UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Life Cycle Assessment: Aspenware Biodegradable Cutlery

Alyssa Brownlee, Chris Li, Maria Lo

University of British Columbia

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A SEEDS Sustainability Project

Alyssa Brownlee
Chris Li
Maria Lo

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Quantis

QUANTIS INT

Quantis provided the software and technical LCA necessary for this project. Quantis Intl. was founded in 2009 to provide conscientious businesses and governments with the tools, guidance and knowledge for achieving sustainability by recognizing their life cycle and effectively reducing their environmental impacts

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ASPENWARE- Michael Fedchyshyn

A manufacturer of wood based disposable biodegradable cutlery, centered in Vernon, British Columbia.

Contact

Alyssa Brownlee	alyssabrownlee@gmail.com
Chris Li	chris.zhk.li@gmail.com
Maria Lo	marialo@interchange.ubc.ca

Executive Summary

This study was sponsored by UBC SEEDS, Social Ecological Economic Development Studies, a program which aims to address sustainability challenges on campus such as which type of disposable cutlery is the most sustainable choice (SEEDS).

In this report, a life cycle assessment was performed for one specific cutlery brand, Aspenware, a manufacturer of disposable and compostable wooden cutlery. The goal of this study is to help UBC and AMS food services determine cutlery consumption habits and impacts in order to make informed decisions when purchasing disposable cutlery. In this study, a full life cycle assessment will be presented for Aspenware, along with a comparison to traditional polystyrene plastic cutlery in terms of greenhouse gas emissions and economic costs. Aspenware will benefit from this study in determining the environmental impact of their products and areas for improvement.

The study applies a life cycle assessment based on ISO 14044 standards. The functional unit of this analysis is per utensil, assuming single use, limited to services and events at the University of British Columbia.

The results, data and methodology used in this report are incorporated into the Quantis SUITE 2.0 LCA software tool, using the database EcoInvent 2.2 (Quantis Intl).

Overall, the production of 2.6 g plastic cutlery and 5 g plastic cutlery results in an approximate increase of 24% and 60% kg CO_2 emissions per piece of cutlery, respectively, when compared to Aspenware. Plastic cutlery is about 43% less expensive than Aspenware. The end-of-life impacts of Aspenware cutlery will have broader implications than simple reductions in carbon dioxide emissions. Plastic may not degrade for many years and this was not quantified in the report's data (Cruise). Aspenware's wooden cutlery composts in less than 49 days, making it a more viable option (Aspenware, 2013). Overall, it is recommended that Aspenware be purchased over plastic cutlery due to the reduced greenhouse gas emissions and its compostable nature which results in less space requirements for on campus composting.

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Abbreviations

BC	British Columbia
CO_2-eq	Carbon dioxide equivalents
DALY	Disability adjusted life years
EF	Environmental Factor
g	Gram
GHG	Greenhouse Gas
J	Joules
LCA	Life Cycle Assessment
m	Meters
m^3	Cubic Meters
SEEDS	Social Ecological Economic Development Studies
t	Tonne
UBC	University of British Columbia

Introduction

Throughout the past few decades, the University of British Columbia has been working with individuals and companies to provide environmentally and economically friendly alternatives. One such instance of this is cutlery; disposable forks, knives and spoons are heavily consumed on a daily basis throughout the UBC campus. Aspenware, a Vernon based manufacturer of wooden cutlery, is interested in supplying the UBC and AMS food services with their product, which they believe has the lowest environmental impacts in their category (compostable cutlery). Compostable cutlery differs from biodegradable cutlery in that "compostable" implies that the product degrades over a short time period. On the other hand, a "biodegradable" product does not have a specific time period over which it is required to decompose (Aspenware, 2013). Aspenware products are currently undergoing a trial run at The Loop cafe in the Centre for Interactive Research on Sustainability (CIRS) building and UBC SEEDS has sponsored this study to determine a good estimate of Aspenware's sustainability.

Goal and Scope

The primary goal of this project is to develop a deeper understanding of various impacts of disposable Aspenware utensils to determine whether Aspenware or plastic cutlery is the best option for UBC. Due to a problem with the degradation of polylactic acid, PLA, plastic utensils at the UBC compositing site, it was suggested that the comparison with Aspenware be made against plastic and non-PLA cutlery only. A secondary goal is to use a life cycle assessment to determine the areas of highest environmental impact, in order to identify areas where Aspenware may reduce the environmental impact of their product. The scope of this product will be from cradle to the grave; that is from the initial wood acquisition to the final disposal of the product via garbage, incineration or compost.

Functional Unit

A functional unit is a measure of the function of the system relating to the input and output flows and used to compare impacts across similar products. The functional unit of this project is per utensil, with the assumption that forks, spoons and knives have the same weight and materials. Results were obtained on the basis that each utensil would only undergo a single use prior to disposal.

