CHBE 484

A Life-Cycle and Economic Analysis: Paper Versus Ceramic Plates in the Barn Restaurant

April 18, 2006

Prepared for Dr. X.T.Bi

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April 18, 2006

ATTN: Mr. Andrew Parr and Ms. Brenda Sawada

Dear Mr. Parr and Ms. Sawada,

RE: Life Cycle Analysis of Paper and Ceramic Plates for the Barn Restaurant Report

The Barn restaurant has been in operation for many years, and the possibility of switching from disposable tableware to reusable tableware is being considered for both sustainability and cost-effectiveness. For this purpose, both a life cycle analysis and a cost analysis will be investigated.

This report will outline the investigation results and assumptions that have been made. If you should have any questions about this report, please do not hesitate to contact us.

Sincerely,

Kevin To, Winnie Chan

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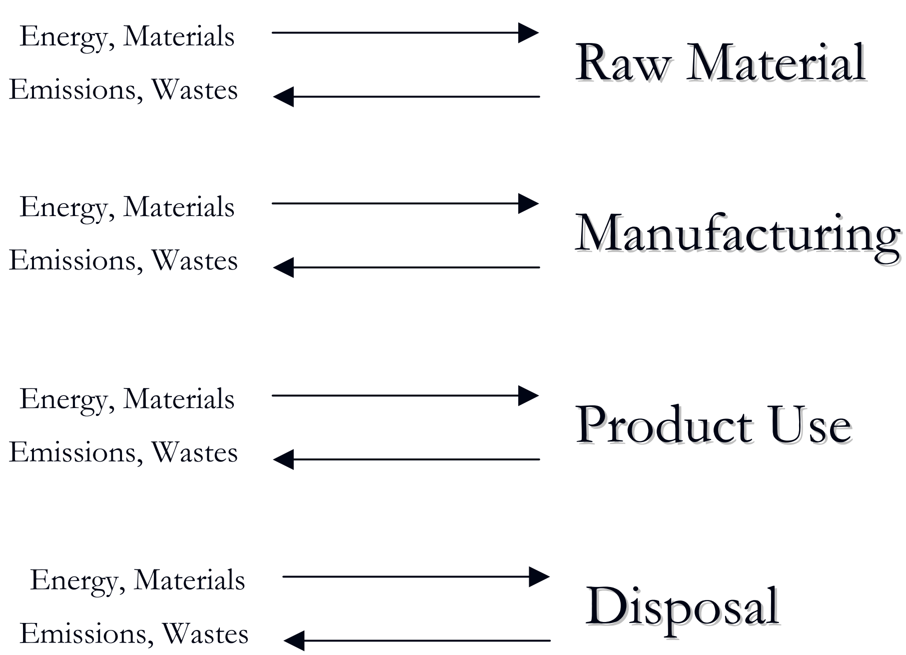
1.0 Introduction

Restaurants today not only have to ensure that their food taste good to customers, maintain excellent customer service, provide acceptable aesthetics, but also limit the ecological footprint the restaurant is making. In this report, the benefits and disadvantages of switching from disposable tableware to reusable tableware in the Barn restaurant at the University of British Columbia are compared. A method that can effectively evaluate the predicted outcome for this switchover is required. The life cycle assessment will be adopted to quantify the environmental impact, and the economic analysis will be adopted to ensure that the function is still profitable. Therefore, both the results from economic analysis and life cycle assessment will be used to assess whether a reusable alternative or the existing disposable tableware is more feasible.

A life cycle assessment is an analysis of energy, material, and waste flows in the life time of a product. The life time starts from raw material acquisitions to ultimate disposal and is divided into four parts as shown is Figure 2.1.

Figure 1.1 – Life cycle assessment framework



Life cycle assessment can be used for environmental impact, risk, and cost assessment. Applications of life cycle assessment include product improvement, comparisons, strategic planning, and public policymaking. This project will include a life cycle assessment in comparing the environmental impacts caused by the use of disposable paper plates versus reusable porcelain plates. However, sometimes it is not easy to accurately quantify or relate environmental impacts; therefore, it is necessary to obtain comparable data in order to make a more effective comparison.

2.0 Reusable table ware

The choice of materials for different table wares are: china for paper plates and cups, while stainless steel is for cutlery. The analysis given in this section will mainly focus on chinaware.

