A Qualitative Cradle to Grave Life Cycle Analysis of a BC Disposable-Coffee-Cup's Sustainability

What is the overall sustainability of disposable coffee cups, and are re-usable coffee cups a better alternative?

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April 4th, 2012

Report prepared at the request of Greener Footprints, in partial fulfillment of UBC Geog 419: Research in Environmental Geography, for Dr. David Brownstein

INTRODUCTION

Today's popular market for grab and go disposable items sells the appearance of an easy and convenient consumerist lifestyle. For a lot of people, the reliance on these products has become an important part of their daily activities. One of the best examples of this can be seen through single-use disposable coffee cups. Although their convenience is undeniable, most people do not consider the impact this product has on the environment as they make their daily trips to their favorite coffee shops, and of course along with it, the trips to the garbage can.

There are various types of materials that a disposable coffee cup can be made of. One of the most common is the polyethylene paper cup, and is currently used by Starbucks, one of the world's biggest coffee franchises (Starbucks 2010). Another common material is polystyrene, or Styrofoam, as it is more commonly known. There are many variations within these categories that are also used as disposable coffee cups, such as some that contain low to 100% of recycled material (Franklin 2009). But for the purpose of this assessment, polyethylene paper and polystyrene cups are the two common material choices that will be analyzed along with a comparison of reusable coffee cups. This analysis will be conducted through a qualitative "cradle to grave" life cycle analysis, revealing the environmental impacts pertaining to a general region of BC.

METHODS

I have used the tool of a qualitative cradle-to-grave Life Cycle Analysis as a method of comparison to determine the option with the least environmental impact, which in this case, is based on the material choice of disposable coffee cups. For this project I have narrowed it down to three main material choices for comparison. These are polystyrene “Styrofoam” cups, polyethylene paper cups, and general re-usable coffee cups. To do this qualitatively, I reviewed research that has already been conducted, and compiled the data into a life cycle inventory for analysis. A cradle-to-grave life cycle analysis consists of various steps of a product’s arbitrary “life cycle,” from the very initial stage to its end of life (Häkkinen 2010). This can encompass numerous life stages, but mainly they involve the extraction of raw materials, material processing and manufacturing, distribution, usage, repair, maintenance, and disposal (Häkkinen 2010). For the purpose of this research, the main stages of data analysis will be focused on raw material extraction, material processing and manufacturing, and disposal or end of life stage. These variables were chosen in order to accurately conduct a complete comparison of the three material choices in which the inputs and outputs of these “life stages,” were considered.

To then assess the environmental impacts associated with these material choices of coffee cups, the data was then compiled into a qualitative life cycle inventory, which enabled the data to be categorized and quantified in these “life stage” categories. The data set was then analyzed and interpreted to assess the overall environmental impact that is resulting from the use of disposable coffee cups, and if re-usable cups is a better alternative.

MATERIAL CHOICE

The three main materials chosen for this qualitative life cycle analysis are polyethylene paper cups, polystyrene cups and reusable cups. Polyethylene paper cups are a common material choice for many of today’s grab and go beverage containers. This is largely due to their ability to maintain their shape and insulating properties over time of use, which many alternative options and new pilot cups have not been able to duplicate (Alliance 2000). Polyethylene is the chemical that is used to line the inside of the paper cup (Häkkinen 2010) as well as seal the seams of the cup, which enables the product to be heat and water resistant (Rhim 2009). This allows the disposable cup to move beyond its normal life span without losing its structural stability under heat (Rhim 2009). The paper material component of the cup is made from paperboard, which is a pulp product that is almost always bleached and is thicker than your average paper, although compositionally there is no large difference (Hocking 1991).

Polystyrene cups, otherwise known as Styrofoam, are made from expanded polystyrene foam, a product made from the chemical compound styrene, which is derived from petroleum and formed by a chemical reaction between ethylene and benzene (Hocking 1991). These cups are popular for their moisture resistance, excellent insulating properties and light weight (Teach 1960). Although Styrofoam is the common name to which these products are referred to, polystyrene disposable coffee cups are a different material, as the true trademarked Styrofoam is actually a extruded polystyrene form, rather than expanded (Anonymous 2006).

Reusable cups come in many forms and are made of a various spectrum of materials. For that reason, it is hard to draw direct comparisons in a life cycle analysis, but in general the varieties tend to show common outcomes when compared for their benefits and costs against common disposable coffee cups, and as a result are useful in this comparative study. The most general form used in this analysis was your typical travel mug opposed to a generic coffee mug, due to their “on the go” convenience. The most common reusable mug types are plastic, ceramic, porcelain, glass or stainless steel (Ruhl 2010). Because of this wide variety, each of these materials have their own life cycles with varying degrees of energy consumption, raw material extraction and other associated negative impacts on the environment. These impacts will obviously be greater than the average single-use cup due to their complexity and quality in manufacturing (Hocking 1994), but in terms of the products life span, whether or not this is the more environmentally option is why this question will be explored.

