An Investigation into the Impact of Current Methods for Produce Storage and Transportation

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ABSTRACT

This document contains an investigation into the use of plastic containers and cardboard boxes for the storage and transportation of produce for the UBC Farm. Since it began distributing the produce it grows, the UBC Farm has been using plastic crates and totes exclusively, and wishes to know how this practice compares to alternative methods. To answer this, environmental, economic, and social factors are taken into account when comparing the performance of cardboard boxes and plastic containers. The containers currently in use are superior in the financial and environmental categories and have similar performance to cardboard in the social category. It is recommended that the UBC Farm does not change its current system. Also suggested are several avenues for further investigation that could improve the UBC Farm's use of plastic containers.

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GLOSSARY

Cardboard Box: Container made of corrugated cardboard, often wax cardboard

Use: One cycle of delivery for a container (includes washing for plastic containers)

Plastic Tote: A container constructed of plastic (normally polyethylene) without holes for airflow

Plastic Crate: A container constructed of plastic with holes for airflow

Polyethylene: A common plastic with a wide variety of properties and uses, made of long chains of carbon molecules

Wax Cardboard: Corrugated cardboard that is lined with polyethylene to prevent it from getting soggy

LIST OF ABBREVIATIONS

HDPE - High Density Polyethylene

PE - Polyethylene

CFIA - Canadian Financial Agency

EPA - Environmental Protection Agency

UBC - University of British Columbia

1.0 INTRODUCTION

The UBC Farm grows nearly 60,000 pounds of produce every year. This produce must be collected, stored, and transported to various consumers including farmers markets, restaurants, and distributors. As the UBC Farm has always used plastic crates and totes to do this, they would like to see if it is the best method or if they should consider an alternative method. We have therefore conducted an investigation of the two most common solutions for storing and transporting produce: the currently used plastic containers and the alternative, cardboard boxes. We have split our investigation into three sections: the environmental impact, the economic impact, and the social impact. We look at how cardboard boxes and plastic containers compare in these three factors and make our recommendation on what the UBC Farm should do based on the results.

2.0 ENVIRONMENTAL IMPACT

There are many ways that the environmental impact of a product or process can be measured, such as greenhouse gas emissions, toxic by-products, etc. While we will discuss many of these qualitatively, our quantitative focus will be on what we feel is the simplest: energy consumption. The reason for this is that it is the most readily available information and the easiest form of comparison. Two processes in a given region can have vastly different by-products, but the energy used will come from the same place and will have the same environmental effects. For UBC's application of transporting produce, we will divide the lifecycle of the packaging into three phases: Production, Use, and Disposal/Recycle.

2.1 Corrugated Cardboard Boxes

The production of corrugated cardboard boxes starts with the harvesting of trees, numerous processes to render the wood into pulp, consolidation of the pulp into kraft paper, then assembly into the actual cardboard. The largest environmental impact in the form of pollutants comes from the pulping and bleaching processes, which generate 25 m^3 of airborne pollutants, (25 m^3/t), 20-40 m^3 of wastewater, and 160-450 kg of solid wastes per tonne of pulp according to Bajpai (2010).The creation of paper requires between 10 and 50 MJ/kg (Bajpai, 2013) after which the manufacture into cardboard boxes requires only 1.5 MJ/kg (Boxmaster). The cardboard boxes weigh approximately 0.2 kg, resulting in between 2 and 10 MJ per box. We will use the average value of 6 MJ per box for comparison.

During use the only real environmental concern is transportation from the manufacturer to the UBC Farm and from the UBC Farm to the consumer. The UBC Farm uses its own truck to pick up materials and make deliveries, which we assume gets an average of 12L/100km and results in 4.32 MJ for every km travelled given that gasoline has an energy density of 32 MJ/L (Engineering Toolbox, 2014). The UBC Farm would buy boxes in batches of 4800, assuming that 200 boxes are used per week between May and October and they purchased enough for an entire growing season. If the round trip to purchase a pallet of boxes is 60 km, this would result in 130 MJ consumed and 0.054 MJ per box. Determining the distance travelled during deliveries is more challenging, we assume a 60 km round trip for this as well, enough distance to deliver to multiple customers in the Vancouver area. At 100 boxes per delivery, this results in 2.59 MJ per box.

