UBC Social Ecological Economic Development Studies (SEEDS) Student Report

An Investigation into Reusable Coffee Mugs

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AN INVESTIGATION INTO REUSABLE COFFEE MUGS

- Formal Report for Sustainability Project

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ABSTRACT

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In order to stock the green vending machine, reusable and disposable coffee cups should be evaluated based on a triple bottom line assessment which contains environmental, social and economic factors. The scope of the report incorporates evaluating paper, ceramic, plastic and stainless steel as potential materials for the transportable coffee mug as well as the vending machine energy consumption. In this evaluation, energy consumption over the life-cycle of each material is assumed to be the main player. The methods utilized in this analysis are gathered from academic articles and trusted web resources.

Each of the materials mentioned above is examined throughout the report. Paper cups create a lot of waste since they are only capable of one use. With proper initiatives, their consumption can be reduced, however these initiatives will be difficult to implement. The ceramic mug's life-cycle is found to be energy taking and have low durability which makes it an unpopular option for the vending machine. Plastic mugs have various user benefits in terms of insulation and ergonomics but were found to be potentially harmful due the release of Bisphenol A which can negatively impact reproductive health. Stainless steel mugs have long-term durability and do not pose any potential health hazards; however, they have high energy consumption and CO2 emissions.

If reusable mugs are to be sold from vending machines in the new Student Union Building, they should be made of stainless steel. However, in order to ensure the feasibility of selling reusable mugs, further research should be conducted regarding public perception of reusable mugs, the reasons why individuals choose not to use them and potential ways to make them more attractive to customers.

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GLOSSARY

Ferro/Ferri	**A combining form with the meanings "iron," "ferric," used in the formation of compound words:** ***ferriferous; ferricyanide.***
Bisphenol A	**An organic compound used to make polycarbonate plastics**
Kaolinite	**A mineral used in ceramic manufacturing, medicine toothpaste production and has chemical composition Al2Si2O5(OH)4.**
Polyethylene	**A thermoplastic polymer, and is the most common plastic produced.**
Coin Mechs	**A component of vending machine which validate currency and detect counterfeit**

LIST OF ABBREVIATIONS

BPA	**Bisphenol A**
SUB	**Student Union Building**
ISSF	**International Stainless Steel Forum**
NREL	**National Renewable Energy Laboratory**
DOE	**Department of Energy**
EPA	**United States Environmental Protection Agency**
LED	**Light Emitting Diode**

1.0 INTRODUCTION

The University of British Columbia is one of the leading universities in the campus sustainability initiative; as part of this initiative, some students of the Applied Science 261 course participate in providing sustainable solutions for Waste-Reducing Vending Products. These waste reducing vending products will be a part of the implementation of green vending machines which will be placed in the current Student Union Building(SUB) as well as the new SUB. The overall objective of this project is to reduce the amount of waste generated by students use of disposable products.

As requested by the stakeholder of the project, Justin Ritchie, our team investigates the applicability of adding transportable coffee mugs into the sustainable products provided by the green vending machine. In order to analyze the products and make appropriate recommendations, a triple bottom line assessment is conducted which includes environmental, social and economic aspects. This report will investigate into the energy consumption of the vending machine and different materials including stainless steel, ceramic, plastic and paper.

For each material, multiple factors are examined to evaluate their feasibility such as manufacturing energy consumption, life cycle cost, potential health issues, and waste management. By considering all these factors into the assessment, a conclusion in terms of recommendation of a respective product is made to the stakeholder of the project and will potentially be offered by the green vending machine.

2.0 ENVIRONMENTAL CONSIDERATIONS

The following sections discuss the environmental impacts of all four candidate coffee containers with a strong focus on life cycle energy consumption, associated emissions and waste management.

2.1 DISPOSABLE PAPER CUP

The largest negative impact of paper cups is its environmental footprint. These single use items can all be seen scattered around, with minimal decomposition. This is due to the inside coating of polyethylene plastic. The only way to return these cups to their base elements is to bury them in landfills for many years. Mostly because of structural issues, paper cups are regulated to contain no more than 10 percent recycled paper, increasing demand of trees for the new card stock. In the US, 23 billion coffee cups are consumed a year; and the production cost mirrors this. 9.4million trees are consumed, 5.7 billion gallons of water, and 7 trillion BTUs of heat are consumed for the production of the 23 billion coffee cups. For a 16oz paper cup, the CO2 production cost is 110g per cup. The end result is 363 million pounds of waste created annually(The Basic Problem with Coffee Cups, 2009).

2.2 REUSABLE CERAMIC COFFEE MUG

Ceramic mugs consume much energy over their lifetime and therefore cause damage to the environment. Ceramic mugs also damage the environment through their dependency on detergents which is an ongoing need throughout their lifetime. On the other hand, using ceramic mugs promote waste reduction and energy saving which could potentially compensate for the environmental damages.

The entire life-cycle of ceramic mugs include preparation of ceramic dough, casting, moulding, pressing the dough, firing of mugs, packaging and transportation of the finished products, and utilization of ceramic mugs and their disposal. The primary input materials are Kaolinite 0.28Kg/cup, Silicon 0.14Kg/cup, Feldspar 0.14kg/cup and water 1.1 liter/cup.