2.1 Chinaware

Typical chinaware used for table ware or cooking ware such as pottery, plates, and cups are classed as ceramics. There are two major types of ceramics: advanced and traditional. The proposed type of china plates for replacing paper plates in the Barn is porcelain ware, which is grouped under one of the traditional ceramic categories. (See Figure 2.1)

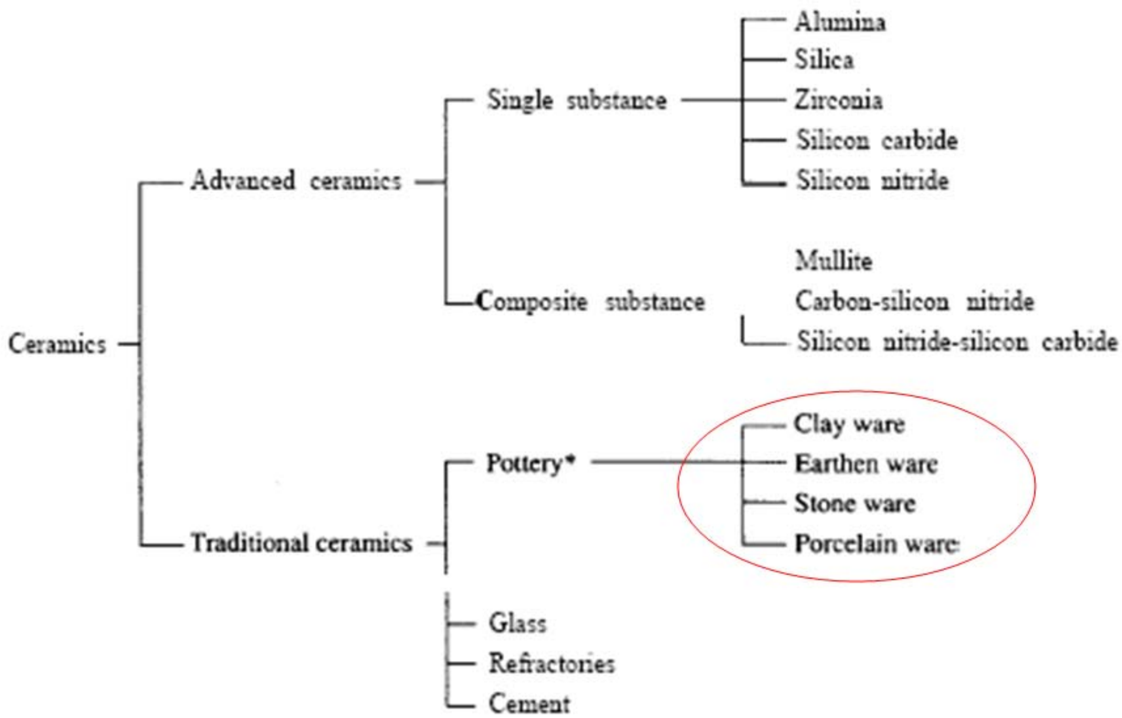


Figure 2.1 Classifications of Ceramics

Porcelain wares are produced by firing raw materials at 1250+˚C until the product becomes translucent. The shrinkage rate of porcelain is about 15%. Other types of pottery require lower firing temperature and thus the shrinkage rate is also lower. Inorganic substances such as alumina (Al_2O_3), silica (SiO_3), zirconia (ZrO_3), and silicon nitride (Si_3N_4) are the major compositions found in modern ceramics.

2.2 Ceramics Manufacturing

Ceramics are manufactured mainly in the Asia, namely China, Thailand, Sri lanka, India, and Japan. Although ceramic products come from different countries, the manufacturing processes are essentially the same. Major processing steps after the extraction of raw ceramic materials include crushing, blending (mixing), forming, drying, firing, and finally packaging. Figure 2.2 shows a simplified ceramics manufacturing process.