RESULTS: MATERIAL EXTRACTION

Material extraction is often the stage where the most obvious negative environmental effects can be seen. As for the three material choices, this can arguably be most drastically noticeable in the raw material extraction stage of paper cups. Since paper cups are made of paperboard, all of them, whether polyethylene coated or not, require lumber as their raw material (Hocking 1991). This lumber is then processed into pulp, and eventually manufactured into multi-ply paperboard which can be either bleached or unbleached (Hocking 1991). This lumber extraction has many negative impacts and noticeable environmental concerns (Hocking 1991b). Logging practices, and even the roads created for logging, often result in slope instability, soil erosion, as well as habitat loss and fragmentation (Hocking 1991b). Stream alterations from clear cutting is also a common result and can cause flooding or droughts in certain areas (Hocking 1991). This is not only costly in vegetation loss which acts as a habitat for many species, but we are adding carbon dioxide into the atmosphere through this deforestation and contributing to global warming effects, when perhaps this could easily be avoided (Bala 2007).

But paperboard material is not the only material choice that drastically impacts the environment. Polystyrene reusable cups have their own fleet of concerns. As polystyrene foam cups are made from styrene, this chemical compound needs to be extracted from petroleum or natural gas (Hocking 1991). As we know there are many environmental concerns associated with the extraction of oil and gas. Variations exist on the type of petroleum, where the drilling sites are located, and how this raw material is extracted. For example, different ecological impacts result from extraction via the tar sands, which can have huge ecosystem recovery concerns (Jordaan 2011), versus an off shore-drilling site, which is highly vulnerable to accidental oil spills (Hocking 1991). Also to be considered is the negative impact that these extraction sites have on human populations. Many small communities who rely on near by rivers as a water source are often exposed to contaminated waters from this raw material extraction (Jordaan 2011). Much pollution and waste is produced from oil and gas extraction and should be considered in this analysis. Aside from the specific pollution concerns associated with oil and gas extraction, similar impacts to logging extraction also occur such as the degradation of land, and habitat loss and fragmentation (Jordaan 2011).

Then there are reusable cups. As previously mentioned, it is hard to make direct comparisons as to how reusable coffee cups in general measure up to the two disposable material choices, but general claims can be made if all variations were to be grouped together. Such as that in their material extraction stages, it can be argued that they have a much greater negative impact due to their complexity of materials (Hocking 1994). For example, many forms can be made of more than one material choice such as aluminum and plastic. This involves more materials, as well as additional factors such as the energy required and transportation effects to get these additional materials to the processing and manufacturing centers, all of which make these calculations extremely intensive.

RESULTS: MATERIAL PROCESSING AND MANUFACTURING

A huge portion of the negative environmental impacts from these coffee cup options comes from their material processing and manufacturing stages. Once the raw materials have been extracted and transported to these centers (which in their own have additional negative impacts), they then can be processed in this next stage. This stage plays a crucial role in their life cycles due to the large degree of negative environmental impacts, and therefore is the main focus of my analysis. For polyethylene paper cups, their energy requirements for processing and manufacturing are quite heavy for this life stage (Hocking 1991b). In order to create the paper coffee cups, pulp products must be processed into paperboard, which is an energy extensive process (Hocking 1991). In order to assess this process, utility power, water effluent and air emissions were compared. These measurements were converted to per ton of metric material for easy comparison (Hocking 1991). For utility use in processing, 9000-12000 kg of steam, 960-1000 kw/h of power from electricity and 50m3 cooling water were utilized per ton of raw materials (Hocking 1991). In addition, 50-190m3 of water effluent was released which contains suspended solids, Organochlorines, and metal salts (Hocking 1991). As for air emissions, 0.2kg of chlorine, 0.2kg of chlorine dioxide, 1-2kg of reduced sulphides, 2-3kg of particulate matter, 3.6 kg of carbon monoxide, 6.0kg of nitrogen oxides, and 10-16kg of sulphur oxides per ton of raw materials were released (Hocking 1991b).

The same data was collected on polystyrene cups as was the above paperboard cups, and again, these measurements were converted to per ton of metric material for easy comparison (Hocking 1991). For polystyrene cups to be processed, their utility requirements for processing were 5500-7000 kg of steam, 260-300 kw/h of electricity, and 130-140m^3 of cooling water per ton of raw materials (Hocking 1991). In addition, water effluent was released at 1-4m^3 per ton of raw materials, which included metal salts and trace amounts of BOD and suspended solids (Hocking 1991). For the air emissions, 0.3-0.5kg of particulate matter, 0.08 kg of carbon monoxide, 0.4kg of nitrogen oxides, and 3-4kg of sulphur oxides were emitted per ton of raw materials (Hocking 1991).