(FROM :http://sustainability.yale.edu/sites/default/files/mita_broca_report.pdf))

Much of the environmental footprint of the ceramic manufacturing process takes place in the molding, pressing, and firing stages. The amounts of pollutants emitted in these two steps are illustrated in the tables 2.1 and 2.2 below. In table 2.3, the amounts of energy and detergent needed to wash the cups are also determined. Note that in tables below, each plate is assumed to contain the same amount of material as a mug and emit the same amount of pollution.

Inputs	**Quantity** Per 2960 plates
Ceramic dough	4765.6 kg
Natural gas (heat)	9915.6288 MJ
Electricity	26208 MJ
Emissions to air	In kg/2960 plates
Carbon dioxide	6.47×10^{2}
Carbon monoxide	2.00×10^{-1}
Nitrogen dioxide	1.19×10^{0}
Sulphur dioxide	7.76×10^{-1}
Hydrocarbons	7.54×10^{-1}
Particulates	6.28×10^{-2}
Aldehydes	7.98×10^{-4}
Organic compounds	1.44×10^{-3}
Ammonia	1.51×10^{-4}
Fluoride	1.23×10^{-2}
Emissions to water	in kg/2960 plates
Suspended substances	2.07×10^{-4}
COD	6.23×10^{-4}
Oils	6.62×10^{-3}
Metallic ions	4.20×10^{-6}
Fluoride	1.86×10^{-3}
Ammonia	8.67×10^{-4}
Sulphate	3.95×10^{-4}
Nitrate	4.42×10^{-4}
Chloride	2.39×10^{-5}
Sodium ion	3.06×10^{-4}

Table 2.1 Raw Material Consumption, Energy Consumption and Emissions during Casting, Moulding and Pressing of Ceramic Dough

Source: Broca,M <http://sustainability.yale.edu/sites/default/files/mita_broca_report.pdf>

Inputs	**Quantity** Per 2960 plates
Casted, moulded, pressed dough	2228.457312 kg
Natural gas (heat)	35155.4112 MJ
Electricity	7392 MJ
Emissions to air	In kg/2960 plates
Carbon dioxide	2.29×10^{3}
Carbon monoxide	7.08×10^{-1}
Nitrogen dioxide	4.23×10^{0}
Sulphur dioxide	2.75×10^{0}
Hydrocarbons	2.67×10^{0}
Particulates	2.23×10^{-1}
Aldehydes	2.83×10^{-3}
Organic compounds	5.11×10^{-3}
Ammonia	5.35×10^{-4}
Fluoride	4.36×10^{-2}

Table 2.2 Raw Material Consumption, Energy Consumption and Emissions during Firing

Source: Broca.M <http://sustainability.yale.edu/sites/default/files/mita_broca_report.pdf>

Details	**Quantities**
Model name	Model 66 DRWSPW-champion company
Capacity	148 racks/hr
Water consumption	302.5298 kg
Detergent dosage	840.64 kg
Electricity consumption	16 MJ

Table 2.3 Inputs into the Packaging and Transportation

Source: Broca.M <http://sustainability.yale.edu/sites/default/files/mita_broca_report.pdf>

2.3 REUSABLE PLASTIC COFFEE MUG

Plastic coffee mugs have both negative and positive effects on the environment. The positive aspects can potentially compensate for the negative ones depending on the user’s behavior.

Most plastics are petroleum-based so the environmental impacts of oil extraction, transportation and processing must be taken into account when analyzing the overall sustainability of plastic coffee mugs. All three aspects are energy intensive processes and significantly alter the landscape of the production region. The total life cycle of plastics (resource extraction, polymer production, processing, and waste management) accounts for 4% of total primary energy use in high-income European countries. Of this energy, 90% is used in production which accounts for 4% of fossil fuel use in Western Europe (Mutha, Patel) . Figure 2.1 outlines “cradle to gate” energy. This represents the energy required for resource extraction, resource refining and material production.

TABLE III

Energy Requirements for the Production of Petrochemical Plastics[a]