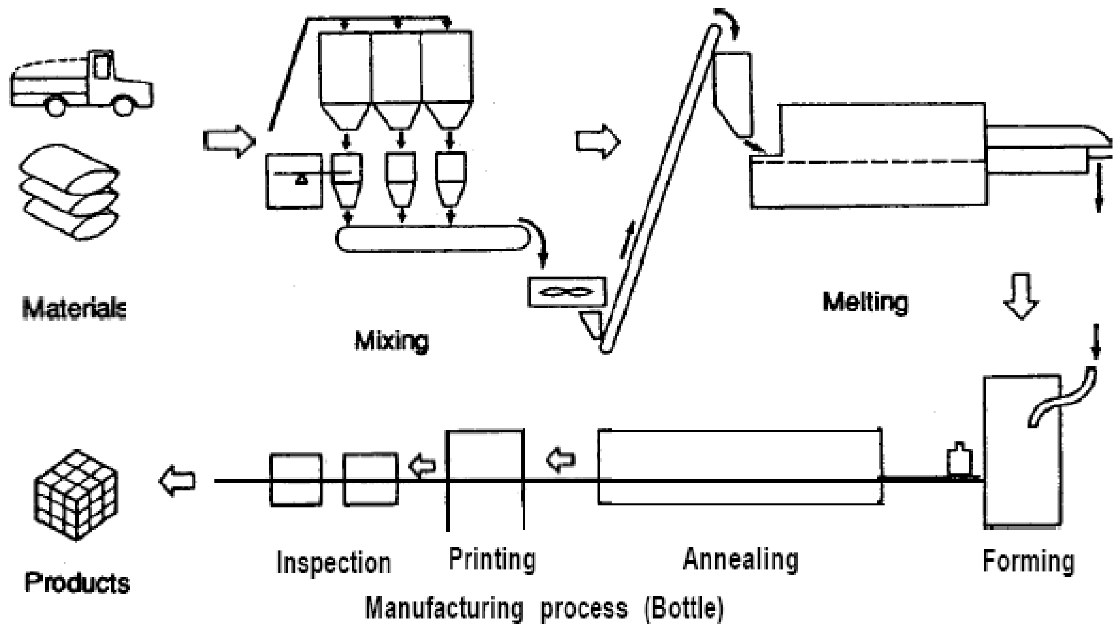


Figure 2.2 – Simplified process flow diagram for ceramics manufacturing

Drying and Firing are the most energy intensive procedures of the entire process, which cost about 5 – 20% of the total ceramic production costs. The sources of energy in the manufacturing process can be divided into three types: heavy oil, liquefied petroleum gas, and electricity. Heavy oil and liquefied petroleum gas are fuels for heat in the drying and firing processes; they account for 65% and 13% of the total energy consumption respectively. Electricity is transformed into mechanical energy for crushing and blending, and that account for about 22% of the total energy consumption. This energy distribution will be used to compute the corresponding environmental impacts and emissions. From literature, the total amount of energy required to produce 1kg of porcelain plates is estimated to be 20,000kJ.

2.3 Emissions

Emissions coming from the manufacturing process are estimated using emission factors found in literature. The majority of air emissions come from the firing process, because the heat required by firing porcelain plates are mainly supplied by burning fuels like natural gas. Some major identifiable air pollutants include CO_2, CO, SO_x, NO_x, HF, volatile organic compounds (VOC), and particulate matters (PM). These air pollutants could contribute to environmental problems like global warming, smog formation, and acid rain. The impacts of these problems will be discussed in the following section. Assuming 400 porcelain plates are needed for the business to operate smoothly, the corresponding total mass of emissions are computed based on the average mass of 600g per porcelain plate. Table 2.1 shows the masses of major emissions for the production of 400 units.

Table 2.1 – Major emissions for producing 400 porcelain plates

Emissions	Mass(kg)
SO_2	0.340
NOx	0.484
CO	0.296
CO_2	147.523
VOC	0.039
PM	0.44
HF	0.41
Fuloride	0.50

These values include emissions from direct manufacturing of the porcelain products as well as the emissions indirectly from electricity generation that is required for the process.

3.0 Disposable table ware

3.1 Paper Manufacturing Process

3.11 Raw Materials Preparation

Logged trees are transported to a paper mill. The first preparation steps of the lumber include debarking and chipping. The bark must first be treated by being placed in a rotating drum where bark is removed by rubbing against each other and against the rotating drum. This process requires approximately 8.5 kWh/t raw material of electricity. The bark that is removed from this process can then be utilized as fuel. After debarking, the logs are then chipped, usually in a radial chipper. These chips are then conveyed to the digester for the next step - pulping. Conveying consumes a large amount of energy, namely, 30.3 kWh/t of raw material.

