2012) and increasing per capita waste generation (Hoornweg and Bhada-Tata 2012). Without creative solutions to reduce garbage production, the issues already present in America's waste disposal system will undoubtedly worsen.

Effective solutions will have to cope with the heterogeneous nature of waste. With a cumulative mass of 28 million Mg, plastic accounts for 12.4% of MSW (EPA 2011). The "plastic" category encompasses different types and sources of plastic (EPA 2011). Items such as polyethylene grocery bags find themselves classified along with polyethylene terephthalate water bottles. Because these plastics originate from a variety of sources, it seems impractical to expect a single solution for global plastic waste production. Instead, effective waste reduction initiatives must begin on a more local level.

The University of California, Berkeley is one of the many institutions committed to improving the environmental impact of its waste stream at the local level. In 2009, the Office of the President set a campus-wide goal to achieve zero waste by 2020 (Birgeneau 2009). Since then, U.C. Berkeley faculty, staff, and students have collaborated on countless initiatives to reach this milestone. One of the most recent efforts involved a reassessment of takeout options at Cal Dining, the campus's main foodservice provider.

Cal Dining began exploring alternatives to conventional takeout clamshells in response to growing consumer demand (Cal Dining 2012a). In 2005, Cal Dining replaced their Styrofoam (polystyrene) containers with clamshells made from bagasse, the fibrous plant material leftover from sugarcane production (Cal Dining 2012a). Currently, Cal Dining uses 3-compartment compostable clamshells from IFN Green (Chacko 2012, Table 1). Compostable clamshells maintain the convenience of single-use packaging, while also allowing for responsible disposal. All clamshells, regardless of composition, follow a similar life cycle: procurement of raw materials, refining of media and production of containers, distribution, consumption, and disposal (Madival et. al 2009). The main difference between compostable and Styrofoam clamshell life cycles occurs at the disposal phase. Compostable containers have the ability to degrade into fertilizer that can grow additional plants. In contrast, Styrofoam clamshells have no significant means for repurposing and most end their lives in a landfill. The lack of a closed-loop cycle for single-use Styrofoam clamshells makes this process inherently unsustainable.

In Fall 2012, I proposed a reusable takeout clamshell pilot program as an alternative to the single-use compostable clamshell program for Cal Dining. “Chews to Reuse” ran from 20 August 2012 to 14 December 2012 in Foothill dining commons. The pilot program used G.E.T. Enterprises’ 100% polypropylene clamshells (Table 2). Customers paid 3 meal points (~$3), received a clamshell, and took their meal to-go. Once they decided to take their next to-go meal, they brought their containers back, deposited it in the designated bin, and received a sanitized container in return. Cal Dining staff periodically wheeled soiled clamshells into the dish room to run through the dishwasher and air dry on a rack. Once they dried, they were restocked by the cash register and the cycle continued.

Table 1. Compostable clamshell profile. Characteristics of IFN Green’s compostable takeout clamshell listed below. Full volume refers to the approximate volume when it reaches the consumer, and flattened volume refers to the approximate volume once the clamshell has been crushed.

Parameter	Dimension
Material	bagasse
Dimensions	0.229 m x 0.229 m x 0.0762 m
Full volume	0.00398 m^3
Flattened volume	0.000664 m^3
Mass	0.0434 kg

Table 2. Reusable clamshell profile. Characteristics of G.E.T. Enterprises reusable takeout clamshell listed below.

Parameter	Dimension
Material	polypropylene

Dimensions	0.229 m x 0.229 m x 0.0889 m
Full volume	0.00465 m^3
Mass	0.263 kg

Reusable clamshells have the potential to minimize the environmental impact of clamshell manufacturing, since Cal Dining would need a smaller number of clamshells for the same utility as a single-use option. While it is possible to recycle plastics, the type and quality of plastic changes each time it is recycled (Wansbrough 2008). Consequently, recycled plastic cannot be used to create another reusable container (Wansbrough 2008). Despite these trade-offs, both reusable and compostable containers appear to be more sustainable than single-use Styrofoam containers. But, when compared to each other, the decision is not obvious. Compostable and reusable clamshells both have ecological advantages and disadvantages in different impact categories, and with different magnitudes. Currently, there have been no studies looking at the comparative environmental impacts of compostable and reusable takeout clamshells. Without this information, both suppliers and consumers may find it difficult to ensure the sustainability of their food packaging.

GOAL AND SCOPE DEFINITION

Goal of analysis

Given the multifaceted nature of the environmental impacts of compostable and reusable clamshells, the goal of my research is to answer the question: Is a reusable takeout clamshell program more sustainable than a compostable takeout clamshell program for Cal Dining? I will assess environmental impacts through four categories: (1) greenhouse gas contribution, (2) energy consumption, (3) solid waste, and (4) water consumption.

Scope of analysis

The steps that define the compostable takeout clamshell life cycle include: (1) the sugarcane growth process, (2) transportation to processing mill, (3) fiberboard manufacturing,

(4) fiberboard molding, (5) transportation to Cal Dining, (6) transportation to landfill or compost, and (7) landfill or compost process. The steps that define the reusable takeout clamshell life cycle include: (1) polypropylene production, (2) plastic injection molding, (3) transportation to Cal Dining, (4) dishwashing at Cal Dining, (5) transportation to landfill or recycling, and (6) landfill or recycling process.

METHODS

I used Life Cycle Assessment (LCA) methodology to quantitatively compare the environmental impact of compostable and reusable takeout clamshells. LCA is a “cradle to grave” approach for assessing the ecological impacts of a product (Scientific Applications International Corporation 2006). The LCA methodology consists of the following four parts:

1. *Goal Definition and Scoping*: Define and describe the product and the context in which the assessment is to be made. Identify boundaries and environmental effects under review.
2. *Inventory Analysis*: Quantify energy, water and materials usage, and environmental releases.
3. *Impact Assessment*: Evaluate the potential human and ecological effects of the previously quantified factors.
4. *Interpretation*: Use these results to select the preferred product with a clear understanding of the limitations of this methodology (Scientific Applications International Corporation 2006).

Life cycle assessment software

I used GaBi 6 software, produced by PE International. GaBi is a LCA software that allows its users to connect environmental impacts to a product across its lifespan. GaBi includes its own database containing life cycle inventories of processes such as polypropylene manufacturing, transportation, and landfill disposal. The software also allows manual input of coefficients in order to customize outputs to reflect case-specific measurements.