Life Cycle Assessment

Life Cycle Assessment, LCA, is a method of determining the impact of products and services during their lifespan. Using LCA it is possible to determine the flows of energy, raw materials and waste used to create, use and dispose of a product. The LCA method is an internationally recognized way of holistically measuring products or processes and their functions by considering both upstream and downstream activities. The *ISO 14044 Environmental management – Life cycle assessment – Requirements and guidelines* is a widely agreed standard for LCA studies and it will be used in this report (Standardization, 2006). As per ISO 14044, the four phases of an LCA study are as follows:

a) Goal and Scope Definition
b) Inventory Analysis
c) Impact Assessment
d) Interpretation

A schematic of this process is shown in Figure 1 below:

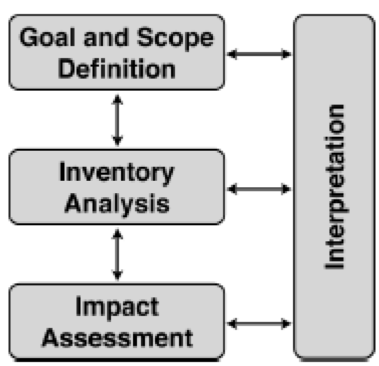


Figure 1: ISO 14044 Phases of an LCA Study (Standardization, 2006)

Impact Categories

To assess the impact of Aspenware utensils during their life cycle, the following categories were used as units of measurement (Quantis Intl):

Climate Change	kilograms of carbon dioxide equivalents
Human Health	disability adjusted life years
Ecosystem Quality	potential disappeared fraction of species per square meter per year
Resources	mega joules of primary energy
Water Withdrawal	meters cubed of water
Water Turbined	meters cubed of water

Tool - Quantis SUITE 2.0

Quantis SUITE 2.0 is client-based life cycle assessment software developed by Quantis Intl. It is designed to assist companies to determine their environmental impacts and to develop strategies and methodologies to reduce these impacts. Quantis SUITE boasts a sleek, appealing interface that draws from a multitude of Life Cycle Inventory databases, including ecoinvent, ADEME Bilan Carbone, DEFRA and a number of national Input-Output databases (Quantis Intl).

For this project, a template specific to the life cycle of the Aspenware product was developed. This is not to say that the entirety of the project is complete and set in stone. The beauty of this tool is the ability to adjust and replace uncertain environmental factors and other variables as time progresses and more information becomes available, resulting in a project that is representative of changes over time. Figure 2 below provides a visual of how the IMPACT 2002+ method interprets environmental flows into five damage categories.

Figure 2: Cradle to grave impacts are determined with LCA. The IMPACT 2002+ method interprets environmental flows into five damage categories (Quantis Intl)

Results and Discussion

Criterion of Data Quality

The quality of the data used in this project can be assessed using Table 1 below. The determination of each assessment is a function of both reliability and representativeness (Source: Dolf, 2012).

Table 1: Criterion of Data Quality

DATA QUALITY	RELIABILITY	REPRESENTATIVNESS
1-High Quality	Specific validated or calculated data	Good geographical and technological representativeness
2- Acceptable Quality	Validated or calculated data from other source	Geographical or technological lack of representativeness
3- Low Quality	Qualified estimate	Geographical and technological lack of representativeness
4- Very Low Quality	Rough estimation	Proxy

(Dolf, 2012)

Assessment Procedure

In this study, there arose three key factors that were assessed to determine whether they have a significant impact on the final results. These three key factors were:

1. Accounting for the return trip during transportation
2. Percentage of waste-wood usage for production
3. User disposal habits and consequent end-of-life impacts

Each of these factors will be considered in greater detail further into the report. However, in order to determine the environmental emissions of the Aspenware product, six possible scenarios were considered which will be discussed later in greater depth:

1. 0% waste-wood usage, no return trip, 76 % composted (baseline)
2. 0% waste-wood usage, no return trip, 100% composted (emphasis on composting)
3. 50% waste-wood usage, no return trip, 76% composted (emphasis on waste wood)
4. 0% waste-wood usage, return trip, 76 % composted (emphasis on return trip)
5. 50% waste-wood usage, no return trip, 100% composted (most favorable)
6. 0% waste-wood usage, return trips, 0% composted (least favorable)

Overall Results

The baseline scenario for this project is accounting for 100% selectively harvested wood and not accounting for return trips during the transportation stage. Aspenware gets 50% of its wood from a leftover wood source that would otherwise be left to rot and the other 50% from selectively harvested wood (Fedchyshyn, 2013). For the sake of a conservative estimate, it is assumed that the forestry industry, or whoever left the wood to rot, did not account for the environmental impact of the unused wood and so this impact is assigned to Aspenware in the conservative baseline scenario.

A graphical overview of the results can be seen in Figure 3. Evidently, the most significant effects come from the manufacturing component. The manufacturing component of this study takes into account extraction impacts. Due to the scope of this study, the use phase impacts of the cutlery are not taken into account. Transportation is the second largest component, and end of life is hardly significant. For each category, this study provides the environmental factor used in ecoinvent 2.2, along with the input flow quantities so that future modification of this study is quite manageable and straightforward. Table 2 provides the overall impacts per functional unit.

Figure 3: Impacts per Functional Unit Overall for Transportation, Manufacturing and End of Life