	Total primary energy use (cradle-to-factory gate) (GJ/t)											
Plastic	APME (1999)[b] Western Europe	Pre-1999 APMEb and BUWAL Western Europe	Curlee and Das (1998) USA	Howard (1995) UK	Kindler and Nikles (1980) Germany	Alcorn (1998) New Zealand	OIT (2002) USA	OIT chemical industry profile reports USA	Patel (1999) Germany	PWMI Japan (1999) Japan	Shutov (1999) USA	Worrell *et al.* (1994) The Netherlands
Epoxy resin	140.7	141.7[c]							107.1			
Melamine resin									79.9			
Nylon-6					156			124.3	122.7			
Nylon-6,6	142.3	143.6[d]			154		241.7	135.1–157.4	163.0		147.6	
Phenol formaldehyde resin					82				60.0		89.2	
Polyacrylonitrile									69.3			
Polyacrylate	PMMA, 102.3	PMMA, 111.7[e]			PMMA, 91				82.6[f]			
Polycarbonate	116.8	116.3[g]			107				80.3		158.5	
Polyethylene (PE)				85				74.1–80.5	64.6			
Polyethylene, high-density	*79.9*	*81.0*[h]	*84.8*		*70–72*	*103*	*131.5*			*65.7*	*98.1*	
Polyethylene, low-density	*80.6*	*88.6*[h]	*89.5*		*69*	*103*	*136.0*			*69.2*[i]	*103.2*	*67.8*
Polyethylene, linear low-density	*72.3*	*83.0*[h]					*121.1*					
Polyethylene terephthalate (PET)	76.2–77.5[i]	81.7–83.8[j]	113.2		84–108	106			59.4	60.0[k]	106.4	78.2
Polypropylene			79.5		73	64[l]	126.0	54.5			95.3	63.2
Polystyrene	86.7[m]	86.3[n]	79.7	96	80–82			100.0–104.5	70.8	68.5	117.1	82.7
Polyurethane (PUR)	104.4–104.9[o]	104.4–104.9[p]		65	98	74			75.5[q]		73.7	
Polyvinyl acetate		66.8[r]							58.2			
Polyvinyl chloride	56.6[s]	56.7[t]	59.5	59	53	70	34.6	44.8	53.2	45.4	79.0	52.4

Figure 2.1 Cradles to Gate Energy of Plastic Production (Mutha, Patel)

Figure 2.1 does not include processing, manufacturing, transporting the final product, or energy used during the service period. It reflects the energy required to get raw plastic, so the energy required to obtain a useable plastic mug would be considerably more. Considering a 100 gram plastic mug made from polycarbonate, 11 680 kJ of energy is required to form the necessary raw materials into plastic. This amount of energy is equivalent to the amount of energy contained in 320ML of crude oil. For the sake of visualization, if a plastic coffee mug was filled with crude oil it would contain enough energy to produce another mug of equal size.

One of the benefits of plastic is that it is recyclable. After the useful life of the beverage container has ended the material can be recycled and used for other manufacturing purposes. However, this benefit would not be realized if the user chose to throw the beverage container into the trash at the end of its life. Plastic is not biodegradable and will likely sit in a landfill for centuries, contributing to the ever-growing problem of waste management.

2.4 REUSABLE STAINLESS STEEL COFFEE MUG

The production of stainless steel coffee mugs is divided into three main stages: The extraction and preparation of ores and production of ferro-alloys, the electricity needed for these processes, the electricity production needed to produce stainless steel, and the production processes at stainless steel sites (International Stainless Steel Forum, June 2010). Then, with the gathered information, the approximate calculation of emissions from a single stainless steel mug is provided.

In descending order of the tables listed below, their contents show: the main ingredients required to produce stainless steel, the CO_2 emissions connected to the extraction of each material, the electricity required for mining and ferro-alloy production, and the production of primary chromium, nickel, and carbon steel scrap (International Stainless Steel Forum, June 2010).

Raw Materials (CO2 ton/ton)	**Element Content**
8.7	32% Ni in ferro-Ni
6.0	56.5% Cr in ferro-Cr
8.5	67% Mo in ferro-Mo

1.4	100% Fe in carbon steel scrap

Table 2.4 CO2 Emissions from Raw Materials Needed to Produce Stainless Steel (International Stainless Steel Forum, 2010)

The results in Table 2.5 quantify the emissions produced during the upstream generation of electricity that is used at the stainless steel site. The amount of CO2 emitted depends on the type of electricity used. Table 2.5 shows the CO2 emitted by each type of electricity plant per mega joule of electricity generated. (International Stainless Steel Forum, June 2010)

Source of Electricity	**Grams of CO2 per MJ**
Hydraulic	1.11
Nuclear	1.67
Combined Cycle	118.61
Natural Gas	245.28
Fuel Oil	247.50
Coal	271.67

Table 2.5 CO2 Emissions by Type of Electricity Generation Plant (International Stainless Steel Forum, 2010)

ISSF estimates that 3,700 MJ of electricity are required to produce one ton of stainless steel at a steelworks. (International Stainless Steel Forum, June 2010) Since different countries have varying CO2 emissions through electricity production as stated by Table 3, “the amount of CO2 emissions connected to the electricity required to produce stainless steel at the stainless steel plant has been calculated to be 0.65 tons of CO2 per ton of stainless steel.” (International Stainless Steel Forum, June 2010)

	Europe	**USA**	**China**	**Japan**	**World**
CO2 (grams of CO2/MJ)	145.7	189.1	228.9	175.4	177.6

Table 2.6 Electricity CO2 Emissions by Country
(International Stainless Steel Forum, 2010)

According to PE International (2009), the amount of CO2 emitted during production of stainless at the steel plant varies between 0.49 and 0.28 tons per ton of stainless. This includes CO2 emissions from the use of fuel on the site where the stainless is produced. (International Stainless Steel Forum, June 2010) "ISSF calculates that average CO2 emissions are 0.36 tons/ton stainless steel." (International Stainless Steel Forum, June 2010)