Life cycle definition

In order to evaluate the environmental impact of reusable and compostable takeout clamshells, I divided the life cycle of each container into four phases and defined parameters for each phase. The phases include: raw materials acquisition, manufacturing, consumption, and end-of-life management. Transportation is included in the process that precedes it. For example, "raw materials extraction" includes the environmental impact of ocean freight transportation from the sugarcane plantation in Thailand to the processing mill in China. Through each subsection below, I outline the trajectory of both clamshells. Figure 1 and 2 give a concise overview of the life cycle, inputs, and locations of both containers, and Appendix A provides a summary of the GaBi 6 parameter adjustments made in the two models. I did not include packaging in this life cycle assessment. Finally, I described the functional unit of my study and discussed the scenarios I used to analyze my data.

Compostable takeout clamshells

Raw materials acquisition. The compostable takeout clamshells began their lives as sugarcane plants in Thailand. Sugarcane is a perennial grass that can grow in varying climates (Marsolek 2003) and has a rotation length of 12-18 months in tropical and sub-tropical regions (Liu and Bull 2001). The crop yield of sugarcane plants is approximately 66,000 kg cane/hectare·year (Beeharry 2001). Bagasse accounts for roughly 30% of the sugarcane plant (Marsolek 2003). Raw bagasse consists of 49% moisture, 49% cellulose, pentosan, and lignin fibers, and 2% soluble solids (Chiparus 2004). After harvesting, the sugarcane underwent mechanical processing to extract the sugar and molasses fractions, and then the remaining bagasse was shipped 3,500 km via ocean freight to a processing mill in China (Jost 2013).

Manufacturing. Once the bagasse reached China, the processing mill extracted the remaining moisture and pressed the dried bagasse into fiberboard sheets (Marsolek 2003). I operated under the assumption that the loss of material from raw bagasse to fiberboard sheets was immaterial (Marsolek 2003). After packaging, the manufacturer loaded the compostable clamshells onto a truck and drove them 499 km to the Yantian port where they were then shipped 11,100 km in an ocean freight to the Port of Oakland (Jost 2013). From the Port of Oakland, the compostable clamshells were driven an additional 11.3 km to San Leandro, CA and then 24.1 km to Clark Kerr Campus dining commons in Berkeley, CA (Jost 2013).

Consumption. I used Clark Kerr Campus (CKC) dining commons as my study site to analyze information on the consumption phase of compostable takeout clamshells. CKC dining commons served as the main eatery for the 922 students living in CKC residential halls. Its relatively isolated location near Piedmont Avenue and Dwight Way allowed me to assume that the majority of diners at CKC dining commons were also residents of CKC residential halls. In order to approximate composting rates for the compostable takeout clamshells, I surveyed 1,340 L of compost and 2,038 L of trash over the course of four days to find a compostable clamshell per liter of compost or landfill ratio. For each bin I sorted through, I recorded the date, volume, and number of containers I found. I used this compostable clamshell/volume ratio to determine the overall percentages of compostable clamshells ending in the compost and landfill. Once consumers disposed of their compostable clamshells, they traveled by truck to one of two Recology Inc. composting facilities: 86 km to Jepson Prairie Organics or 119 km to Grover Environmental Products (King 2012). Since the compost went to both facilities, I used an average of 103 km as my travel distance.

End-of-life management. Compostable clamshells that end in the compost underwent processes that accelerated decomposition. These processes used energy expending machinery and water (Lundie and Peters 2005). I bounded my study with the formation of the fertilizer that resulted from the compost process. Compostable clamshells that ended in the landfill degraded at a significantly slower rate without the moisture and heat. I calculated material waste based on the volume of clamshells reaching the landfill. Because the compostable clamshells were pliable, I used an average of the flattened clamshell and fully intact clamshell to calculate total material waste volume.

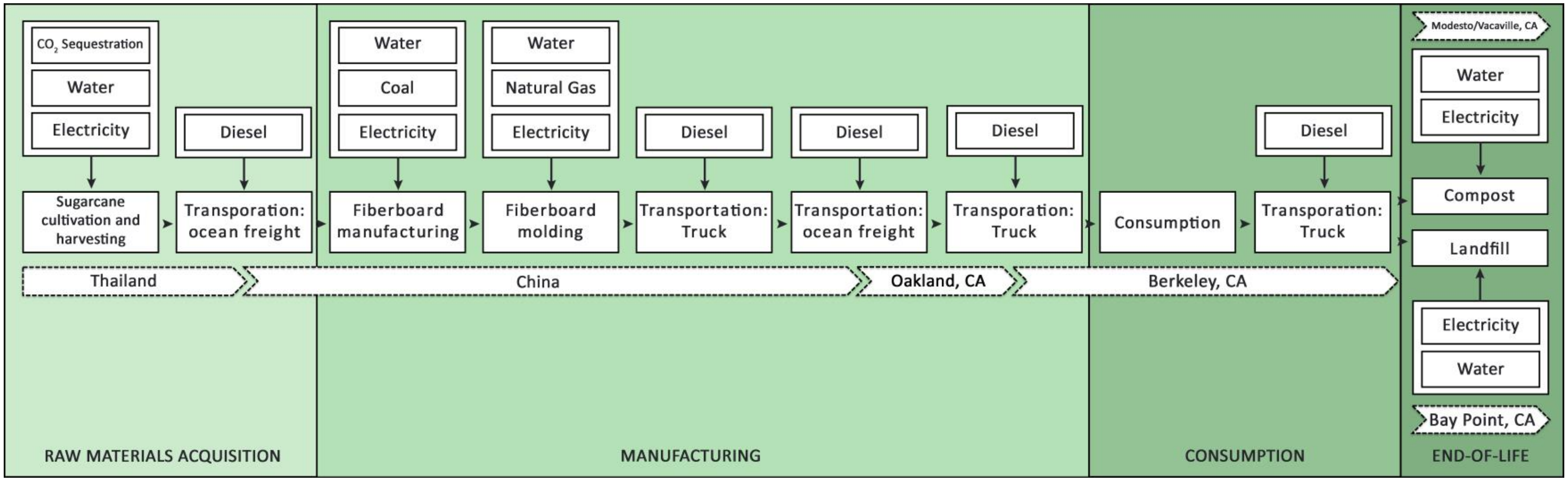

Figure 1. Compostable clamshell life cycle definition. The center progression charts the flow of bagasse from initial cultivation to end-of-life management. The boxes above show all inputs accounted for in this study. The dashed arrows below chart the changes in location throughout the clamshell's life cycle. The larger green boxes group processes within each of the four broader categories.