3.12 Pulping

Wood typically contains 50% fiber, 20-30% non-fibrous sugars, and 20-30% lignin (Kline). In order to free the fibers from lignin and then suspend the fibers in water, pulping is carried out. There are two main pulping processes which include mechanical and chemical.

Mechanical pulping is an older technology that is used mainly for lower grade papers such as newsprint and recycled paper. The pulp produced by this method yields weaker paper. This method grinds raw materials down to individual fibers and the yield is the highest of all methods of pulping. The most common mechanical pulping method is the thermo-mechanical pulping. This mechanical pulping method produces the highest grade of all mechanical pulping methods. However, drawbacks to this process include the high-energy requirement and the darker coloured pulp produced. In this process, wood chips are steamed before the refiner process, and steam consumption is approximately 0.9 GJ/t of pulp. Electricity consumption is approximately 2041 kWh/t pulp.

Chemical pulping is the most common method for wood pulping in the United States. About 82% of pulp produced is by using chemical process. Chemical pulping produces pulp of very high quality and is used in high quality paper production. A down side to this process is that the yield can be quite low at 40% to 55%. The most common of the chemical process is the Kraft (Sulphate) process. Wood chips must be pre-steamed in this process to remove any trapped air. Then a highly alkaline solution containing sodium hydroxide and sodium sulfide called white liquor is added along with wood chips into a digester. The digester is then heated to about 170^{o}C and pressurized. The white liquor permeates the chips over several hours in the digester and dissolves the non-fibrous materials in the wood. The fibers are then separated and are blown into low-pressure tanks where spent liquor and contaminants are washed away where they can be concentrated and burned to recover energy. The fibers then move to the bleaching process. This pulping process consumes roughly 4.4 GJ/t pulp of steam and 406 kWh/t pulp of electricity. The chemicals used in this process can be recovered. The black liquor can become concentrated and recover energy, and the remaining liquor can be recausticized. Concentration of the black liquor takes place in multiple effect evaporators and direct contact evaporators where steam is used to evaporate water from the black liquor. The Direct contact evaporator uses exhaust gases from the recovery boiler to make the process more efficient. This side process requires about 4.4 GJ of steam/t of pulp and 25 kWh of electricity/t pulp.

Chemical recovery is also available. For example, the lime kiln can calcine the calcium carbonate in lime mud to produce quicklime. The Tampella system can also recover chemicals and energy from the sulfite process through a series of reactions. If the lime kiln recovery system is adopted, 2.3 GJ/t pulp of oil/gas and 15 kWh/t pulp of electricity is required.

3.13 Bleaching

The remaining lignin that is still closely bonded to the pulp must be removed through a series of bleaching stages followed by washing. Before the 1980's, elemental chlorine and chlorine-linked chemicals were commonly used for bleaching; however, due to environmental concerns, alternatives such as ozone, hydrogen peroxide, and enzymes are used instead. Depending on the type of paper, different bleaching methods are adopted. The effluent is usually of biodegradable nature and is treated in a secondary treatment system prior to discharge. The energy required in wastewater treatment will not be investigated. The average energy consumption for bleaching processes is 4.3 GJ/t pulp steam and 159 kWh/t pulp electricity.

3.14 Paper making

Paper making or forming includes three main steps including stock preparation, pressing and drying. Processed pulp enters gap formers and is injected into the head box through a gap of air onto a twin wire unit. Moisture is removed from the fibers through the wires forming a paper web between wires from the pulp. Rolls, blades, and vacuums then facilitate the removal of excess water from the web. Pressing takes place between two felt liners pressed between rotating cylinders. The more water that can be pressed out, the less energy is required for the drying process later on. An additional step in pressing would be to steam shower the pulp to 80^{o}C. By doing this, water can be more easily removed by pressing and reduce dryer loads. Conventional drying methods are being replaced by newer methods such as the Condebelt dryers to reduce energy consumption. On average, stock preparation requires 272 kWh/t pulp of electricity and 0.7 GJ/t pulp of steam. The pressing stage requires about 238 kWh/t pulp of electricity. The drying process requires 10 GJ/t pulp of steam and 21 kWh/t pulp of electricity.