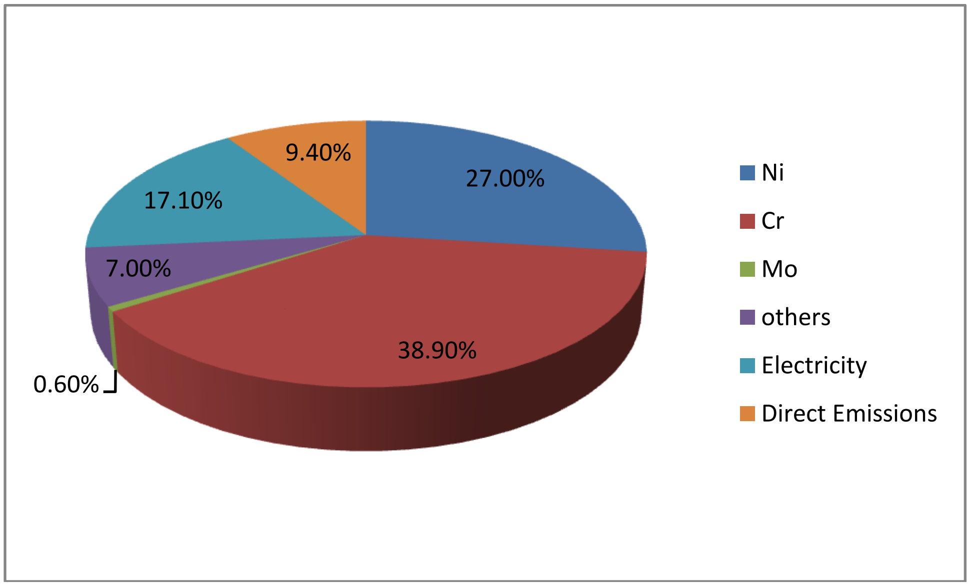

Figure 2.2 Distributions of CO2 Emission
(International Stainless Steel Forum, 2010)

% raw materials	42%
% carbon steel scrap	22%
% stainless scrap	36%

Table 2.7 Steel Compositions
(International Stainless Steel Forum, 2010)

Blast furnace	11%
Electric arc furnace	62%

Mixed route	27%

Table 2.8 Production Method
(International Stainless Steel Forum, 2010)

Emissions from raw materials (ton CO2/ton stainless steel)	2.8
Emissions from electricity and steam (ton CO2/ton stainless steel)	0.65
Direct emissions (ton CO2/ton stainless steel)	0.36
Total Emissions	3.81

Table 2.9 Emissions
(International Stainless Steel Forum, 2010)

Stainless steel is 100% recyclable and has one of the highest recycling rates of any material. It is true that not all stainless steel is recycled, so it is estimated that 70% of stainless are recycled at the end of their life cycle. The world production of stainless steel has increased from less than 20 million tons to over 25 million tons in eight years and part of the 100% recyclability might explain this limited growth.

For example, a stainless steel coffee mug weighs approximately 300g. Then, since there is 3.81 tons of CO2 in 1 ton of stainless steel, there would be 3.81 grams of CO2 in 1 gram of stainless steel. Therefore, the CO2 emission generated from each stainless steel coffee mug would approximately be 1.143kg.

3.0 SOCIAL CONSIDERATIONS

The following sections discuss the social considerations of all four potential coffee containers with a focus on user benefits, user drawbacks and potential health issues.

3.1 DISPOSABLE PAPER CUP

Part of the convenience of using paper cups is that they are a one use item that is thrown away without having to be cleaned. This saves the consumer time and the effort to carry the used cup with them. Many beverage consumers may want to consume more than one beverage in a day, and there is no compounding problem with disposable cups, since each one starts off clean. With reusable cups, the prospect of filling a dirty cup may seem off putting; while washing may also seem tedious. Other social aspects of paper cups is that it carries brand power, allowing the consumer to be associated with the beverage provider; and can even be a display of disposable income.

Safety considerations are minimal with paper cups, as the potentially dangerous plastic coating that could cause leaching is never used twice. This situation minimizes the absorption of plastic.

3.2 REUSABLE CERAMIC COFFEE MUG

Ceramic coffee mugs are convenient alternatives for disposable cups as they come in variety of designs appealing to many consumers. These mugs are easily washed and won't get stained. Ceramic is considered to be the premium material for hot drinks as it insulates heat and will not absorb the odor of the coffee. Mugs can be manufactured to have insulating properties allowing the user's beverage to remain at a desirable temperature over a long time period. Of course, the performance of the mug depends on the manufacturer, cost, type of ceramic and overall design. Ceramic mugs are generally sealable making them suitable for the user to carry with them throughout the day. Many are designed with spill-proof lids as added convenience and safety measures. Ergonomic features can be easily implemented which greatly add to the user's comfort since ceramic is such a versatile material

3.3 REUSABLE PLASTIC COFFEE MUG

The social impacts of employing a reusable, plastic coffee mug in place of other alternatives are difficult to quantify. There are many potential benefits and drawbacks to using a plastic coffee mug, however, each are subjective and are valued differently depending on the individual. The user benefits of plastic coffee mugs are quite similar to those mentioned in the previous section regarding ceramic mugs, mainly insulation, safety and ergonomics.