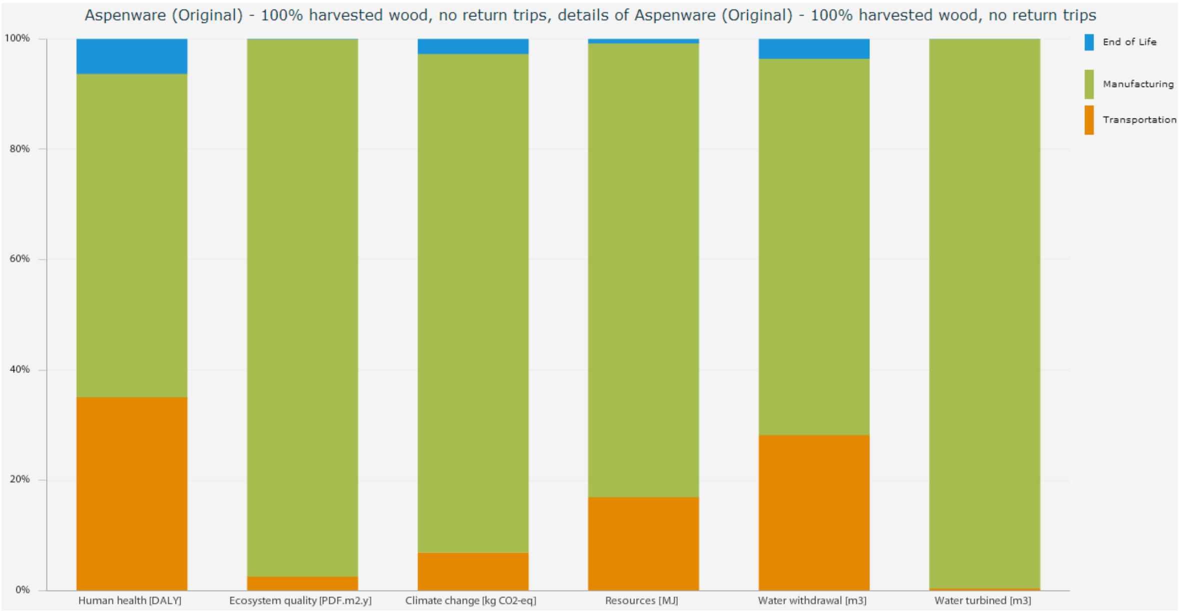


Table 2: Overall Impacts per Functional Unit

Climate Change (kg CO_2 eq)	Resources (MJ primary)	Human Health (DALY)	Ecosystem Quality (PDF.m^2.yr)	Water Withdrawal (m^3)	Water Turbined (m^3)
1.00E-02	6.79E-02	2.13E-09	1.09E-02	1.88E-05	2.36E-01

Transportation

The transportation of Aspenware's wood-based cutlery was anticipated to be a major contributor to the overall environmental impact of each piece of cutlery. This is largely due to the distances separating the sourcing, veneering, drying, manufacturing and distributing facilities as seen in Figure #. Vehicles are assumed to be carrying their maximum capacity in either mass or volume at all times, dependant on which is maximized first. Impacts are based on vehicles of European construction, due to the original locale of the database inputs. The full life cycle of the vehicles is considered rather than the operation life cycle.

The transportation of the wood source to the veneering facility is accomplished by 40-ton logging truck, travelling approximately 100km. The transportation from veneering to drying is accomplished by a 5-ton truck travelling 215km. The transportation from drying to manufacturing and from manufacturing to distribution is accomplished by a 40-ton truck.

Aspenware has a number of distributors across all of North America. For the sake of simplicity, it is assumed that 50% of the product will be distributed in the United States of America, while the other 50% will be distributed in Canada. As limited by the scope of this project, only the distribution process in Canada, and more specifically to UBC, will be discussed. Since the impact of the cutlery purchased and distributed by the US is neglected, this assumption greatly affects the results and tailors the results solely towards the impact of cutlery intended for consumption at UBC.

The transportation of Aspenware's waste wood is not taken into account for emissions. Rather, the carbon credit is assigned to the recycled wood purchaser. Table 3 provides the data assumptions and sources for transportation, and Table 4 provides the impacts per functional unit for transportation. Figure 8 (in the Appendix) displays the different stages of transportation.

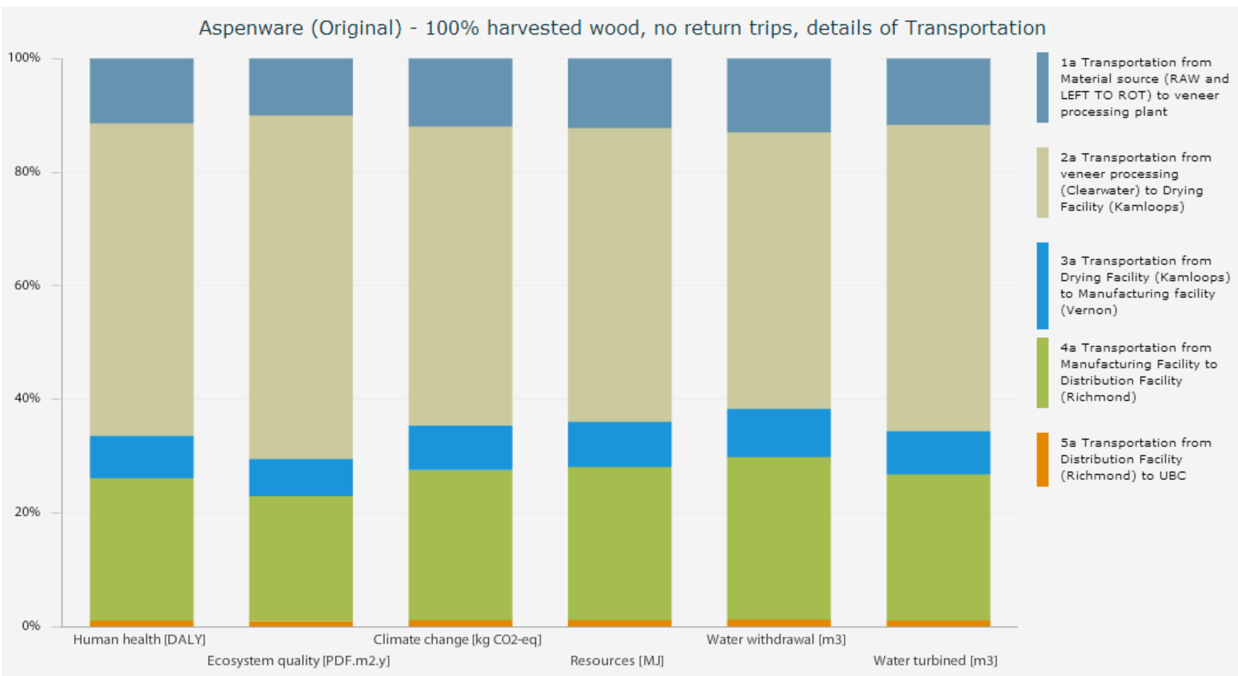
Table 3: Data Assumptions and Sources for Transportation