The process of recycling cardboard produces similar pollutants to the creation of virgin cardboard, with more solid waste but less energy consumption, requiring only 5 to10 MJ/kg (Bajpai, 2013). 1 kg of waste paper can produce 0.85 kg of usable paper based on a reject rate of 15% according to (Bajpai, 2013). This results in an energy cost of 0.85 to 1.70 MJ per box to recycle. We will use the average value of 1.23 MJ for comparison. While the resulting paper would not be used again for produce transportation, it can be used for other purposes which would otherwise require virgin resources, resulting in a reduction of energy consumption.

2.2 Plastic Totes

The plastic used for most Rubbermaid totes and food crates is a High Density Polyethylene (HDPE). The Rubbermaid totes carry Canadian Food Inspection Agency (CFIA) certifications and are suitable for the UBC Farm. For this study it is assumed to be the material used at the UBC Farm. The production of HDPE begins with petroleum and natural gas as the primary resource material. The petroleum and natural gas must be refined to formulate the plastic resin. The refinement consists of what is referred to as a cracking process which uses a high thermal heat to break down the large hydrocarbons into smaller and simpler hydrocarbons. These smaller hydrocarbons are processed into polymer chains and combined to create a specific formulation of plastic resin. The resin is heated and using injection molding, the final crate or tote is produced. The creation of the plastic resin accounts for the largest input of energy towards producing the crates and totes. From a study performed by the US EPA, the approximate energy to produce a HDPE product is 33.4 MJ/kg ("Plastics", 2010). With a plastic container weight of 1.6 kg (Intercrate, 2014), this gives 53.4 MJ per box.

An important feature in the use of plastic is that the boxes can be re-used (see glossary for 'use'). The UBC Farm typically harvests half of the annual year. The totes and crates are each washed once a week on average. A crate or tote typically last between two and three years before breaking, thus ending its useful life (K. Menzies, personal communication, 2014). On average, this equates to 65 use-cycles per container per life. Dividing the energy required to produce a plastic container by this number gives a per use energy of 0.82 MJ. Each time the container is re-used, it must be washed for sanitary considerations. This requires the use of detergents and water. The UBC Farm has provided their tabulated water usage (see Appendix 1). Overall a crate or tote consumes four liters of water per wash, equating to 260 liters of water in its respective life-span. The energy required from the water consumption is considered to be negligible in this study.

The in-use energy consumption comes from transportation. This is calculated in a similar way to the cardboard boxes. It's assumed that all boxes that need to be replaced each year are purchased at once, meaning that 160 boxes are purchased each trip. We again assume a 60 km round trip requiring 259 MJ which results in 1.62 MJ per box. But we must divide this cost by the 65 times each box is used, resulting in 25.0 KJ per use. The energy required for delivery will be the same as the cardboard boxes because the same amount of produce is shipped either way, resulting in 2.59 MJ per use.

Once a crate or tote is no longer usable due to a breakage, it must be discarded, or recycled appropriately. HDPE is petroleum based and can be incinerated for re-captured energy. However, the process is not efficient with a typical Combustion System efficiency of 17.8% and is therefore not recommended ("Plastics", 2010). Alternatively plastic can be put in a landfill. It is not biodegradable, therefore producing no emissions. Lastly, the plastic containers can be recycled by way of regrinding to beads and re-molded or re-used in new products. The energy required for this is considerably less than producing plastic from raw materials, only 4.9 MJ/kg ("Plastics", 2010). Once again, dividing by the total number of uses gives 75 KJ per use. There are a number of local companies that offer this service such as Westcoast Plastic Recyling Inc. and WCS Recycling.

2.3 Comparison

The energy consumption for production, use, and disposal outlined in the previous sections are totalled in Figure 1. As indicated, the reusable plastic tote consumes less energy for each use than a disposable cardboard box, primarily due to its consumption during production being spread over its lifespan. The transportation forms a considerable amount of the total energy use, and there is little difference between the two containers. This is due to the way the UBC Farm distributes its produce; the same number of trips must be made either way. As the quantity of produce and transportation distances increase, cardboard becomes increasingly competitive because proportionally more of its energy consumption comes from production instead of transportation. This combined with the fact that single use containers do not need to be shipped back can result in cardboard containers requiring less energy overall when transported further than 1,500 km according to Levi (2011). There are of course many other factors to consider, such as the fact that plastic totes require water for washing during use while cardboard boxes do not. The 4 L per use is very comparable to the 20 L for every kg of pulp produced during manufacture of cardboard.