3.2 Emissions

Each plate was weighed to be 16.31 grams, and the equivalent Carbon emission for the paper production process yields 3.80 g C/plate. In one year, 36,000 paper plates yields 136.8 kg C. This is calculated from literature where emissions are associated with individual steps in the production of paper. Also it is assumed that the sub-process chosen is the most common one in industry, for example, a chemical pulping method is adopted instead of a mechanical pulping method. In addition, depending on the fuel type, different emission factors were sought in Carbon equivalent form. As the process emits mainly carbon, the other minor compounds are omitted.

Table 1. Summary of energy usage for paper production process

Raw materials preparation				
debarking	8.5	kWh/t	elec	
conveyor	30.3	kWh/t	elec	
Pulping				
mechanical	1650	kWh/t	elec	
chemical	4.4	GJ/t	steam	
	406	kWh/t	Elec	
recovery boiler	1.1	GJ/t	-10	GJ/t reusable heat
	58	Elec	-17	GJ/t reusable heat
lime kiln	2.3	GJ/t	oil/gas	
	15	kWh/t	Elec	
bleaching	4.3	GJ/t	steam	
	159	kWh/t	elec	
Papermaking				
stock prep	274	kwh/t	elec	
	0.7	GJ/t	steam	
Pressing	238	kwh/t	elec	
drying	10	GJ/t	steam	
	21	kwh/t	elec	

Compared to the Canadian paper process energy consumption, the United States energy consumption is significantly higher. Also, note that the source of electricity in British Columbia is much cleaner than the majority of those from the United States.

Table 2.

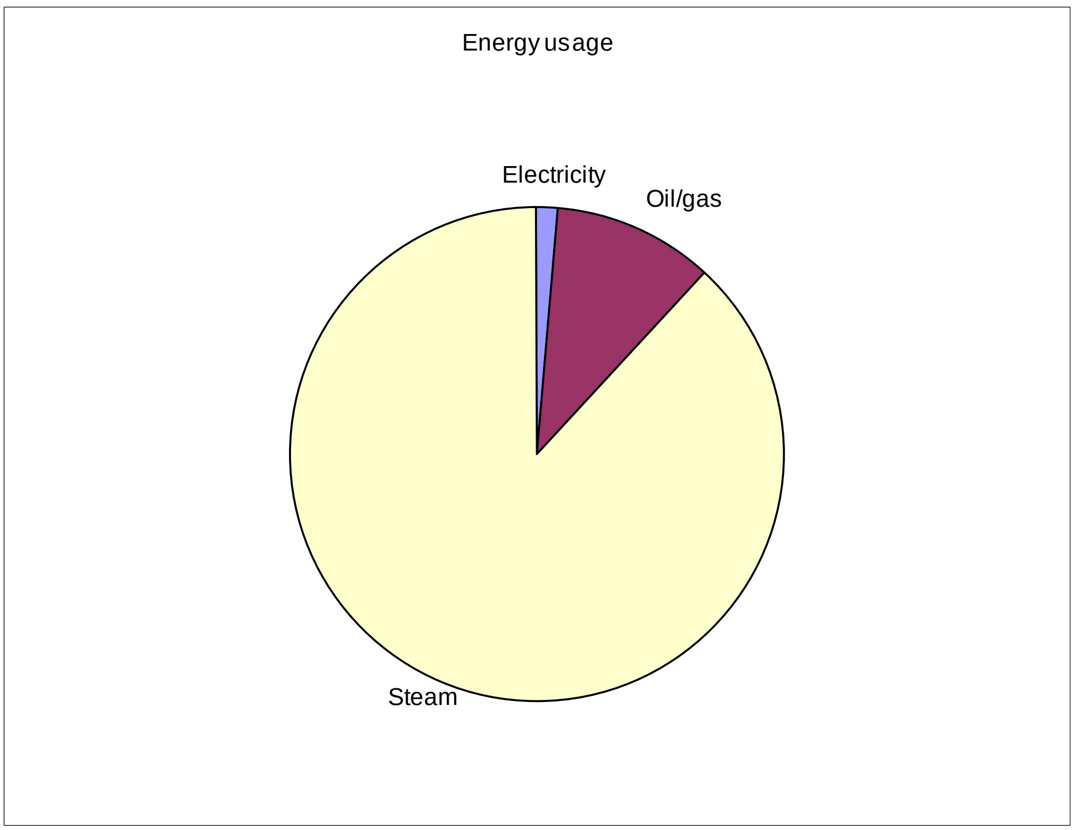
Canadian paper pulp mill energy consumption	
	Electricity kWh/dry tonne
Chip handling	40
Refiners	2160
Pumps, screens, agitators, blowers	240
Heat recovery	10
	2450