Flow	Data	Unit	Assumptions	Data Sources	Environmental Factor (EF)	Quality
Transportation from **material source** to **veneer processing** plant (Clearwater)	6.00E-04	tkm	Know the mass post drying is 3E-6 ton/piece. Pre drying mass = (2 * post drying mass) due to water loss. Therefore, mass = 2*3E-6 = 6E-6 ton/piece. Distance = 100 km. Assume trucks 100% diesel.	Aspenware Internal Documents	ecoinvent 2.2 - transport, lorry >28t, fleet average (1944)	**2- Acc.**
Transportation from **veneer processing** (Clearwater) to **drying facility** (Kamloops)	1.29E-03	tkm	Know the mass post drying is 3E-6 ton/piece. Pre drying mass = (2 * post drying mass) due to water loss. Therefore, mass = 2*3E-6 = 6E-6 ton/piece.	Aspenware Internal Documents	2.2 - transport, lorry 3.5-20t, fleet average (1940)	**2- Acc.**
Transportation from **drying facility** (Kamloops) to **manufacturing facility** (Vernon)	3.90E-04	tkm	Mass has reduced by 50% after drying. Transported over 130 km. 1piece= 3g = 3E-6 ton/piece. 40-ton truck.	Aspenware Internal Documents	2.2 - transport, lorry >28t, fleet average (1944)	**2- Acc.**
Transportation from **manufacturing facility** (Vernon) to **distribution facility** (Richmond)	1.32E-03	tkm	Assume 1 piece= 3g = 3E-6 ton/piece. Vernon -> Richmond = 440 km.	Aspenware Internal Documents	2.2 - transport, lorry >28t, fleet average (1944)	**2- Acc.**
Transportation from **distribution facility** (Richmond) to **UBC** (Vancouver)	5.40E-05	tkm	Assume same constraints as manufacturing to distribution trip. Richmond -> UBC= 18 km.	Aspenware Internal Documents	2.2 - transport, lorry >28t, fleet average (1944)	**2- Acc.**

Table 4: Impacts per Functional Unit for Transportation

Climate Change (kg CO_2 eq)	Resources (MJ primary)	Human Health (DALY)	Ecosystem Quality (PDF.m^2.yr)	Water Withdrawal (m^3)	Water Turbined (m^3)
6.883E-04	0.01150	7.474E-10	2.715E-04	5.316E-06	8.169E-04

Figure 4: Impacts per Functional Unit for Transportation



Manufacturing

Due to the commercial sensitivity of Aspenware's product, this area of discussion is likely to be somewhat limited. On a per piece basis, the energy and material input flows and waste output flows of each operation were analyzed. As the base of operations for Aspenware's manufacturing is in British Columbia, the energy input is assumed to be supplied by hydroelectricity. The material input is assumed to be largely wood-based, due to the negligible quantities of other material inputs. The outlet waste flows taken into consideration include waste water and waste wood.

Packaging of the wood-based cutlery is limited to size-averaged cardboard boxes for containment and wooden pallets for shipping. Table 5 provides the data assumptions and sources for manufacturing, and Table 6 provides the impacts per functional unit for manufacturing.

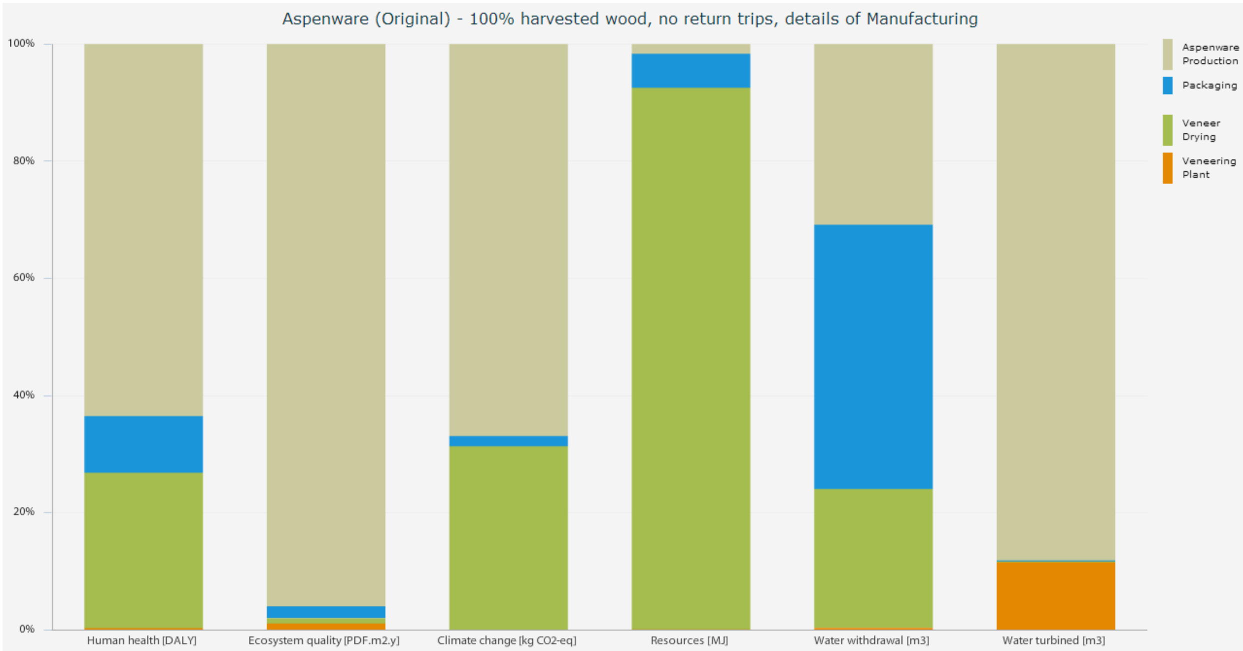
Table 5: Data Assumptions and Sources for Manufacturing