For reusable cups, using the same criteria as the two material types above is difficult as data available lacks due to the complexity of the varieties of material composition. As a general overview, a median was taken from an arbitrary sample of reusable 8-9oz cups manufactured in the countries of Canada, the United States, China and the United Kingdom to represent the total energy requirements in manufacturing for each cup (Hocking 1994). This result showed that polystyrene cups had the least energy requirements per cup to manufacture at 198kJ/cup, and ceramic reusable mugs with the greatest energy requirements in processing at a vastly higher 14,088kJ/cup followed by reusable polystyrene at 6,300 kJ/cup and heat-proof glass at 5,501kJ/cup, showing that the reusable material all had higher energy requirements than the disposable when looking at a per cup analysis (Hocking 1994).

RESULTS: DISPOSAL

Disposal patterns become complicated as different material types are evaluated at different regional levels. This is largely due to recycling capacities that different regions have, and whether they accommodate certain materials for recycling based on proximity to recycling centers or landfill capacities (Recycling Council 2012). This is true for British Columbia, where municipal recycling is based on each municipality’s own decision making processes (Recycling council 2012). Polyethylene paper cups can be recycled today at some locations, most notably at Starbucks locations across BC (Goveas 2011), but total participation is difficult as the waste management industry views recyclables as a commodity, so it is hard to keep suppliers from mixing these recycled materials in with the landfill as a cheaper alternative (Goveas 2011). It is because of their polyethylene resin coating that these paper cups are generally not recyclable with your other generic paperboard goods (Hocking 1991), and with a company such as Starbucks distributing 4 billion cups globally every year, it's hard to imagine how much of that material actually gets recycled (Goveas 2011). To a degree, these paper cups are beneficial because they will biodegrade in the environment slowly over time, but in arid regions such as Cache Creek, BC this can take up to 50 years (Hocking 1991b). It is also important to point out that the polyethylene coating that lines the paper cups does not biodegrade, and remains in the landfill after the paper breaks down over time (See Figure 1). Although their ability to biodegrade does lessen the environmental impact of the product in terms of landfill accumulation, paper cups actually contribute to increases in green house gas emissions by releasing methane into the atmosphere at a rate that per molecule has 5 to 20 times the rate of warming in comparison to a molecule of carbon dioxide (Hocking 1991). Recyclability of these paper cups also becomes a problem when the mills do not have the proper equipment to process the materials (AMEC 2009). Processing time is often longer, cost is more expensive, and the polyethylene chemicals can ruin the machines (AMEC 2009).

Figure 1. Polyethylene lining that remains after the paper of paperboard cups biodegrades (Ziada 2009).

Polystyrene cups on the other hand are not biodegradable, but can be recycled as long as the material is not reused for food applications (Hocking 1991). If they are recycled, they are granulated, rinsed with water, then recycled into polystyrene resin (1991b), which is used for packing material, insulation and even patio furniture (Hocking 1991). Some experimentation has been done using microbes that are mixed in landfills with the polystyrene cups in order to get the material to break down into a useful biodegradable plastic, but this has largely been unsuccessful and more research needs to be conducted (Booth 2006). Although a lot of polystyrene ends up in our landfills, the volume they take up is significantly less than the other material choices (Hocking 1991b). The mass of an average polyethylene paper cup in a landfill is 10.1g opposed to a polystyrene cup, which is only 1.5g (Hocking 1991). Another added benefit with polystyrene's end of life stage is that they do not release methane back into the atmosphere as paper cups do, although it should be noted that other emissions such as pentane released in styrene foam production was not accounted for in this analysis (Hocking 1991).

Reusable coffee cups have likely the most environmentally friendly end of life stage out of the three material choices. This is because the cups are 100% recyclable, that is if you view the scenario on a personal use basis. Depending on the variety, the reusable cups can be continually used over again almost to a number of infinite uses. So the concern with reusable coffee cups becomes not with their disposal, but rather their maintenance for continual use, which can be measured for comparison via the impacts from washing (Hocking 1994). Depending on the person, the reusable cups tend to be washed quite regularly, and therefore the energy requirements and water usage should be considered (Hocking 1994). When these washing requirements are tested against energy requirements of the disposable cups, it is found that the energy from washing a reusable cup is vastly more demanding than the energy requirement of manufacturing a polystyrene cup and half that of a paper cup (Hocking 1994). Due to the wide variety of reusable cups and the various washing machines and energy sources, it was found that a general range can be reached of anywhere between 15 and 1000 uses required in order to break even in energy requirements from washing of reusable cups and production of a disposable cup (Hocking 1994).