Table 3. Equivalent Carbon emissions based on energy source and amount

Raw materials preparation					PJ	Carbon emissions coeff ktC	tC
debarking	8.5	kWh	elec		2.36E-09	1.15E-07	1.15E-04
conveyor	30.3	kWh	elec		8.42E-09	4.08E-07	4.08E-04
Pulping							
mechanical	1650	kWh	elec		assume chemical pulping only		
chemical	4.4	GJ/t steam			0.0000044	0	0
	406	elec			1.13E-07	5.47E-06	5.47E-03
recovery boiler	1.1	GJ/t	-10	GJ/t reusable heat	0.0000011	5.34E-05	5.34E-02
	58	elec	-17	GJ/t reusable heat	1.61E-08	7.81E-07	7.81E-04
lime kiln	2.3	GJ/t	oil/gas		0.0000023	0.00004692	0.04692
	15	kWh/t	elec		4.17E-09	2.02E-07	2.02E-04
bleaching	4.3	GJ/t	steam		0.0000043	0	0
	159	kWh/t	elec		4.42E-08	2.14E-06	2.14E-03
Papermaking							
stock prep	274	kwh/t	elec		7.61E-08	3.69E-06	3.69E-03
	0.7	GJ/t	steam		0.0000007	0	0
press	238	kwh/t	elec		6.61E-08	3.21E-06	3.21E-03

dry	10	GJ/t	steam		0.00001	0	0	
	21	kwh/t	elec		5.83E-09	2.83E-07	2.83E-04	
						1.17E-04	1.17E-01	
					2.31361E-05		0.2331	tonne C emitted per tonne paper
					23136055.56	kJ/t paper		
					23136.06	kJ/kg paper		
					377.35	kJ/paper plate		

Chart 1. Type of energy used over entire paper production process



4.0 Environmental Impacts

People, being residents on the planet, cannot separate themselves from the environment. In the recent decades, those who are aware of the different environmental impacts from industries have been actively adopting ‘greener’ methods of production and usage. Different chemicals all have their respective effects on environmental concerns and health risks. It is necessary to understand what the major environmental concerns are, what causes them, and what impacts they have before comparing the emissions calculated for both types of plates. Global warming, ozone depletion, smog formation, and acid rain formation are the four widely studied environmental concerns.

Global warming is a long term environmental concern caused by greenhouse gases. A greenhouse effect is the consequence of greenhouse gases, which occurs when excess amounts of gases such as CO_2 and H_2O (steam) absorb heat from the sun and are trapped in the atmosphere. As gases and heat accumulate in the atmosphere, the Earth’s temperature rises and as a result, weather and climate changes take place. One degree Celsius change in the Earth’s temperature would have tremendous effects on ecosystem. We have a major concern with having too much CO_2 gas because it has a 120 year life time in the atmosphere which enhances the pace of global warming. From the life cycle assessment of porcelain plates, the total CO_2 and CO emissions are approximately 147.5kg and 0.3kg respectively for 400 plates, which gives approximately 148kg total carbon emission. For paper plates, the total carbon emission is 138kg/yr. Emissions other than carbon are ignored when comparing the global warming impact because they account for insignificant amounts compared to carbon emissions. This assumption is made since environmental impact from different species cannot be comparable if they are not uniform. From direct comparisons, paper plates have less global warming impact than using porcelain plates in the first year. However, assuming an average useful life of two years for each porcelain plate which is considerably conservative, using porcelain plates would still be a better choice in terms of global warming impact.