Flow	Data	Unit	Assumptions	Data Sources	Environmental Factor (EF)	Quality
Electricity for veneering	6.00E-01	Wh/pc	117 kWh/day	Aspenware Internal Documents	2.2 - electricity, hydropower, at run-of-river power plant [kWh] - RER (Ecoinvent 2.2: 985)	**1-High**
Natural Gas	3.92E-05	GJ/pc	Assume 25.5 GJ used per 10 pallets	Aspenware Internal Documents	2.2 - natural gas, burned in gas turbine [MJ] - GLO (Ecoinvent 2.2: 1397)	**1-High**
Wastewater	1.05E+01	ml/pc	Assume half the mass of the wood input is water	Aspenware Internal Documents	2.2 - treatment, plywood production effluent, to wastewater treatment, class 3 (2271)	**1-High**
Electricity for production	4.60E+00	Wh/pc	Aspenware uses ~ 85% of energy bill for manufacturing. Remaining 15% shared among companies in building	Aspenware Internal Documents	2.2 - electricity, hydropower, at run-of-river power plant [kWh] - RER (Ecoinvent 2.2: 985)	**1-High**
Wood Waste	2.00E-05	kg/pc	25% waste with an additional ~0.5% falldown rate through the punching process.	Aspenware Internal Documents	2.2 - hardwood, Scandinavian, standing, under bark, in forest (5745)	**2- Acc.**
Pallet	1.54E-05	Pallet/pc	Assume standard wooden pallet	Quantis Suite-guidelines for average pallet	2.2 - EUR-flat pallet (2526)	**1-High**
Cardboard Box	5.45E-05	kg Cardboard/pc	Boxes are 650 in^2 and made of kraft cardboard	Aspenware manufacturer	2.2 - packaging, corrugated board, mixed fibre, single wall, at plant (1698)	**1-High**

Table 6: Impacts per Functional Unit for Manufacturing

Climate Change (kg CO_2 eq)	Resources (MJ primary)	Human Health (DALY)	Ecosystem Quality (PDF.m^2.yr)	Water Withdrawal (m^3)	Water Turbined (m^3)
9.065-03	0.05590	1.252-09	0.01060	1.289E-05	0.2350

Figure 5: Impacts per Functional Unit for Manufacturing



End of Life

In order to determine the end of life factors of Aspenware cutlery, a sample study at The Loop cafe in the CIRS building was used to determine consumer disposal habits. In this four-day study, the waste from the cafe was analyzed to determine if patrons had properly disposed of their waste in a choice of four waste receptacles: beverage, paper, compost and garbage. At that time, Aspenware was currently deploying its trial run of wood-based cutlery in lieu of a previous eco-friendly contender, PLA-based cutlery. Previous usage of PLA cutlery had delivered less than satisfactory results. For one, the toughness and color of the utensil made the product seem as if it was simply plastic, causing most patrons to dispose of it in the trash. The PLA product also failed to compost properly in the UBC site composter. Hence, for the purposes of this project and life cycle assessment, only the results pertaining to the disposal of wooden utensils (knife, spoon and fork) were considered. The mass of the utensils was averaged and assumed to be 3 g. For the sake of simplicity, each meal is assumed to use only one utensil, and that utensil is expected to be disposed thereafter.

Based on the results it was found that about 76% of the cutlery is properly disposed into the on campus compost, while 24% of the cutlery is incorrectly disposed into the other three waste receptacles (The Loop Garbage Study, 2013). Of the 24% cutlery improperly disposed, it is assumed that 15% of that cutlery is disposed of in a landfill, while 9% of that cutlery is disposed of in the incinerator (bcliving, 2013). Google Maps was used to find an approximate distance from UBC to the closest respective facilities; the UBC composting unit (negligible distance), the Delta landfill and the Burnaby waste-to-energy incinerator. These distances are important in determining the transportation impacts.

An important factor to note in this study is the sampling area, namely the cafe in the Centre of Interactive Research on Sustainability (CIRS) building. Given its location, it is likely that a majority of the patrons of the cafe are environmentally conscious and have refined disposal habits. Hence, this study may not be representative of consumer disposal habits across the campus. Despite this, it was argued that a patron making the switch from plastic cutlery to wood-based cutlery would most likely be environmentally conscious in the first place.

One factor which is difficult to quantify is the reduction in volume due to composting. Although the end of life component is very small compared to manufacturing and transportation, as seen in Figure 3, end of life may be a significant factor to consider when making a purchasing decision. Aspenware cutlery is certified to decompose in 49 days or less resulting in a reduced volume in the composter, resulting in increased storage for even more cutlery compared to non biodegradable options (Aspenware, 2013). One of UBC's complaints about PLA cutlery was that it didn't decompose and ended up occupying a lot of volume in the composter. Table 7 provides the data assumptions and sources for end of life, Table 8 provides the impacts per functional unit for transportation, and Table 9 provides the end of life disposal routes.