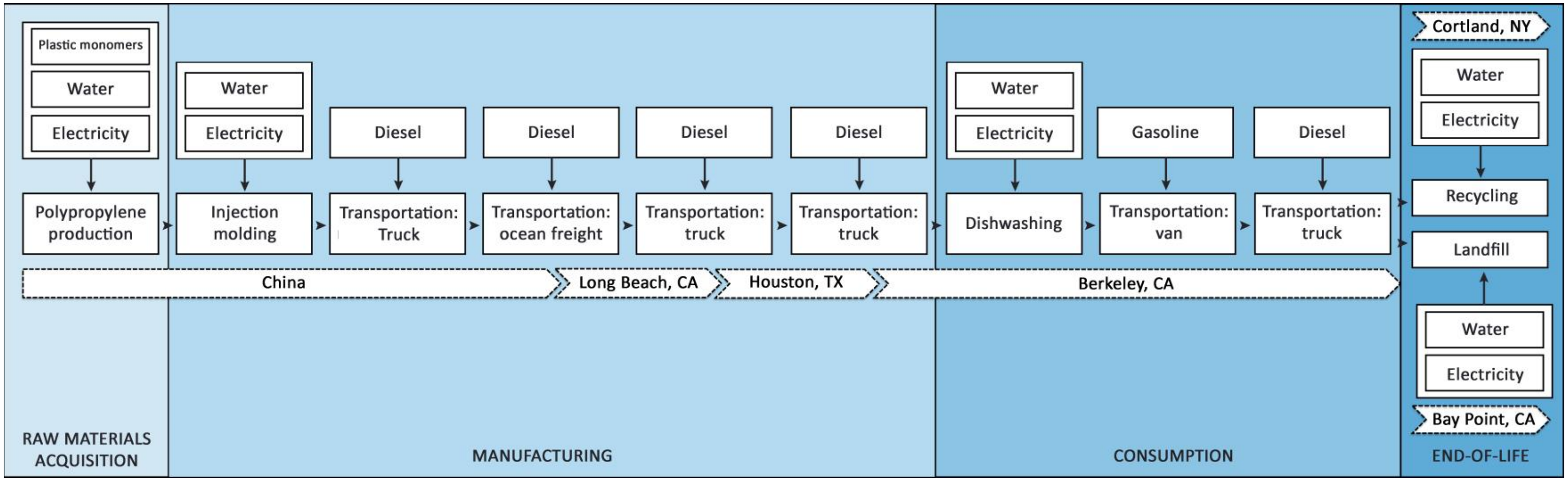

Figure 2. Reusable clamshell life cycle definition. The center progression charts the flow of polypropylene from initial production to end-of-life management. The boxes above show all inputs accounted for in this study. The dashed arrows below chart the changes in location throughout the clamshell's life cycle. The larger blue boxes group processes within each of the four broader categories.

Reusable takeout clamshells

Raw materials acquisition. Reusable takeout clamshells began their lives with the formation of polypropylene (#5) plastic in China (Copeland 2009).

Manufacturing. The polypropylene was injected into a mold to form the reusable clamshell (Copeland 2009). The manufacturers then packaged the reusable clamshells and shipped them 10,100 km on an ocean freight to Long Beach, CA (Copeland 2009). From Long Beach, CA the reusable clamshells boarded a truck and traveled to the G.E.T. Enterprises central distribution center in Houston, TX (Copeland 2009). The reusable clamshells then switched trucks and drove to Foothill dining commons in Berkeley, CA.

Consumption. I used Foothill dining commons as my study site to analyze information on the consumption phase of compostable takeout clamshells. Foothill dining commons served as the main eatery for the 1283 students living in Foothill residential halls. Its relatively isolated location near Hearst Avenue and Gayley Road allowed me to assume that the majority of diners at Foothill dining commons were also residents of Foothill residential halls. Cashiers recorded data on reusable clamshell purchases and returns on their registers. I also recorded the number of broken or cosmetically damaged reusable clamshells that patrons returned to Cal Dining. I used both sets of data to approximate the breakage rate for clamshells in circulation and a recycling rate of broken and damaged reusable clamshells for the pilot program. For the breakage rate:

$$\frac{\#\, reusable\ clamshell\ purchases\ + \#\, clamshell\ returns\ for\ sanitation}{\#\, broken\ clamshells}$$

For the recycling rate:

$$\frac{\#\, reusable\ clamshells\ sent\ to\ Whole\ Foods}{\#\, reusable\ clamshells\ not\ returned\ at\ the\ end\ of\ the\ semester + \#\, reusable\ clamshells\ sent\ to\ Whole\ Foods}$$

At the end of the program, I drove all damaged reusable clamshells 3.06 km to Whole Foods' Gimme 5, a polypropylene recycling partnership between Whole Foods and Preserve. Number five plastics from this program traveled on a truck 7,260 km to Cortland, NY for recycling at the Preserve facility (Preserve 2012).

End-of-life management. Reusable clamshells that reached the recycling facility sustained energy and water intensive processes. Because polypropylene is manufactured to resist degradation from consumer use, reusable clamshells take a significantly longer time to degrade in landfills than in recycling facilities. I calculated material waste based on the volume of reusable clamshells reaching the landfill.