DISCUSSION

When these three main life stages of raw material extraction, processing and manufacturing and disposal are considered, a clear outcome emerges when it comes to which of the two disposable material choices is more environmentally friendly. In terms of air emissions, a total of 22.7kg per metric ton is produced for paper cups contrasted to polystyrene cups which total 53kg per metric ton (Hocking 1991b). But keep in mind that this figure is based on a per metric ton basis, and because polystyrene cups have vastly less mass than paper cups, the reality is that on a per cup basis they emit significantly less air emissions than paper cups (Hocking 1991b). In terms of electricity use, polystyrene cups use roughly 30% of the electricity and half the steam of Paper cups during manufacturing (Hocking 1991b). A Polystyrene cup's chemical requirements are also significantly small, 3% that of a paper cup (Hocking 1991). On the other hand, 10-100x more contaminants are present in wastewater streams of polystyrene depending on the removal requirements of certain regulations than paperboard wastewater streams (Hocking 1991b). Styrene loss from pentane blowing agents is also a big emission contributor that needs to be addressed, and is not accounted for in this qualitative analysis (Hocking 1991). But overall, when total energy requirements from resource extraction to disposal are factored in together on a per cup basis, ceramic reusable cups are the most energy intensive followed by heat proof glass, reusable polystyrene, uncoated paper, and the best of these options in terms of energy requirements is the polystyrene foam (Hocking 1994). Some other key points to factor in are in consideration of sustainability, such as that the lumber used to manufacture paper cups is a renewable resource, where as the oil and gas used for polystyrene manufacturing is not a renewable resource (Hocking 1991).

Keeping in mind that this analysis is largely based on energy requirements and emission outputs, these results reflect the importance of these variables in the coming future when concerns like global warming and environmental degradation for capital gain becoming increasingly pressing concerns. That being said, long-term analysis would support that neither of these disposable options are the better material choice. We should instead be using reusable coffee cups. But there is a grey zone to this claim, and consumers should be aware of their own usage, and whether the amount that they use and wash their reusable cups is enough to have less of an environmental impact than the processes and materials that were required to manufacture the product and put it on the market.

RECOMMENDATIONS

In the short term we should be using polystyrene cups, especially if we are weighing heavy importance on manufacturing processes and the energy consumption involved, as they use significantly less energy than the paper polyethylene disposable option (Hocking 1991). Some other recommendations might include the implementation of an environmental fee or tax on paper cups. This fee could then be used to properly recycle the cups, which is a common problem in many places today where they don't offer the option of recycling (Recycling Council 2012). This fee could also act as potential funding so pulp and paper mills can afford the proper equipment to process these recycled products, as currently most equipment cannot process the material due to the polyethylene lining on paper cups that damages the machines (AMEC 2009). This tax may also simply raise awareness and deter people from using paper or other disposable cups when it is not necessary. Another recommendation to reduce the waste would be to not provide sleeves for heat. This wouldn't be targeting the actual cups themselves, but they are still a product used very commonly, which usually has a high level of non-recycled material (Franklin 2009). Customers could also be provided with the opportunity to purchase one of the retailer's reusable sleeves, similar to how they can purchase reusable cloth bags in a grocery store. Another recommendation is the offering an at-the-till rebate as motivation for customers. Some companies such as Starbucks already offers their customers this discount (Starbucks 2009). This could be attractive to companies who don't have to spend as much money ordering cups as well as the consumers for saving money that easily adds up over their daily coffees. But in general, the primary recommendation would be for consumers to use reusable coffee cups, and to use them as much as possible in order to lessen their environmental impact over time (Hocking 1994).

CONCLUSION

Due to the convenience of disposable coffee cups, it is unlikely that the average coffee drinker will change their habits in the near future, especially when there are no incentives or benefits for consumers or businesses involved to motivate them and create support. Using reusable coffee cups can be seen as an unnecessary nuisance, and many will opt out due to its inconvenience. This is why new innovative ideas and more environmentally friendly alternatives need to be explored for disposable coffee cup materials rather than simply pushing for a mass conversion to reusable coffee cups. As discussed in this analysis, reusable coffee cups must be used a number of times in order for them to be more environmentally friendly than a disposable cup, and if consumers are not willing to fully commit to switching over, their impact could have more of a negative effect than a positive one (Hocking 1994).

In the mean time, it may be best for companies and consumers to try and use polystyrene cups rather than polyethylene paper cups, as their energy requirements and air emissions are far less than the polyethylene paper cup (Hocking 1991b). There is also hope that in the future more research will reveal a feasible way of using microbes to help biodegrade polystyrene into a useful recyclable form (Booth 2006). But whenever possible, those consumers who wish to take action should use re-usable coffee cups and use them as many times as possible. The more you use your reusable coffee cups, the less of an environmental impact you have.

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