Table 7: Data Assumptions and Sources for End of Life

Flow	Data	Qnty	Unit	Assumptions	Data Sources	Environmental Factor (EF)	Quality
Incineration	0.003	0.09	kg	Assume mass of one utensil is 3 grams. 9% incinerated* 3g = 0.00027 kg	BCLiving (2013)- Garbage crisis: our waste by the numbers	disposal, wood ash mixture, pure, 0% water, to municipal incineration (2128)	**2- Acc.**
Transportation from UBC to incineration	0.00006	0.09	tkm	UBC to Burnaby waste-to-energy incinerator: 20 km. 24 ton diesel truck used (direct trip). Single piece of cutlery incinerated (3 E -6 tons)	Aspenware Internal Documents, Google Maps	transport, lorry >16t, fleet average (1943)	**2- Acc.**
Landfill	0.003	0.15	kg	Assume mass of one utensil is 3 grams * 15% to landfill =0.00045kg	BCLiving (2013)- Garbage crisis: our waste by the numbers	disposal, municipal solid waste, 22.9% water, to sanitary landfill (2223)	**2- Acc.**
Transportation from UBC to landfill (Delta)	0.00009	0.15	tkm	UBC to Delta Landfill: 30 km. Assume 24 ton diesel truck used (direct trip). Based on fraction of single utensil sent to landfill (4.5 E -7 tons)	Aspenware Internal Documents, Google Maps	transport, lorry >16t, fleet average (1943)	**2- Acc.**
Composting	0.003	0.76	kg	Assume mass of one utensil is 3 grams *76% recycled = 0.00228 kg	The Loop Garbage Study (2013)	disposal, building, plaster-cardboard sandwich, to recycling (2152)	**2- Acc.**

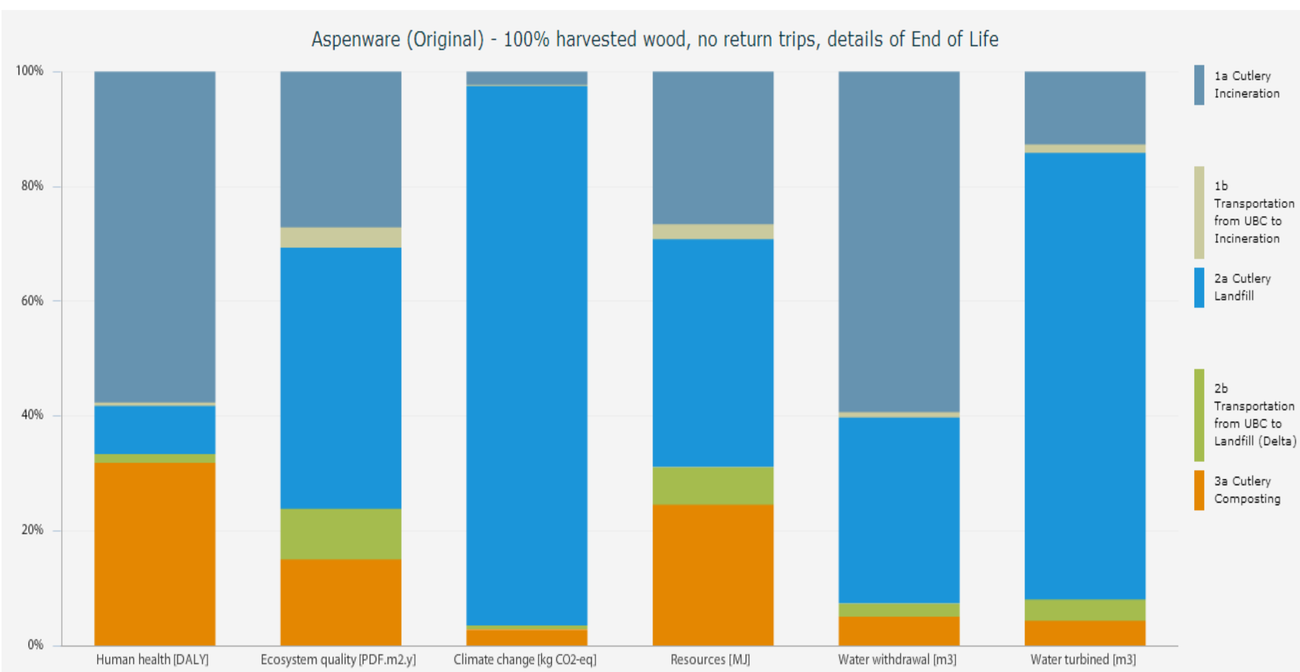
Table 8: Impacts per Functional Unit for End of Life

Climate Change (kg CO_2 eq)	Resources (MJ primary)	Human Health (DALY)	Ecosystem Quality (PDF.m^2.yr)	Water Withdrawal (m^3)	Water Turbined (m^3)
2.695E-4	4.609E-4	1.286E-10	7.605-06	6.328E-7	5.850E-5

Table 9: End of Life Disposal Routes

	Fraction of Cutlery Disposal	Assumptions	Data Sources	Quality
Composting	76%	Consumers correctly recycle 76% of cutlery	The Loop Garbage Study (2013)	**2- Acc.**
Non Composting	24%	100%-76%: fraction not recycled	The Loop Garbage Study (2013)	**2- Acc.**
Incineration	9%	Landfill: incinerator ratio = 1: 1.6. Of 24% not recycled: 1.6x + x = 24%: x = 9% amount of cutlery that goes to incinerator	BCLiving (2013)- Garbage crisis: our waste by the numbers	**2- Acc.**
Landfill	15%	24%-9%=15% (amount that goes to landfill in Vancouver)	BCLiving (2013)- Garbage crisis: our waste by the numbers	**2- Acc.**

Figure 6: Impacts per Functional Unit for End of Life



Alternative Scenarios

Various hypothetical scenarios were created to examine the effect of different parameters. Five scenarios, in addition to the base scenario, were created, including situations accounting for: 100% of the product to be composted at the end of life, 50% reduction of material inputs by choosing wood that would otherwise be left to rot, a least favourable scenario, a most favourable scenario, and return trips in the transportation stage.