Functional unit

Comparing environmental impacts of compostable and reusable clamshells is difficult because of the nature of their consumption. For compostable clamshells, the variable is number of clamshells used, whereas for reusable clamshells, the variable is number of uses. In order to compare impact categories between containers, I chose the number of uses before breakage of 1 reusable clamshell as my baseline unit, and selected the equivalent number of compostable clamshells for comparison. I analyzed my data using two scenarios, one that showcases the manufacturer's intended use of both clamshells and one that examines parameters I discovered in the reusable clamshell pilot and existing compostable clamshell program at Cal Dining. The parameters for each case are as follows:

Use by design

- 360 compostable clamshell vs. 1 reusable clamshell
- 1 use per compostable clamshell vs. 360 uses per reusable clamshell
- 100% composting rate vs. 100% recycling rate

Pilot

- 43 compostable clamshells vs. 1 reusable clamshell
- 1 use per compostable clamshell vs. 43 uses per reusable clamshell
- 25% composting rate, 75% landfill rate vs. 21% recycling rate, 79% landfill rate

RESULTS

The relative environmental impacts of reusable and compostable takeout clamshells depended heavily on the number of uses each reusable takeout clamshell sustained before reaching its end life. The impacts of both clamshells also varied greatly depending on recycling and composting rates. I found that a reusable clamshell required 14 reuses before one clamshell generated the GHG emissions, energy, and material waste of an equivalent amount of compostable takeout clamshells. Consequently, a consumer that used 15 compostable takeout clamshells would have a greater overall environmental impact in these three categories than a consumer that uses a reusable clamshell 15 times. However, the water footprint for reusable clamshells remained greater than compostable clamshells under both scenarios.

Greenhouse gas contribution

I discovered that 5.5 compostable clamshells had the equivalent GHG emissions as a reusable clamshell that had been used 5.5 times. In the "use by design" scenario, 360 compostable clamshells used once embodied 85.5 kg CO_2 and one reusable clamshell used 360 times embodied 1.27 kg CO_2 (Figure 2). In the pilot scenario, 43 compostable clamshells used once embodied 10.2 kg CO_2 and one reusable clamshell used 43 times embodied 1.49 kg CO_2 (Figure 2). The largest contributors to the GHG impact category for the compostable takeout clamshell included the raw materials acquisition and manufacturing which, combined, accounted for 73% of GHG emissions (Table 3). Despite the carbon dioxide sequestration from plant growth in the raw materials acquisition phase, the data shows a net GHG emission. The largest contributors for the reusable clamshell also included raw materials acquisition and manufacturing, accounting for 64% of GHG emissions (Table 3).

Table 3. Summary of life cycle phase contribution to each impact category. According to the data I collected, I found the percent contribution of each life cycle phase to each impact category within each clamshell's life cycle.

Clamshell Type	Impact category	Life cycle phase	Percent Contribution
Compostable	GHG	Raw materials acquisition	34%
		Manufacturing	40%
		Consumption	0%
		End-of-life management	26%
	Energy	Raw materials acquisition	2%
		Manufacturing	96%
		Consumption	0%
		End-of-life management	2%
	Material waste	Raw materials acquisition	0%
		Manufacturing	0%
		Consumption	0%
		End-of-life management	100%
	Water	Raw materials acquisition	34%
		Manufacturing	62%
		Consumption	0%
		End-of-life management	4%
Reusable	GHG	Raw materials acquisition/manufacturing	64%
		Consumption	27%
		End-of-life management	9%
	Energy	Raw materials acquisition/manufacturing	86%
		Consumption	3%
		End-of-life management	11%
	Material waste	Raw materials acquisition/manufacturing	0%
		Consumption	0%
		End-of-life management	100%
	Water	Raw materials acquisition/manufacturing	0%
		Consumption	99%
		End-of-life management	1%

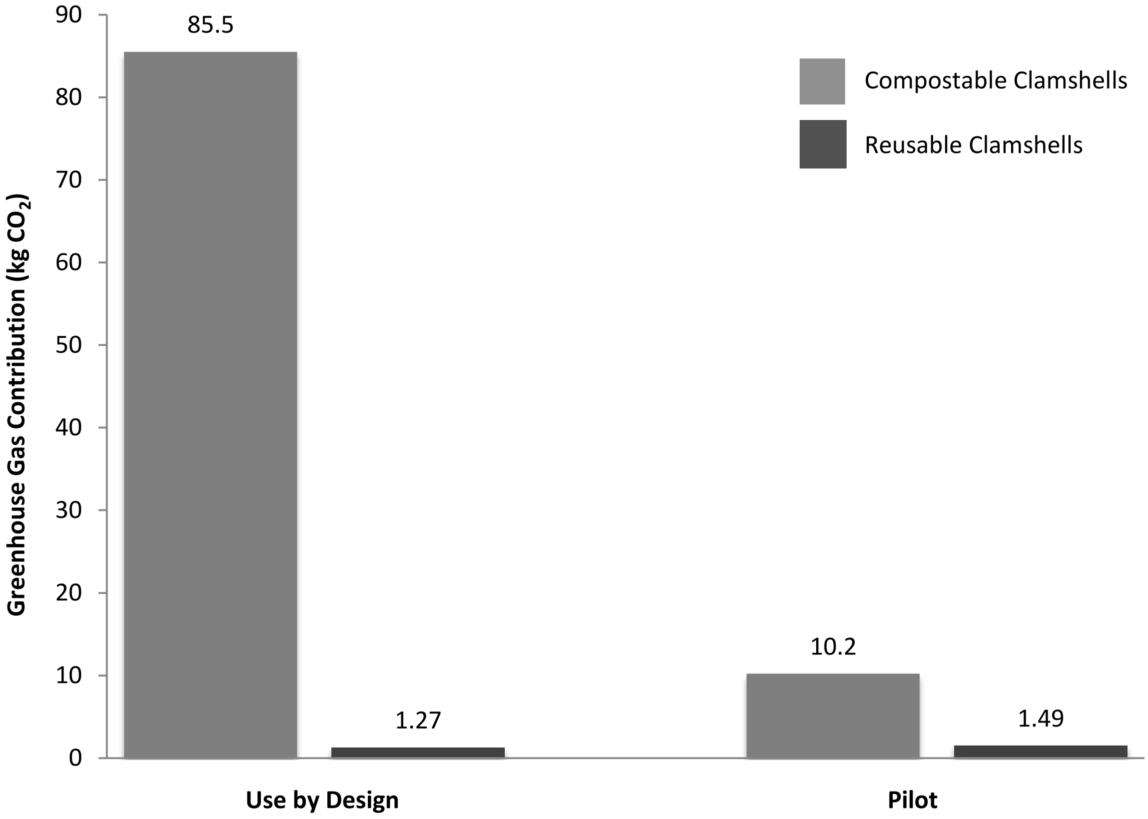

Fig. 2. Greenhouse gas contribution of reusable and compostable takeout clamshells. Bar chart compares the GHG contribution of compostable (light grey) and reusable (dark grey) takeout clamshells. Use by design scenario refers to the GHG impact of 360 compostable clamshells and 1 reusable clamshell used 360 times before disposal. Pilot scenario refers to the GHG impact of 43 compostable clamshells and 1 reusable clamshell used 43 times.