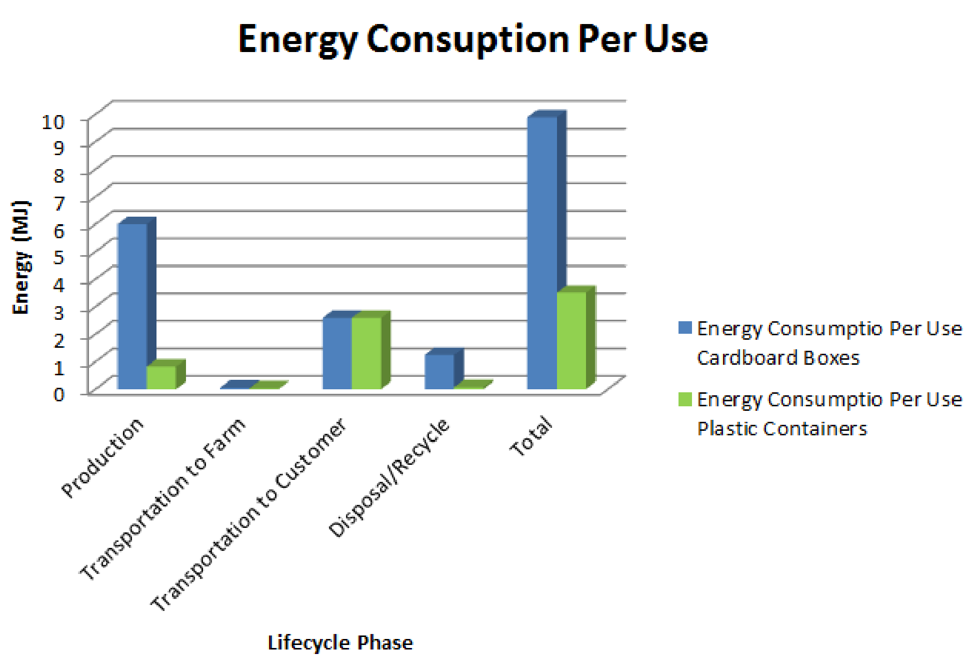

Figure 1 : Energy Consumption Per Use

3.0 ECONOMIC IMPACT

The economic impact is the most traditional way to compare the two container options. By comparing the various costs involved in the use of the containers, you can clearly discern which of the options is better through the difference in numbers. The economics involved for both the cardboard boxes and the plastic containers can be divided up into the purchase cost, the maintenance cost, and the transportation and disposal cost.

3.1 Purchase Cost

The largest economic factor is ultimately the cost to purchase the containers. Right now the UBC Farm possesses roughly 400 containers at a time, consisting of about 300 plastic totes and 100 plastic crates. If the UBC Farm switched to cardboard boxes, only half of these containers would actually be able to be replaced. This is because, besides being used for storage and transportation, the containers are also used to collect the produce directly from the field, which are then washed before being put into clean containers. The cardboard boxes could not replace the first set of containers as they are not water resistant.

Currently the UBC Farm gets its plastic crates from Intercrate and its plastic totes are simply bought from regular stores whenever they are on sale. Below is a table that outlines the unit price for each container, the number of times they can be used before being replaced, and the cost for the number of necessary units.

Table 1: Cost and Reusability of Container Types

	Cardboard Box	Plastic Crate	Plastic Tote
Unit Cost	$1.50	$12.80	$5.00
Number of Uses	1	65	65
Price For 100 Units	--	$1,280.00	--
Price For 200 Units	$300.00	--	--
Price For 300 Units	--	--	$1,500.00