Aspenware receives its wood inputs from two sources. Approximately 50% of its wood fibre is salvaged during operations that would otherwise see the wood left to rot, and the other 50% comes from selectively harvested, not clear-cut, trees (Aspenware, 2013).

The base scenario, titled Aspenware (Original), accounts for 100% of the wood input, does not account for return trips of the delivery trucks, and assumes that the cutlery is disposed of according to The Loop Garbage Study (2013). To account for the benefits of using waste wood in the production process, no environmental impacts were assumed for 50% of the wood input; it is assumed that the initial consumer of the wood already accounted for these environmental impacts. However, this only decreases the impact on the ecosystem quality by 43% from the original scenario and has no effect on the other indicators. This is because the Quantis Suite database is set up such that the wood source environmental factor only accounts for the ecosystem quality associated with the wood harvested from forests; it does not affect the stages of manufacturing, transportation, or end of life.

One of the major benefits promoted by Aspenware is its ability to completely degrade in the compost in 49 days. However, the end of life impacts are so small compared to the manufacturing and transportation stages that even when accounting for 100% composting, the biggest impact is a 2 % reduction in the climate change indicator, as compared to the original scenario. The other indicators experience an insignificant reduction of less than 2% with perfect disposal.

If Aspenware were the sole proprietor of their delivery trucks, which it is not, the return trips from the delivery trips would have to be accounted for. This would increase the environmental impact of all the indicators with a 35% increase in impact on human health, 3% increase in impact on ecosystem quality, 7 % increase for climate change, 17 % increase for resources, 28% increase for water withdrawal, and 0% increase for water turbined.

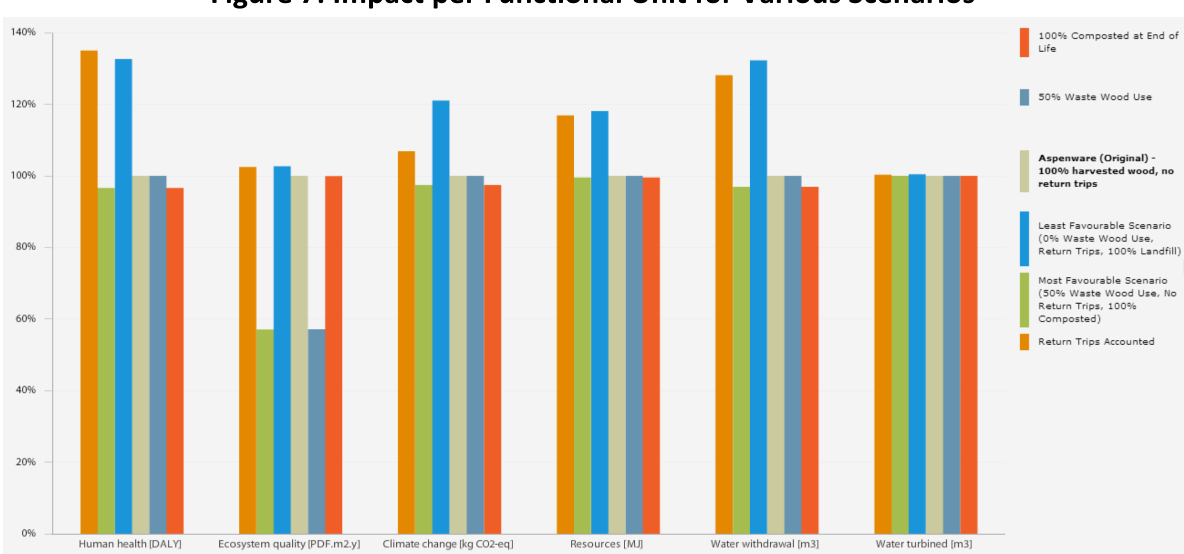
By using a combination of the parameters above, the most favorable and least favorable scenarios were created. The least favorable scenario accounts for the return trips of the delivery trucks and assumes that all cutlery is sent to the landfill. This yields the highest environmental impacts for all the indictors except for human health. For the purposes of this study it is assumed that landfill disposal is worse than incineration. However, as seen in Figure 7, the return trips scenario has a greater impact on human health than the (theoretically) least favourable scenario because, as determined by the database, incineration has greater human health impacts. Therefore, depending on which indicator is weighted more heavily, different parameters can be chosen for the least desirable scenario. When comparing the least favorable scenario to the return trips accounted scenario, it can be seen that they have little difference in impacts. Whether or not Aspenware accounts for the return transportation trips contributes a significant difference in the product’s overall environmental impact.

The most favorable scenario neglects the impact of 50% of wood inputs, doesn’t account for return transportation trips, and assumes that 100% of the used cutlery is disposed of via compost. This scenario yields a reduction of 3% in impact on human health, 43% reduction in impact on ecosystem quality, 2 % reduction for climate change, 1 % reduction for resources, 3% reduction for water withdrawal, and 0% reduction for water turbined, compared to the original scenario. Therefore, there is no significant difference in the disposal method of used cutlery. However, there is a significant decrease in the impact on ecosystem quality when neglecting the impacts of 50% of the waste wood required to produce Aspenware cutlery. Table 10 provides the impacts of various scenarios.