Despite the advantages of plastic coffee mugs, there are drawbacks that cannot be overlooked. Some individuals may feel burdened by having to carry a mug with them all at all times and would never consider using one due to this inconvenience. The initial purchase cost may also turn away potential users. However, the most compelling disadvantage, and the one that is not at all based on user preference, is the potential toxicity of plastic beverage containers.

Bisphenol A (BPA) is commonly used in the production of polycarbonate plastics, food cans, plastic packaging and other everyday items. Animal studies on BPA have identified it as an endocrine disrupting chemical that can have negative effects on reproductive function in high enough doses. Analysis of BPA in urine samples has shown that BPA is present in 93% of the United States' population (Belcher, Cooper, Kendig, 2011).

A study performed by Belcher, Cooper and Kendig attempted to measure the rate of BPA migration into pure water at room temperature held by beverage containers manufactured from different materials. A chart of the findings is presented in Table 3.1.

ID Number	Material	Brand	Conc. (ng mL−1)	Migration (ng h−1)
1	Polycarbonate	Nalgene	0.306 ± 0.060	0.240 ± 0.033
2			0.178 ± 0.028	0.154 ± 0.021
3			0.199 ± 0.024	0.170 ± 0.017
4			0.251 ± 0.066	0.216 ± 0.044

1	Tritan™	Nalgene	0.007 ±0.005	0.007 ±0.003
2			0.008 ±0.002	0.005 ±0.001
3			0.008 ±0.003	0.006 ±0.002
1	Stainless steel	Steel Works	0.026 ±0.023	0.014 ±0.007
2		Sigg	0.056 ±0.018	0.043 ±0.012
3			0.010 ±0.004	0.009 ±0.003
1	Al EcoCare™	Sigg	0.006 ±0.003	0.005 ±0.001
2			0.028 ±0.008	0.021 ±0.002
3			0.016 ±0.001	0.014 ±0.005
4			0.016 ±0.001	0.013 ±0.004
1A	Al/epoxy	Sigg	0.140 ±0.014	0.120 ±0.005
2A			0.131 ±0.019	0.151 ±0.005
3A			0.091 ±0.004	0.075 ±0.001
4A			0.081 ±0.015	0.065 ±0.011
5A			0.104 ±0.022	0.094 ±0.006
6A			0.059 ±0.019	0.044 ±0.009
1B	Al/epoxy	New Balance	1.902 ±0.522	1.710 ±0.311
2B			0.767 ±0.058	0.658 ±0.016
3B			0.931 ±0.211	0.840 ±0.080
4B			1.305 ±0.979	1.072 ±0.072

Table 3.1 BPA Migration Experiment (Belcher, Cooper, Kendig, 2011)

One interesting fact discovered during this experiment was that higher temperature liquids greatly increased the BPA migration rate from containers made from polycarbonate (Belcher, Cooper, Kendig, 2011). Since coffee is considerably hotter than room temperature, the actual amount of BPA released into the beverage would be greater than the presented data. It is clear from the experiment that in order for a plastic coffee mug to be considered as a viable solution, it must not be manufactured from polycarbonate. Nalgene's Tritan plastic is a potential solution but after browsing their website, no coffee mugs were found - they only manufacture water bottles. Since Nalgene is unlikely to reveal the constituents of Tritan, it may be difficult to find a suitable BPA-free coffee mug from another manufacturer.

3.4 REUSABLE STAINLESS STEEL COFFEE MUG

The ease of cleaning stainless steel surgical instruments and appliances is an obvious illustration of the way the material helps safeguard peoples' health as this can be applied to cleansing stainless steel coffee mugs. Also, stainless steel is an exceptionally neutral and corrosion resistant material and for this specific reason, it is a normal choice in the food industry, pharmaceutical production, or for medical devices. "Stainless steel [] largely prevents the formation of any nutritive medium upon which bacteria can grow." (Euro Inox, July 2006)

Although stainless steel is pricier than its competitors, its other qualities, such as being highly resistant to breaking, large dent resistance, light weight, and long term durability overshadows the extra financial cost of the vendor and the buyer. Also, pure stainless steel products are BPA - free with the absence of plastic. Stainless steel has a 10% chromium coating and does not need a 'lining', this chromium coating assists with protecting the stainless steel from corrosion, ensuring a long lifespan. Further research would have to be done regarding a specific stainless steel mug and its potential health issues.

4.0 ECONOMIC CONSIDERATIONS

The following sections discusses the economic considerations of all four potential coffee containers with a focus on the financial benefit of re-usability and the associated costs of environmental impacts outlined in Section 2.