Energy consumption

In order for the equivalent in compostable clamshells to exceed the embodied energy of the reusable clamshells, a patron must reuse the plastic container at least 14 times. 360 compostable clamshells expended 846 MJ while 1 reusable clamshell used 360 times expended 33.1 MJ (Fig.4). Additionally, 43 compostable clamshells expended 102 MJ while 1 reusable clamshell used 43 times expended 30.5 MJ (Fig. 4). Ninety six percent of energy expenditure occurred during the manufacturing phase of the compostable clamshells, and 86% occurred during raw material acquisition/manufacturing for reusable clamshells (Table 3).

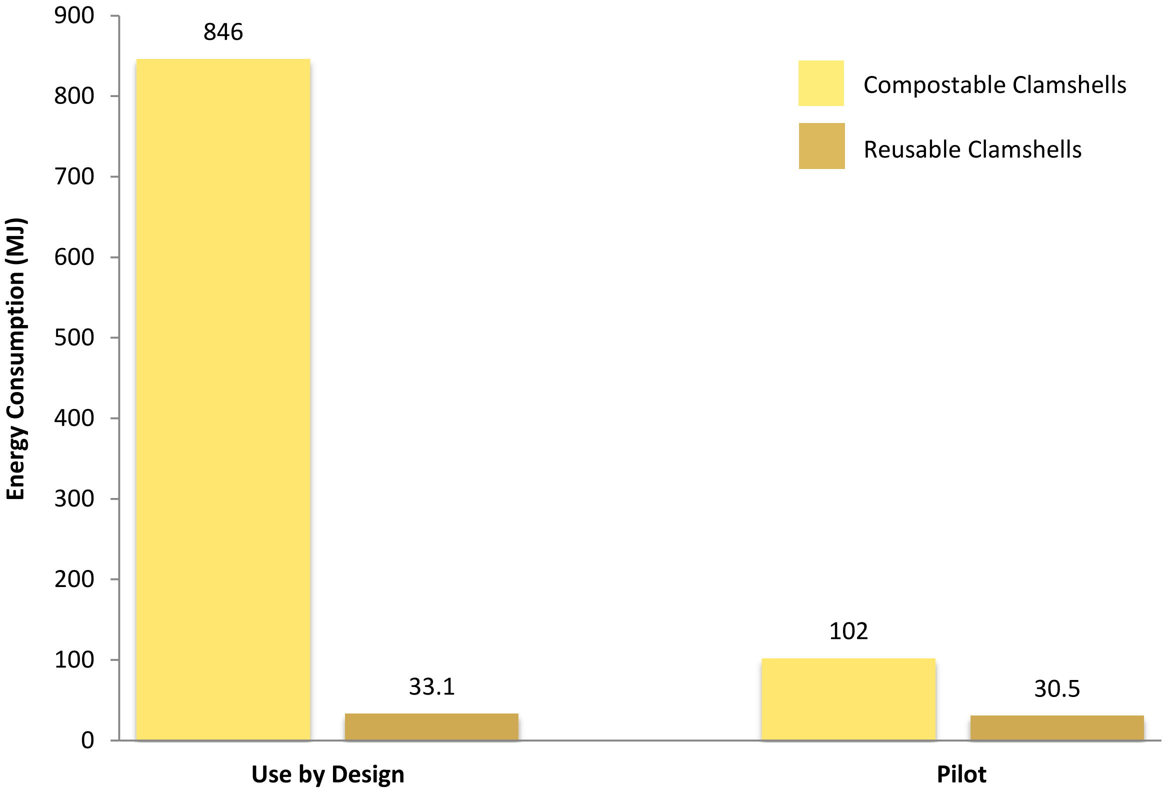

Fig. 4. Energy consumption of reusable and compostable takeout clamshells. Bar chart compares the energy consumption of compostable (yellow) and reusable (brown) takeout clamshells. Use by design scenario refers to the energy consumption of 360 compostable clamshells and 1 reusable clamshell used 360 times before disposal. Pilot scenario refers to the energy consumption of 43 compostable clamshells and 1 reusable clamshell used 43 times.

Material waste

The number of reuses necessary to create equal amounts of material waste between both container types varies with recycling and composting rates, as well as the total number of containers used. Under use by design circumstances, all materials should have either been composted or recycled, leaving behind no material waste. However, under the pilot conditions, 43 compostable clamshells create 0.1 m^3 of waste and 1 reusable clamshell creates 0.00367 m^3 waste. The study assumed all material waste resulted from end-of-life management (Table 3).