The ozone layer protects earth surface by deflecting and lowering the intensity of ultra-violent light ray coming from the sun. Stratospheric ozone depletion is caused by the presence of chlorine atoms because they catalyze the photo-dissociation of ozone. Although the presence of ozone at stratosphere is very important, it is a destructive gas at a near earth surface level. The formation of ozone at a lower level is caused by NOx and VOCs, which is leads to another environmental impact: smog formation. In addition, NOx and SOx are contributors to acid rain. However, due to lack of emission data, these environmental impacts were not evaluated. In fact, the actual amounts of these chemicals are expected to be insignificant.

5.0 Economic Analysis

5.1 Paper Plates

It was provided that 1500 paper plates are used per week at the Barn restaurant; however, this number includes both small and large plates. Our analysis is based on 22 cm plates only, so it is assumed that 750 plates of 22 cm are used per week. The unit price for these plates are 3.7 cents each. Assuming that this amount is consistent over the year, annual costs for 22 cm paper plates alone amount to $1325.52. Forms of disposal at the moment are landfill or incineration off campus. Garbage pickup costs were not provided, so garbage removal cost has not been included in this analysis. Another method of disposal that may be possible would be the south campus composting site. However, due to the lack of organic and moisture in the content of the plates, the compost produced from mainly paper plates would not be of high quality. Composting the paper plates would be the most environmentally friendly form of disposal. Emissions from composting, incineration, and landfilling are not been compared due to the complexity of the problem.

Table 5.1. Paper plate cost per year

	paper
Capital cost	
Unit price ($)	0.03682
amount per week	750
price per week	27.615
Total $/year	1325.52

5.2 Ceramic Plates

Ceramic plates have a large price range, anywhere from $0.50 CDN to $8 CDN. The cost estimate in this analysis included a 22 cm ceramic to be taken as $4 CDN. If the plate should cost more or less, table 8 would change accordingly. An analysis was performed on the replacement costs of plates over the years. The ceramic plates are assumed to have a life of five years with no salvage value at the end. Again, if the plates can be used longer, the economics would be even better. The per cent replacement per year has been illustrated and found in table 8. Even if 30% of the plates must be replaced each year, the total annual cost (straight line depreciation with no inflation accounted for) including operational costs would be $980.28, which is still lower than an annual purchase of paper plates which amounts to $1325.52.

The operational costs of a dishwasher has been estimated. Assuming that the existing dishwasher meets health and safety requirements, no capital cost is required for a new dishwasher. A medium sized dishwasher was used in this analysis. Assuming five loads are washed per day for 365 days of the year, $2651.16 will be spent on electricity. There is no information on how much hot water is required for each wash load, so energy required for heating water was omitted.

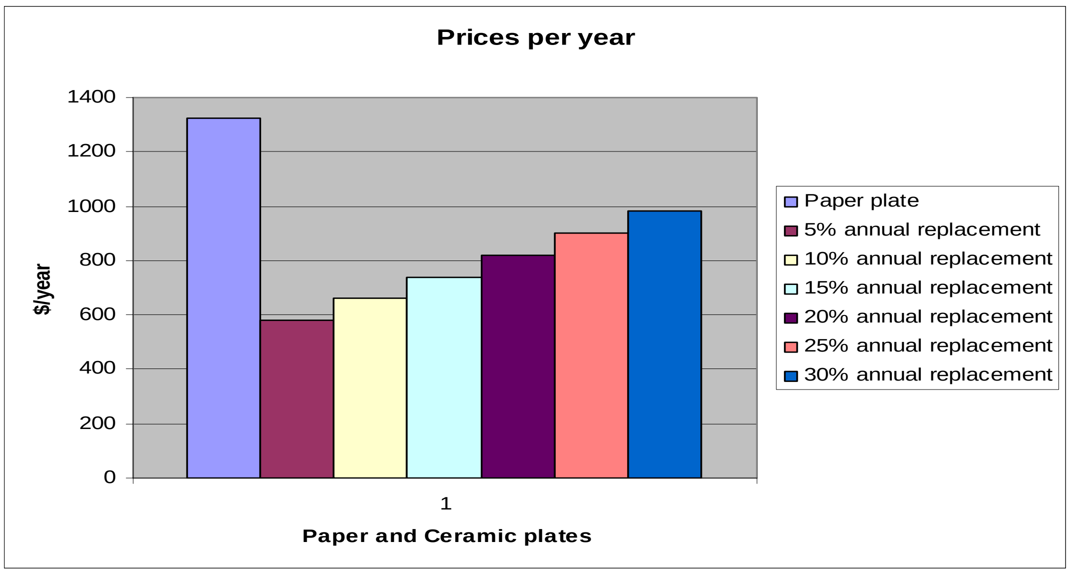
Table 5.2. Dishwasher operational cost

Dishwasher operation cost	
electricity:	
$/kWh	0.068
Dishwasher:	
Electricity	
kWh/yr	2651.163
$/yr	180.2791
Water	
gallon / year	10159
$/yr	0
Operating cost/ yr	180.2791