4.1 DISPOSABLE PAPER CUP

Since paper cups are well established in many different restaurants, we can assume that they are the lowest cost alternative. A somewhat new idea is to encourage the customer to bring their own cup. This would reduce cost through having less storage, fewer cups that need to be bought, and reducing store garbage. This idea is easy to market, as is can be presented as an eco-sensitive alternative, and have a price incentive. This is seen in many stores that serve coffee, but not seen as frequently in restaurants. A standard metal coffee cup is estimated to last 3000 cycles, and if the store offers a mild 10 cents per use, this system can potentially save the customer $300 per metal coffee cup. As we can see, reusing a cup financially benefits both the store and customer.

4.2 REUSABLE CERAMIC COFFEE MUG

To simply practice sustainability by using a reusable coffee mug, one should theoretically use the same cup several times. Therefore the question boils down to how many times a consumer should use the same reusable cup so that its economic impacts (mainly energy consumption) become less than that of a disposable cup?

Firstly, the amount of manufacturing energy, transportation energy and maintenance energy per use (mainly washing and sanitizing) must be figured out in order to decide if the ceramic cup is the more economic product to be placed in the vending machine. For the purpose of calculations, the two equations below have been derived. In the equations below, A represents the energy required to manufacture one single reusable cup. B is the energy requirement of one time washing and sanitizing the mug, while E expresses the number of times the cup is used before washing. For example the consumer might drink two cups of coffee in the same cup consecutively and skip washing the cup. F represents the number of refills before and after using the cup. In the second equation, an additional parameter G is added which stands for the energy recovered from recycling the material.

Total Energy Consumption per use of a reusable cup = (A+EB)/(E+F)

Break Even Number of Uses = (A-G)/((C/D)-(B/(E+F)))

(http://www.springerlink.com/content/c275588280002wp8/fulltext.pdf Hocking, M.B)

The equations above take into account the energy required to make and maintain a reusable cup. The boundaries of this energy evaluation are from the point raw materials are extracted to the point of final product. Unfortunately, size of the mass producing factory, efficiency of electricity generated and hygienic washing method are also varying. As a result, some assumptions have been approved by the researcher(s) to simplify the calculations. 48.2Kj/g is required to make a ceramic cup and it weights an average of 292.3 grams. Accordingly, the ceramic cup needs to be used at least 39 times to break even with the energy required to make a typical disposable cup and should be used about 1000 times to fully neglect the manufacturing energy. Figure AA is a graph of energy consumption per use versus number of servings for different materials which proves that reusable cups become more sustainable as they are used more often. Figure BB illustrates energy cost of producing a mug in multiple steps according to different sources.

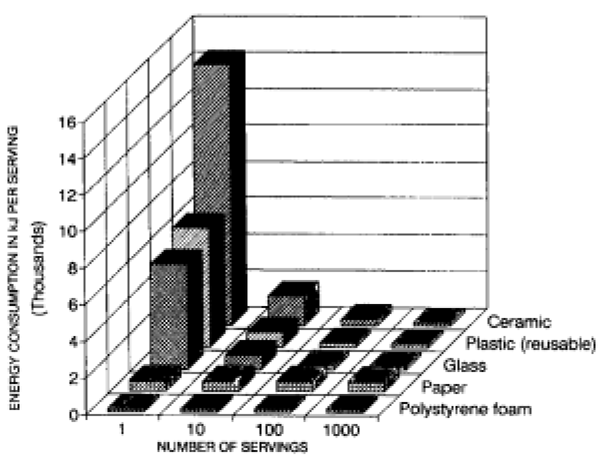

Figure 4.1 Energy Consumption per Use vs. Number of Servings
Source:(http://www.springerlink.com/content/c275588280002wp8/fulltext.pdf Hocking, M.B)

Table 1. Energy costs to produce ceramic tableware

kJ/g	Remarks	Reference
7.91	Firing only, teapots, mugs, etc., >1985	Holmes (1987)
8.40	Glazing only, hotel porcelain, 3 tonne/day	Becker (1980)
16.8	Firing only, teapots, mugs, etc., <1985	Holmes (1987)
21.4	Average for 19 UK earthenware factories, 1989[a,b]	Energy Efficiency Office (1990)
48.2	Firing and glazing, Dutch experience, total energy required from materials in the ground[c]	van Eijk and others (1992)
53.2	Average for 12 UK china/porcelain factories, 1989[b,d]	Energy Efficiency Office (1990)
58.8–88.2	18th, 19th century experience, coal firing, Staffordshire and Pakistan	Rice (1987)
180.5	Small scale (1 m^3, 35 ft^3) gas-fired, downdraft kiln, 400 mugs/cups per batch[b]	Dexter (personal communication)

[a]Range reported for earthenware was 2.53–54.6 kJ/g.
[b]Drying, firing, and glazing energy only.
[c]Includes 9.1 kJ/g as electricity.
[d]Range reported for china/porcelain was 26.5–85.1 kJ/g.

Figure 4.2 Energy Cost of Ceramic Production
(http://www.springerlink.com/content/c275588280002wp8/fulltext.pdf, Hocking, M.B)

4.3 REUSABLE PLASTIC COFFEE MUG

The economic factors of employing a plastic coffee mug are difficult to analyze since they can be looked at from both society's and the user's perspective.