Source: Boxmaster, Intercrate, and store websites

The total cost for purchasing 400 of the plastic containers comes out to $2,780. The 65 use-cycles of the plastic containers is equivalent to two years, so this is a cost that would be paid every two years. On the other hand, the total purchase cost for the cardboard option would be around $20,890 every two years (shown in Equation 1). It is assumed that half of the containers would be replaced with cardboard boxes and that the amount bought is equal to the number needed to last the same length of time as the plastic containers. If we halve these numbers to get the yearly costs and compare them, we get a difference of $9,055 in favor of the plastic option (shown in Equation 2)

$$\left(\$300 \times \frac{65 \text{ uses}}{1 \text{ use}}\right) + \left(\frac{\$2780}{2}\right) = \$20890$$

Equation 1: Total cost of cardboard boxes for 2 years

$$\left(\frac{\$20890}{2 \text{ years}}\right) - \left(\frac{\$2780}{2 \text{ years}}\right) = \$9055/\text{year}$$

Equation 2: Yearly saving for the plastic option

3.2 Maintenance Cost

The only maintenance cost involved with the UBC Farm's containers is the cost to wash the plastic containers. Below is a table detailing the water use and labor hours involved in washing the containers.

Table 2: Time and Water Use of Washing Containers

Objects Washed	50 Crates and 150 Totes	150 Lids
Water Used	247.7 Gallons	139.2 Gallons
Washing Time	4.93 Hours	2 Hours
Setup/Organization Time	0.83 Hours	
Total Time	7.6 Hours	
Total Water Used	386.9 Gallons	

Source: see Appendix 1

The cost of the water is ultimately not very significant, totaling to $23.61/year. The cost of water per cubic meter in Canada is shown in Figure 2 and the calculation for the yearly water cost is shown in Equation 3.

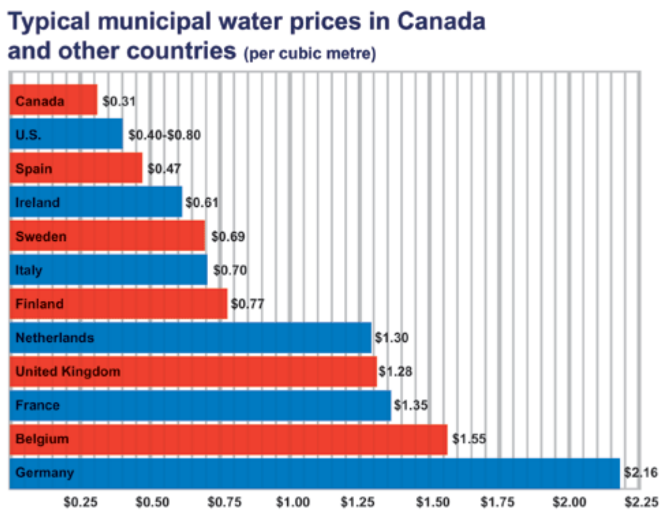

Figure 2: Municipal Water Prices
Source: Environment Canada, 2013

$$\frac{386.9 \text{ gallons}}{\text{wash}} \times \frac{3.785 \text{ litres}}{\text{gallon}} \times \frac{\$0.31}{\text{m}^3} \times \frac{1\text{m}^3}{1000 \text{ litres}} \times \frac{52 \text{ washes}}{\text{year}} = \$23.61/\text{year}$$

Equation 3: Yearly cost of water for washing the containers

The labour cost for the washing process can be calculated by using how long the process takes and the average hourly wage of the farm workers (UBC Human Resources, 2013). With this, the total labour cost is equal to $7,662.93/year (see Equation 4 for calculation). However, in the end this number isn't an accurate representation as the UBC Farm uses a lot of volunteers and this number is calculated under the assumption that all workers are paid. We will still use this as a major portion of the maintenance cost, but it should be kept in mind that it's a sizable overestimation of the actual labour cost.

$$\frac{\$19.39}{\text{hour}} \times \frac{7.6 \text{ hours}}{\text{wash}} \times \frac{52 \text{ washes}}{\text{year}} = \$7662.93/\text{year}$$

Equation 4: Yearly Labour costs for washing the containers.

While the cardboard boxes do not have any maintenance costs themselves, due to only half of the containers being replaced with cardboard ones, half of the plastic option's maintenance cost, or $3,843.27/year, can be considered the maintenance cost for the cardboard option. On top of this, the cardboard boxes would also have to be put together after purchase and so there would end up being a small labour cost for that as well. An exact number for this is unknown but it would not drastically change the total overall cost for the cardboard option.