Table 5.3. Cost of ceramic plates with varying percentage replacements per year

	ceramic	5% annual replacement	10% annual replacement	15% annual replacement	20% annual replacement	25% annual replacement	30% annual replacement
Costs							
Unit price ($)	4						
Unit required	400						
total capital cost ($)	1600	80	160	240	320	400	480
Operating cost (dishwasher)							
Electricity $/yr	180.28	180.28	180.28	180.28	180.28	180.28	180.28
Average Annual capital cost							
Capital/5 years use	320.00	320.00	320.00	320.00	320.00	320.00	320.00
Total $/year		580.28	660.28	740.28	820.28	900.28	980.28

Chart 5.1. Price comparison between paper and varying ceramic plate replacements per year



6.0 Conclusion

Having investigated the various issues with paper and ceramic plates, some conclusions can be drawn. From both life cycle and economic assessment, it was found that porcelain ware would be a better choice. Although the actual long term breakage and loss of porcelain ware was not studied, the analysis showed that even with conservative factors of useful life and replacements per year, porcelain ware was preferable in terms of cost and carbon emissions. Therefore, based on qualitative results, china ware is suggested for aesthetics while quantitative results still need to be verified because a number of assumptions were made and average values like electricity emission factors were used in the calculations.

7.0 Other considerations

A rational conclusion was drawn based on the analysis. However, many substantial considerations were not included. The methodology of a full life cycle assessment could not be followed due to the lack of available information.

1. Raw material acquisition:

- Emissions associated with the mining process for ceramic raw material were not included. Also, the environmental impacts of mining activities would be hard to evaluate since mining causes irreversible land destruction. There is not a conventional way to quantify the environmental impact of the land loss. Acid mine drainage can also take place where other organisms can be directly affected. On the other hand, the emissions from transportation of raw material to manufacture site should also be included, but this varies with location.
- Wood chips are the main raw material acquired by harvesting trees. Again the environmental impact from logging equipment and transportation of logs should be taken into account. Also, if recycled paper was included, emissions would certainly decrease.

2. Manufacturing process

- In the actual manufacturing processes, there are many other wastes that are not mentioned in the analysis. Only air emissions were included, while wastewater components were ignored. Additive chemicals used in the manufacturing processes such as the glazing of ceramic, pulp bleaching agents, are likely discharged into the environment, be it treated or not.
- The environmental impacts of clean water consumption required for both ceramic and paper making were not evaluated. Large amounts of water are needed in the paper production process.

3. Product use

- China wares need to be washed after use. There are definitely environmental impacts associated with the washing process. Clean water, detergent, and electricity are needed to wash the dishes. Waste water coming out from the dish washer could contribute to water pollution; however, electricity from British Columbia is considered clean

4. Disposal

- Emissions and environmental impacts from different disposal methods were not included; however, incineration, landfill, and composting all have associated emissions.

The majority of information from literatures focuses on emission and waste inventories of the manufacturing process, while data for raw material acquisitions and disposal cannot be found with ease. Only the production part of the life cycle could be transformed into comparable information. Conclusion drawn based on this limited information implied a great uncertainty in the life cycle analysis. However, it would be implausible to conduct an ideal full life cycle analysis because the nature of a product's life cycle is extremely complex and varied and involves infinite outside parameters. A sound logical and reasonable estimation could be taken as a reference in the decision making process.

8.0 Acknowledgement

We would like to thank Dr. Xiao Tao Bi for providing us with all the necessary background information for this investigation and providing support. Also, we would like to thank Ms. Brenda Sawada and Mr. Andrew Parr for this great opportunity for us to put our knowledge to practical use. Finally, we would like to thank Ms. Dorothy Yip for providing us with quantities from the Barn restaurant.

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