As mentioned, it takes roughly the equivalent energy of 320 mL of oil to create the plastic needed for one coffee mug. At today's oil prices that amounts to approximately $0.20 worth of energy. However this does not factor in labor, equipment and transportation costs for resource extraction and material processing – all of which would be difficult to determine. Society also has economic responsibilities at the end of the beverage container's life - disposal and recycling costs could be factored in as well.

Perhaps the easiest way to analyze the economics is to consider the purchase price of the container since the cost of production process is passed on to the consumer. Further analysis would be needed to locate suitable vendors and discuss bulk purchase discount, giving a more accurate overview of the economic feasibility of plastic coffee mugs.

4.4 REUSABLE STAINLESS STEEL COFFEE MUG

Stainless Steel is used in a variety of applications such as industrial applications, home use, and transportation. As seen in Table 7, countries import and export large quantities of stainless steel to each other which stimulates the economy. Although only a small portion of this would be allocated to stainless steel coffee mug production, stainless steel, itself, has a substantial market.

	NAFTA	Latin America	Western Europe	Eastern Europe	Middle East	Africa	Asia	Others	**Total**
NAFTA	335.8	51.8	148.3	1.3	2.3	1.4	103.2	0.7	**644.9**
Latin America	19.9	47.2	17.7	0.9	1.4	2.0	17.6	0.1	**106.8**
Western Europe	620.2	87.5	5,189.1	567.2	67.7	64.9	567.5	29.9	**7,193.9**
Eastern Europe	8.3	0.6	184.9	99.9	0.6	1.3	7.0	0.0	**302.6**
Near/Middle East *	3.4	-	13.4	0.5	52.1	0.9	8.3	0.6	**79.2**
Africa	45.1	26.8	118.2	3.8	20.3	9.3	91.3	0.7	**315.6**
Asia	342.5	119.5	774.5	157.0	191.4	68.6	3,971.8	87.5	**5,712.7**
Others	0.2	0.6	8.5	0.9	0.2	0.1	4.9	1.0	**16.4**
Total	**1,375.6**	**334.0**	**6,454.6**	**831.5**	**336.0**	**148.4**	**4,771.6**	**120.5**	**14,372.1**

Table 4.1 Foreign Trade Flow Stainless Steel Products in 2010 (1000 metric tons)
(International Stainless Steel Forum, 2010)

By promoting stainless steel coffee mugs, this would benefit the local/domestic/ international suppliers/manufacturers of stainless steel. If the demand for stainless steel coffee mugs were to increase the supply and constant recyclable nature would also increase; thereby, resulting in a good economic life cycle.

The life cycle of a stainless steel coffee mug would include the production, maintenance, and recycle cost. Further analysis into local/domestic/international suppliers would provide an accurate cost approximation for manufacturing a stainless steel coffee mug.

5.0 VENDING MACHINE ENERGY CONSUMPTION

As mentioned in previous sections, our product the transportable coffee mug will be held and sold in the "Green Vending Machines" at various locations on campus. While concentrating on conducting the triple bottom line assessments of the products, we should not overlook the energy consumption of the vending machines themselves. The "green vending machine" that will be implemented, should not only be used to sell "green products", but also be reasonably sustainable to fit the objective of the project. This section will provide an in-depth look on the power consumption of green vending machines, and investigate into possible solutions for reducing the energy used.

It is an undoubted that vending machines are significant sources of energy consumption in public places, as they generally operate 24 hours per day, and 7 days a week. In addition to the electricity they consume, they also increase the cooling loads of the positions they locate. Measurements at the National Renewable Energy Laboratory (NREL) have shown that a typical vending machine that dispenses 500 cans of soft drink with an illuminated front panel consumes between 7 and 11 kWh/day in a public environment, which can be converted into a range of 2500 to 5000 kWh of electricity consumed per year. (M. Deru, 2003)

The number of vending machines has also greatly incremented over recent years. A recent research conducted by the Department of Energy (DOE) of the United States has shown that there are more than three million vending machines in US or one machine for every 100 Americans. With the considerable number of vending machines in service, the problem of their power consumption has been escalated as well. Thus, it is important for us to realize a solution to harness vending machines' powerful automated functionalities without breaking our goal of improving sustainability.

In order to regulate the energy efficiency of vending machines, and encourage more sustainable designs of new generation vending machines, the Department of Energy (DOE) and United States Environmental Protection Agency (EPA) have co-authored the "Energy Star" standards for vending machines. Those vending machines which meet the requirement specified by this standard are eligible for being labeled as "Energy Star" products. The specifications of the “Energy Star” standards are outlined in the table below.