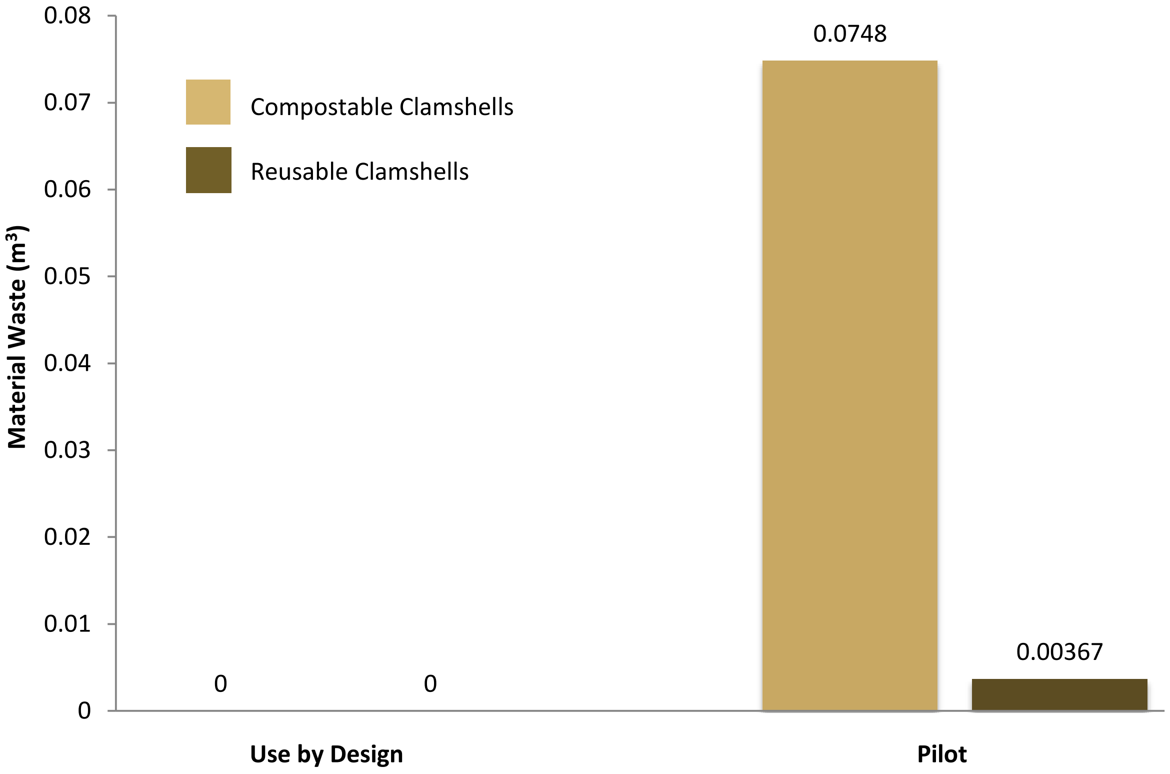

Fig. 5. Material Waste of reusable and compostable takeout clamshells. Bar chart compares the material waste of compostable (light brown) and reusable (dark brown) takeout clamshells. Use by design scenario refers to the material waste of 360 compostable clamshells and 1 reusable clamshell used 360 times before disposal. Pilot scenario refers to the material waste of 43 compostable clamshells and 1 reusable clamshell used 43 times.

Water consumption

Reusable clamshells always used more water than compostable clamshells. The higher the usage rate, the higher the water foorprint of the reusable clamshells. 360 compostable clamshells needed 3,510 L of water throughout their life cycle, and 360 uses of 1 reusable clamshell needed 12,300 L of water. In the pilot scenario, 43 compostable clamshells consumed 436 L of water and 1 reusable clamshell used 43 times consumed 1,460 L. Ninety six percent of water use in the life cycle of a compostable clamshell occured in raw material acquisition and manufacturing phases. In contrast, 99% of water use in the life cycle of a reusable clamshell occured in the consumption phase.

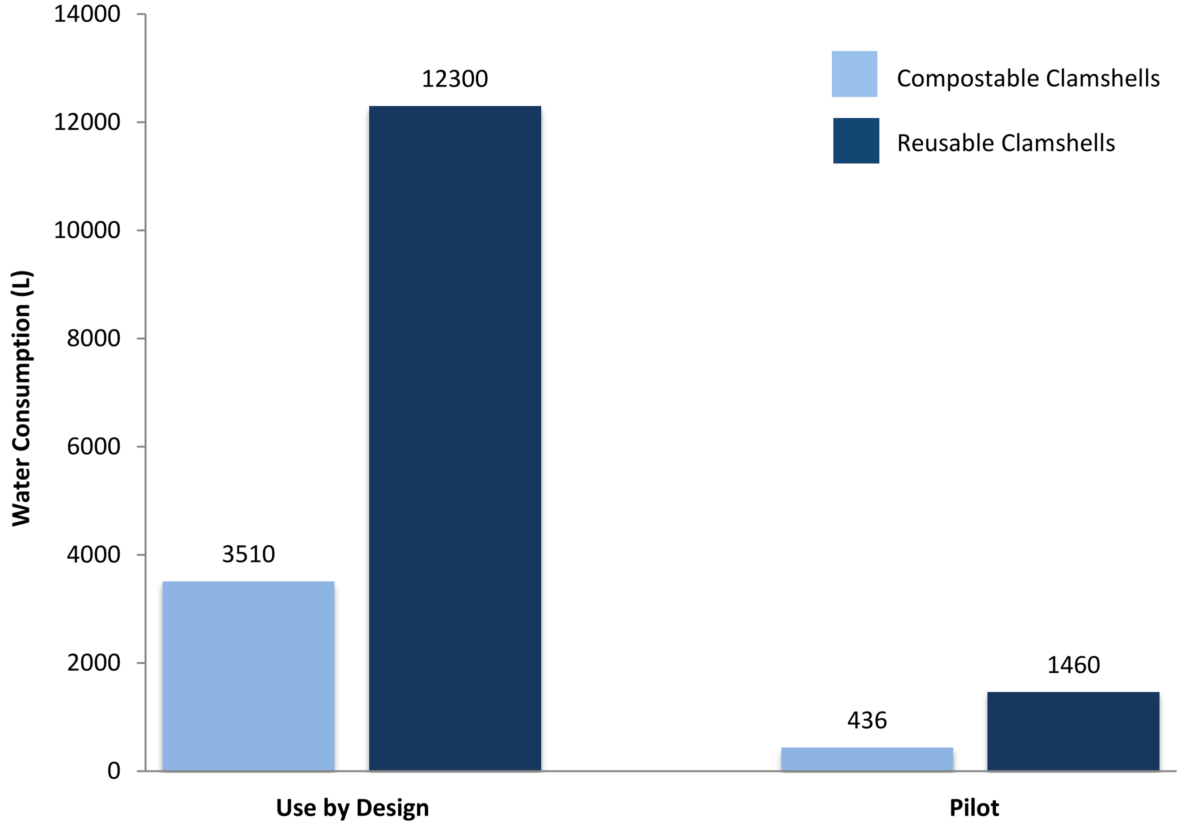

Fig. 6. Water consumption of reusable and compostable takeout clamshells. Bar chart compares the water consumption of compostable (light blue) and reusable (dark blue) takeout clamshells. Use by design scenario refers to the water consumption of 360 compostable clamshells and 1 reusable clamshell used 360 times before disposal. Pilot scenario refers to the water consumption of 43 compostable clamshells and 1 reusable clamshell used 43 times.