3.3 Transportation and Disposal Cost

For the transportation and disposal costs, there is very little difference between the cardboard option and the plastic option. The differing weights going to (cardboard boxes + produce vs. plastic containers + produce) and returning from (empty for cardboard option vs. only the containers for plastic option) the buyer causes negligible change in the cost of gas and there are no other transportation costs relevant to the UBC farm (Albrecht et al, 2013). As for the disposal costs, with the cardboard option the boxes would be disposed of by the buyer and so would have no economic cost to the UBC Farm, while for the plastic option there are the free services that will pick up and dispose of the containers for the farm (Westcoast Plastic Recycling, 2014). With this, the transportation and disposal costs for both options can be considered to be the same.

Since this means the transportation and disposal costs can be ignored, by comparing the difference between the purchase cost and the maintenance cost we can determine which option is better. This comparison results in the plastic option being cheaper by $5,211.73/year, quite a large number that only gets bigger over time.

4.0 SOCIAL IMPACT

One of the three basic categories of triple bottom line analysis is the social aspect. The social category attempts to account for any factors that affect society at large and were not accounted for in either the financial or environmental analysis. Due to the variety of indices used and how unrelated some of them are no common metric is used. The results of this analysis are qualitative in nature, and are limited to the differences between the options. One of the major categories for social impacts is ease of use. Ease of use is limited in scope to the UBC Farm and their customers, as it is assumed that any increase in difficulty handling the containers will result in an increase in price, and can already be accounted for. Ease of use was judged quantitatively based on the differences one may encounter when using a cardboard box compared to a plastic totes or crate.

4.1 Ease of Use

The major drawback of plastic totes and crates is that they must be washed after every use. This is a requirement for any reusable container due to health concerns. Based on weekly washes and taking 7.6 hours for one wash, a total of over 700 labour hours is spent washing containers every year.

The plastic totes, unlike plastic crates and cardboard boxes require slight modification to allow air flow when the lids are on. This is accomplished by drilling a few holes into the tote. This processes isn't overly time consuming as it only needs to happen once for the entire lifetime of the tote.

Cardboard boxes have some issues relating to their durability. Cardboard becomes much weaker when wet, to the point of becoming unusable if completely wet. This is a problem in Vancouver where there is frequent rain and putting wet produce into the box could result in a broken box.

Depending on design the cardboard boxes may not have handles and if they do they may not be as comfortable.

Both cardboard and plastic boxes store easily. Cardboard boxes can be unfolded, and plastic boxes nest in one another, allowing for compact storage. At the restaurant and other customer's location the cardboard boxes can be thrown out after being emptied freeing up space. The plastic containers have to be stored somewhere until the UBC Farm makes another delivery at which point they can be taken back.

4.2 Production

Various issues were identified surrounding the production of plastic and cardboard containers. In both cases they tend to be made in the developing world. There are alternatives that make containers in North America and locally, but there are still unknowns of how and where their material is coming from. The UBC Farm takes advantage of current local suppliers. Intercrate produces crates locally and Rubbermaid makes 50% of its totes in North America. For cardboard there is Boxmaster who makes them locally. For this analysis the rates of labour and effort that goes into producing the containers assumed an industry average and not the specific companies the UBC Farm may or may not be using.

According to Albrecht et al. (2013) the use of female labour in the construction of plastic boxes is four times that of cardboard boxes. This is largely due to the logging and paper supply chain that is involved with cardboard boxes. On a per container basis the fatality rate is $1*10^{-9}$ for plastic compare $4*10^{-9}$ for cardboard. Cardboard does have a much lower injury rate of $8*10^{-7}$ for plastic. When a per use basis is used plastic greatly outperforms cardboard. The overall labour hours that go into making a single box are 120 sec/box for plastic and 150 sec/box for cardboard. Lower labour hours are considered better as it allows people to focus on other aspects of life and contributing to society in other manners.

4.3 Health

Cardboard, wax cardboard, and the high density polyethylene, which the containers are made of are safe for human health, and do not leach toxins. There is a large health issue if the plastic containers are improperly washed.