Energy Consumption	
Old Criteria — Effective April 1, 2004	**Current Criteria — Effective January 1, 2007**
Y = 0.55 [8.66 + (0.009 x C)]	Y = 0.45 [8.66 + (0.009 x C)]
Y = 24 hr energy consumption (kWh/day) after the machine has stabilized C = vendible capacity	

Table 5.1 the "Energy Star” Specification of Vending Machine

Source: Energy Vending Machines Purchasing & Procurement

<http://www.energystar.gov/index.cfm?c=vending_machines.pr_proc_vendingmachines>

The average amount of energy consumed by vending machines also varies between different types of vending machines for different purposes such as beverages, snacks, frozen/normal foods, and general goods. However, vending machines consist of several functional components, which generally include: display boards, coin mechs, bill validator, vending motors and internal circuit boards. The components listed here together determine the power consumption of the vending machines. In addition, the vending machines that have internal refrigerators to provide cooling functions (usually beverage or frozen food vending machines) will certainly consume more electricity.

As stated above, vendors of vending machines are encouraged to meet the requirements of the "Energy Star" standard of vending machines. This standard will also be an important factor for stakeholders of the project to consider when purchasing the "green vending machine" for this project. Moreover, as the client of vending machines, it is unrealistic for us to change any internal components or designs of the vending machines in order to reduce their energy consumption. However, there are still a series of improvements can be implemented to significantly reduce the power consumption of vending machines, which are introduced in the following details:

- **Low Power Mode**

A lot of vending machines are designed with low power mode and can be configured to switch to low power mode automatically during periods of extended inactivity. (E Source Companies, 2009) During running in low power mode, the vending machines will switch off the lights to facilitate the saving of additional energy where appropriate. In addition, the vending machine will be able to resume to its normal operating conditions at the conclusion of the inactivity period. Also, there are some vending machines are equipped with LED lights instead of traditional gas-discharge lamps with ballast will contribute to a further reduction of energy consumption.

- **De-lamp Vending Machines**

Another way of reducing the energy consumed by the vending machine is to completely de-lamp the lights used in vending machine and fully utilize illuminations from the environment. In fact, the lights and ballasts used in vending machine (without refrigerators) are the most significant source of power consumption, which consume on average 180 Watts according to the research done by NREL. (M. Deru, 2003) At a rate of $0.06 per kWh for electricity, de-lamped vending machine can produce savings of approximately $100 per year. In addition, we could potentially increase the social acknowledgement of the project objective by implementing a special decoration for de-lamped "green vending machine", such as a sign that says "This machine is operating without lights to save power."

- **Energy Saving Sensors**

In addition to the above methods, the use of energy saving sensors, also referred to as occupancy sensors, will reduce the vending machines' power requirements during long periods of inactivity, such as nights and weekends. The occupancy sensor and controller, typically in the form of an infrared sensor, is used to monitor the active movements around the location of the vending machine, and power down the vending machine or switch it to the low power mode when there is no activity detected for a period of time, and reactivate the vending machine when motion is detected. According to the data provided by Bayview Technology - a energy saving solution provider, energy saving sensors save between 30~50% of the annual electricity costs of a vending machine, depending on the application and occupancy of the location. (E Source Companies, 2009) This occupancy sensor option could be considered as an add-on or replacement to the de-lamping when it's not advisable.

To conclude, following the importance of energy consumption, the model chosen for "green vending machine" implemented in this project should be assessed carefully in terms of their power efficiency; and "Energy Star" branded products are more recommended. Moreover, there are certain procedures and methodologies of improving the sustainability of the "green vending machine" that are highly recommended.

6.0 CONCLUSION & RECOMMENDATIONS

It is not a common occurrence for a practice to benefit the merchandiser, consumer, and environment at the same time, yet it is a possibility with reusable cups. The consumer can save money, the merchandiser does not have to purchase as many cups, and the produced waste declines. The only obstacle in the way is a perceived stigma regarding reusable cups. The difficulty would be to encourage the majority to continually use reusable cups.

Energy consumption regarding the life-cycle of ceramic mugs is quite high. As a result, they require several number of usages to compensate the environmental and economic damages caused during their life-cycle, thus the ceramic mug is not a applicable product to be placed in the vending machine. We do not recommend employing reusable plastic coffee mugs because of the potential health risks of plastic coffee mugs due to BPA migration and our inability to locate a suitable product. Plastic toxicity is a fairly recent issue and we currently do not have enough information to make a confident decision concerning product safety. We do, however, recommend stainless steel coffee mugs due to its 100% recyclable nature and durability. Also, since we use stainless steel in so many other areas, such as pipelines, household appliances, and medical devices, we have found no potential health risks associated with stainless steel products. The only downside of stainless steel products is the high energy consumption and its high CO_2 emissions.

If reusable coffee mugs are to be sold from vending machines in the new SUB, we recommend they be made of stainless steel. However we feel further research is necessary regarding public perception of reusable mugs. Individuals that are concerned about the environment or consider a travel mug to be convenient most likely already own one and will not need to purchase them from the vending machines in the SUB. Those that do not use a travel mug likely have reasoning behind their decision. For example, some individuals may consider them an inconvenience or some may not want to pay the initial purchase price. More research should be done into the reasons why reusable mugs are being neglected. This research may support implementing incentives for using a travel mug, conducting information sessions to educate individuals on the effects of using disposal cups or forgoing the concept of a vending machine selling reusable coffee mugs altogether.

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