DISCUSSION

Conventional environmental practices emphasize "reuse" over "recycle" (Broca 2008, Lewis et.al 2010). My research demonstrated similar patterns, but also exhibited a trade-off between the sustainability of reusable and compostable products. While the reusable clamshells demonstrated a lower environmental impact for both "use by design" and "pilot" scenarios, they showed a larger water footprint than compostable clamshells for both scenarios.

Water trade-off

Because increased use of reusable clamshells further aggravates water expenditure, it is not possible for reusable clamshells to use less water than compostable clamshells. However from an operational standpoint, this trade-off seems to occur within an easily adaptable impact category. Unlike GHG emissions or energy consumption whose impacts occur largely within the raw materials acquisition and manufacturing phases, the largest water footprint occurs within the consumption phase. Therefore, Cal Dining can significantly improve the water footprint of the reusable containers through alterations in their water conservation practices. Discounting the water category, practical application of a reusable clamshell system will produce an overall smaller environmental impact than compostable clamshells, as long as the reusable clamshells average at least 15 uses.

Comparison to existing literature

My LCA demonstrated similar GHG emissions, energy consumption, and solid waste patterns to previous LCAs of reusable and compostable products. In a 2008 LCA comparing reusable and compostable plates, Mita Broca found that reusable plates created five times the environmental impact of compostable plates (Broca 2008). She also found that after 50 uses, reusable plates had an equal or smaller environmental impact than compostable plates. However, her study addressed water consumption in terms of acidification and eutrophication potential. Her findings, therefore, do not directly account for the water needed to wash the reusable plates. Similar patterns appear in a study published by *Packaging Technology and Science* concerning reusable and compostable grocery bags (Lewis et. al 2010). Again, after 50 uses, the reusable grocery bags became environmentally preferable to compostable bags in all evaluated impact categories. Bags do not require the same caliber of sanitation that food clamshells do. Therefore, the variance between water footprints of a reusable and compostable bags will not be as great as reusable and compostable clamshells.

The results of my study relied heavily on the parameters provided in the consumption phase. For example, the use by design scenario saw almost no material waste production while the pilot scenario modeled 0.0748 m^3 in compostable waste and 0.00367 m^3 in recyclable waste. This pattern of variable environmental impact according to user-specific behavior appeared prominently in another LCA on reusable and compostable coffee cups (Ligthart and Ansems 2007). In their main conclusions, the authors asserted that the individual user had a direct influence on the environmental impact of each type of cup. Therefore, more conscientious practices in relation to water use and conservation could translate to a lower environmental cost in that impact category. This reduction in water use could build an even stronger case for reusable clamshells over compostable clamshells.

Limitations

Due to the nature of my study, I relied heavily on information provided by the manufacturers of both reusable and compostable clamshells. Neither company had data cataloguing the environmental impacts produced during manufacture of the clamshells. My study consequently depended heavily on general datasets provided by the GaBi 6 software and other existing literature. While these values do not reflect a resolution specific to the machinery and precise practices of each manufacturer, they do account for the overall environmental impact due to the general flow of processes for each clamshell.

The system boundaries I established for both reusable and compostable clamshells created limitations to the scope of my study. For example, I chose to exclude all packaging materials involved in shipping clamshells from the supplier to Foothill and Clark Kerr Dining Halls. Both clamshells arrived in cardboard boxes with plastic liners, but the quantity and size of packaging materials differed. However, I looked at the environmental impact of the clamshells on a relatively small scale, which made it unlikely that a slight difference in shipment packaging would significantly change the overall outcome. Even if these values did contribute significantly to the overall environmental impact of each clamshell, the outcome would only accentuate my observed trends since the reusable clamshells required less frequent shipments.

I would also like to note several variables that could influence the environmental impacts of the consumer phase for both clamshells. The low composting rate cited in the pilot scenario for the compostable clamshells may have been influenced by the lack of sufficient composting infrastructure. Currently, Clark Kerr only provides bins for food compost inside the dining hall. In order for an individual to compost their clamshell, they would have to bring their clamshells back to the dining hall or find a compost bin on campus. Another variable involved the ratio of clamshells ending in the compost or landfill. The numbers used to create this ratio relied on a relatively sparse dataset. I surveyed a total of 1,340 L of compost and 2,038 L of trash over a four day period, which may not reflect the true composting rate.

Finally, my study also did not provide an exhaustive review of all environmental impact categories. For example, I did not consider the consequences of polluted water, the potential human health impacts, or the effects of stratospheric ozone depletion. I chose GHG contribution, embodied energy, water use, and material waste because these categories were the easiest to measure and simplest to comprehend. These four were also cited as common impact categories in the EPA's *Life Cycle Assessment: Principles and Practice* handbook.

Future directions

In the future, research should aim to discover best practices for extending the longevity of the reusable to-go containers. The longer the reusable clamshells last, the longer they stay out of landfills and recycling facilities, and the more resources we save. I would also recommend a study that combines information found in my study with life cycle assessments of the packaging of each respective container. A study of this nature would test the validity of my previous assumptions.

Conclusions and broader implications

Despite its limitations, this study provided a more in depth and comprehensive understanding of the trade-offs between reusable and compostable products. Like many contemporary environmental solutions, this study showed a trade-off between reusable clamshells and compostable clamshells. This LCA also pinpointed an area of improvement for reusable clamshells – water consumption – that consumers can directly impact. Based off of the lower environmental impacts of GHG contribution, energy consumption, and material waste and the potential for improvement in water consumption, reusable clamshells are the more sustainable takeout clamshell choice for Cal Dining. This conclusion can help strengthen the case for reusable products, and provide guidance for consumers trying to make environmentally conscious purchasing decisions.

ACKNOWLEDGEMENTS

Special thanks to John Battles for his unwavering support of every aspect of this project, and the Battles lab for all the help along the way. Thank you to the entire Cal Dining team for the implementation of Chews to Reuse, specifically Brian Walker, Michael Laux, Nicole Won, Nicholas Lam, Patrice Thomas, Florence Fung, Chuck Davies, and Shawn LaPean. Chews to Reuse would also not have been possible without the Green Fund Grant I received from the Chancellor's Advisory Committee on Sustainability. Thank you to Anton Sudradjat for mentorship with GaBi 6 software, and finally, thank you to Rachael Marizon for the hours of editing.