5.0 CONCLUSION AND RECOMMENDATIONS

We have looked at the environmental, economic, and social impacts of both cardboard boxes and plastic containers. While the plastic totes consume more resources during actual use due to the requirement for washing, when the entire lifecycle is taking into account they consume less energy due to the environmental cost of production and recycling being spread over the many times each container is used. Economically the plastic containers are the clear choice, buying them in the relatively low volume required by the UBC Farm is very expensive. The answer to which container has a better social impact is less clear cut. Cardboard boxes have better ease of use, requiring only unfolding instead of drilling and modification, but plastic containers have advantages when it comes to wider social effects such as the workforce involved in production.

Given that the reusable plastic containers perform much better in two of the categories we analysed, and equally in the third we recommend that the UBC continues using its current system for storing and distributing its produce.

5.1 Further Investigations

During our investigation we identified various topics and ideas, which while out of scope of comparing different types of containers, may be fruitful to the UBC Farm if further investigation is done.

Alternative Washing Method:

An alternative washing method was identified during the investigation (Rapusa & Rolle, 2009). It evolves sanitizing the crates by dipping them in a chlorinated solution at 43*C for 2 minutes. Other sanitation agents are usable such as Iodophors and Quats. It will likely take more energy to keep the water heated than washing by hand. Using the soaking method of disinfecting is less effective than a thorough manual wash.

Figure 3: Soak Washing Method

Automated Washing:

Using an automated washing method would greatly reduce the work required to complete the washing. It is likely it will take more energy, water and cleaning agent then the current method. It may also be very expensive to develop, and is a potential idea for a capstone project or two.

Alternate Nozzle:

One of the simplest methods of reducing water consumption may be to use a different type of nozzle on the wash hose, similar to a low flow shower head. A mode selection between a narrow high powered spray for cleaning dirt off, and a broader flow pattern for rinsing may be useful.

Better Accounting of Specific Production Practices for Suppliers That The UBC Farm Uses:

To get a much better picture of the resources and effects of using a specific container for UBC. The specific supplier that UBC uses would have to be thoroughly investigated. The triple bottom line of a plan that operates in Vancouver to one that operates in China can be vastly different.

Bin Liner:

Using a bin liner may allow for the ease of disposing without discarding complete containers. There is a risk of stuff building up between the bin liner and bin. There may be regulation in place that requires complete washing. Weaker plastics which are often used as bags tend to be less stable and more likely to leach toxins.

3rd Party Washing Service:

In other areas there are independent washing services that will wash plastic containers. Depending on price, this could be an effective way of reducing labour hours. This service does not currently exist in Vancouver. VIP Bin Cleaning currently operates a service that washes plastic garbage bins in Vancouver.

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APPENDIX 1: Tote Washing

Tote Washing Water Consumption and Labour Time Estimate
December 17, 2013
Michael Millar

The following water consumption data was measured using a DLJ water meter on December 16, 2013 by UBC Farm Field Research Assistant Michael Millar. Water consumption and time were recorded for 52 crates, 150 totes, and 10 lids. An estimate for 150 lids was made from the measurements taken from 10 lids. An estimate of total labour time was made for the washing time as well as the setup and organization time.

Crates and Totes		Lids		Total Crates (52), Totes (150), Lids (est. 150)	
Time (min) / (202 Crates and Totes)	296	**Time** (min) / (10 lids)	8	**Time** (min)	406
Time Hrs	4.93	**Time Hrs**	0.13	**Gallons Used**	386.9
Number of crates	52	**Number of lids**	10	**Gallons / min**	0.95
Number of totes	150	**Number of min / lid**	0.8		
Total crates + totes	202	**Gallons Used**	6.9		
Number of min / tote + crate	1.47	**Gallons / min**	1.16		
Gallons Used	247.7	**Gallons Used** (est. 150 lids)	139.2		
Gallons / min	0.84	**Total min** (est. 150 lids)	120		

Total washing time and water consumption for 52 crates, 150 totes, 10 lids, and an estimated 150 lids.

Estimated Total Labour Time	Time
Total washing (min) totes/crates/lids	406
Total setup and organization (min) (est.) including Moving tables Moving stacks together Organizing tote/crate sizes Clearing space to work Peeling tape Taking down and moving stacks Taking down and moving tables	50
Total Time (min)	456
Total Time (hrs)	7.6

Total estimated labour time for 52 crates, 150 totes, and an estimated 150 lids including setup and organization time.