RESOURCES

Beeharry, R. 2001. Carbon balance of sugarcane bioenergy systems. Biomass and Bioenergy. 20:361-370.

Birgeneau, Robert. 2009. 2009 Campus sustainability plan. University of California, Berkeley.

Broca, M. 2008. A comparative analysis of the environmental impacts of ceramic plates and biodegradable plates (made of corn starch) using the Life Cycle Assessment tool. TERI University. New Delhi, India.

Cal Dining. 2012a. Sustainability Resume.

Cal Dining. 2012b. To Go Boxes Sales and Numbers.

Chacko, Sunil. 2012. Cal Dining. Personal Communication.

Copeland, A. 2009. Beyond Disposables: Eco-Clamshell Reusable To-go Program. Eckerd College.

Environmental Protection Agency. 2011. Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2010. U.S. Environmental Protection Agency.

Hobart. 2013. 2013. Hobart FT900 Flight-type dishwasher. <https://my.hobartcorp.com/resourcecenter/ProductDocumentation/F39628.pdf> (Version 04/07/2013)

Hoornweg, D. and P. Bhada-Tata. 2012. What a waste: a global review of solid waste management. Report No. 68135. Washington D.C., USA.

Golden Bear Transfer Station. 2013. Personal Communication.

Jost, D. 2013. IFN Green. Personal Communication.

King, L. 2012. University of California, Berkeley Campus Recycling and Refuse Services. Personal Communication.

Kongboon, R. and Sampattagul, S. 2012. Water footprint of bioethanol production from sugarcane in Thailand. Journal of Environment and Earth Science, 2: 62-67.

Lewis, H., Verghese, K. and Fitzpatrick, L. 2010. Evaluating the sustainability impacts of packaging: the plastic carry bag dilemma. Packaging Technology and Science, 23: 145-160.

Linthart, T. and A. Ansems. 2007. Single use cups or reusable (coffee) drinking systems: an environmental comparison. Report 2006-A-R0246(E)/B. TNO Built Environment Geosciences. Apeldoom, Netherlands.

Liu, D. and Bull, T. 2001. Simulation of sugarcane and biomass accumulation in sugarcane using a process based-model. Ecological Modelling, 144:181-211.

Lundie S. and G. Peters. 2005. Life cycle assessment of food waste management options. Journal of cleaner production, 13: 275-286.

Madival, S., R. Auras, S. P. Singh, and R. Narayan. 2009. Assessment of the environmental profile of PLA, PET and PS clamshell containers using LCA methodology. Journal of Cleaner Production 17:1183-1194.

Marsolek, M. 2003. Carbon Footprint Analysis of StalkMarket Bagasse Tableware. Asean Corporation.

Preserve. 2012. Our Process. <http://www.preserveproducts.com/ourprocess/index.html> (Version 05/06/2013)

Ratchayuda, K. and S. Sampattagul. 2012. Water Footprint of Bioethanol Production from Sugarcane in Thailand. Journal of Environment and Earth Science 2: 61-66.

Scientific Applications International Corporation. 2006. Life Cycle Assessment: Principles and Practice. Contract No. 68-C02-067. Reston, Virginia.

United States Census Bureau, Population Division. 2012. Table 1. Projections of the Population and Components of Change for the United States: 2015 to 2060. NP2012-T1. Washington D.C., USA.

Wansbrough, H. 2008. Plastics Recycling. New Zealand Institute of Chemistry. <http://nzic.org.nz/ChemProcesses/environment/14E.pdf> (Version 05/10/2012).

Wilbulswas, P. 2006. Thailand's energy mix for power generation – options for a constrained future. <http://www.jgsee.kmutt.ac.th/see1/cd/file/keynote%203.pdf> (Version 04/25/2013).

APPENDIX A: Supplementary Data input into GaBi 6 Software

Container	Life cycle phase	Adjustment	Magnitude	Units	Source
Compostable	Raw materials acquisition	Photosynthesis	-0.0794	kg CO2	Marsolek 2003
		Emissions from machinery	0.00156	kg CO2	Marsolek 2003
		Thailand energy grid mix			
		Natural gas	71.7	%	Wibulswas 2006
		Coal and lignite	16.0	%	Wibulswas 2006
		Fuel oil	6.40	%	Wibulswas 2006
		Diesel oil	0.50	%	Wibulswas 2006
		Hydro-energy	5.40	%	Wibulswas 2006
		Sugarcane cultivation water use	3.24	L	Kongboon 2012
		Ocean freight travel to Yantian port	3500	km	Jost 2013
		Truck travel to China manufacturing	499	km	Jost 2013
	Manufacturing	Energy for machinery	0.416	MJ	Marsolek 2003
		Steam for molding fiberboard	0.0957	L	Marsolek 2003
		Natural gas burned	0.0344	kg	Marsolek 2003
		Truck payload	30.0	tons	Marsolek 2003
		Truck travel factory to Yantian port	499	km	Jost 2013
		Ocean freight travel to port of Oakland	11100	km	Jost 2013
		Truck travel to San Leandro	11.3	km	Jost 2013
		Truck travel to Clark Kerr dining commons	24.1	km	Jost 2013
	Consumption	Truck travel to Golden Bear Transfer Station	20.9	km	Golden Bear Transfer Station 2013
		Truck travel average to Jepsen Prairie/Grover Compost	81.1	km	Lin King 2012
		Truck travel to Keller Canyon Landfill	65.8	km	Lin King 2012
	End-of-life management	Electricity from composting machinery and wastewater treatment	122	MJ	Lundie 2005
		Water for breakdown	0.405	L	Lundie 2005
		Volume of compost in landfill	0.00232	m^3	Own measurements

Reusable	Manufacturing	Ocean freight travel to Long Beach, CA	10100	km	Copeland 2009
		Truck travel to Houston, TX	2190	km	Copeland 2009
		Truck travel to Foothill dining commons	3070	km	Own measurements
		Dishwasher energy use	0.190	MJ	Hobart 2013
		Dishwasher water use	33.2	kg	Hobart 2013
	Consumption	Van travel to Whole Foods Market	3.06	km	Own measurements
		Truck travel to Cortland, NY	7260	km	Preserve 2012

Table A. Supplementary data for GaBi 6 software. The above table includes all adjustments I made to the existing GaBi 6 datasets used to produce the study specific data required for this study.