Table 10: Impacts of Various Scenarios

	100% Composted at End of Life	50% Waste Wood Use	Aspenware (Original) – No Wood Discounting, No Return Trips	Least Favourable Scenario (0% Waste Wood Use, Return trips, 100% Landfill)	Most Favourable Scenario (50% Waste Wood Use, No Return Trips, 100% Composting)	Return Trips Accounted
Human Health [DALY]	2.05E-09	2.13E-09	2.13E-09	2.83E-09	2.05E-09	2.87E-09
% Difference to Aspenware Original	-3%	0%	0%	33%	-3%	35%
Ecosystem quality [PDF.m2.y]	0.0109	6.21E-03	0.0109	0.0112	6.21E-03	0.0112
% Difference to Aspenware Original	0%	-43%	0%	3%	-43%	3%
Climate change [kg CO_2-eq]	9.76E-03	0.01	0.01	0.0121	9.76E-03	0.0107
% Difference to Aspenware Original	-2%	0%	0%	21%	-2%	7%
Resources [MJ]	0.0677	0.0679	0.0679	0.0803	0.0675	0.0793
% Difference to Aspenware Original	0%	0%	0%	18%	-1%	17%
Water withdrawal [m3]	1.83E-05	1.88E-05	1.88E-05	2.50E-05	1.83E-05	2.42E-05
% Difference to Aspenware Original	-3%	0%	0%	33%	-3%	28%
Water turbined [m3]	0.236	0.236	0.236	0.237	0.236	0.237
% Difference to Aspenware Original	0%	0%	0%	0%	0%	0%

Figure 7: Impact per Functional Unit for Various Scenarios



A Comparison to Plastic Utensils

For the purposes of this study, Aspenware cutlery was compared to plastic cutlery made of injection molded general purpose polystyrene. It was assumed that each piece of plastic cutlery weighs 2.6 grams (lowest quality, soft cutlery) and the average retail cost per piece is $0.04 (Made in China, 2013). As seen in Table 11 below, plastic cutlery production results in 24% greater kg CO_2 emissions. Plastic cutlery is about 43% less expensive than Aspenware. Both values are based on cradle to grave system boundaries from resource extraction to end of life disposal. It is assumed that the plastic cutlery is simply disposed of in the landfill at its end of life. It is important to note that these results are based on numerous assumptions and have a large margin of error. As a result, the difference in CO_2 emissions may not be very significant since there is about a 20% difference. Now that this study has outlaid the impacts of Aspenware, further research needs to be done into the ecosystem impacts of plastic cutlery. It is presumed that the ecosystem impact of plastic is much larger than that of Aspenware due to Aspenware's ability to quickly decompose, much unlike plastic.

If the mass of plastic cutlery were assumed to be 5 g, which is a minimum for higher quality medium to heavy weight cutlery, the results are a lot more favourable for Aspenware, as seen in Table 12. Higher quality cafes and food establishments may require better quality and less flimsy plastic utensils. One of Aspenware's claims is that its knife can cut through steak. Low weight plastic cutlery would not be capable of cutting through a steak, and if such a function is desired, medium to high weight cutlery would be necessary. In such a case, our results suggest that Aspenware is better in terms of CO_2 emissions with a 60% reduction.

More research has to be done to quantify the impact of plastic cutlery on human health, water resources required and ecosystem quality impacts to provide a better comparison between Aspenware and plastic cutlery.

It is important to note that the end-of-life factors of Aspenware's cutlery will have far broader implications than reductions in carbon dioxide emissions. Plastic may not degrade for hundreds of years and it was not possible to quantify this in our numerical results (Cruise). Aspenware's wooden cutlery composts in less than 49 days, making it perhaps a more viable option (Aspenware, 2013).

Table 11: Comparison of Aspenware and Plastic Cutlery (2.6g)

	CO_2 emissions (kg CO_2/utensil)	**Unit Cost** ($/utensil)
Polystyrene Plastic Cutlery	1.310E-02	$0.04
Aspenware Cutlery	1.000E-02	$0.057
Percent Difference	**-24%**	**43%**

Table 12: Comparison of Aspenware and Plastic Cutlery (5 g)

	CO_2 emissions (kg CO_2/ utensil)	**Unit Cost** ($/utensil)
Polystyrene Plastic Cutlery	2.520E-02	$0.04
Aspenware Cutlery	1.000E-02	$0.057
Percent Difference	**-60%**	**43%**

Recommendations and Conclusions

Life cycle analysis is a powerful scientific tool to quantitatively analyze the full environmental impact of a product or service. By examining the effects of all the resources, energy, waste, and emissions from the cradle to the grave, LCA identifies areas of focus for product innovation and development. Not only will this decrease the environmental impact of the product but potentially cut costs by reducing energy consumption. In order to maximize the effectiveness of an LCA report, it is important to clearly state the system boundaries, assumptions, and inputs so that the client can understand the full scope and accuracy of the report as well as make amendments as necessary.

A full life cycle analysis assesses the impact of a product or service using an array of indicators such as climate change and ecosystem quality, each with a different set of units. Therefore, the results are subjective to the client's interpretation. Depending on which factors the client may weight more heavily, one report may yield different decisions for two different clients. While it is difficult to compare a kg of CO_2 emissions to a MJ of energy usage, normalization of the results to 100% can serve as a useful tool when comparing two similar products. Areas such as resource availability, compost volume requirements, cultural and social acceptability, and cost may also factor into the final decision, but such parameters are difficult to quantify.

It is recommended that Aspenware focus on its manufacturing and transportation stage if it seeks to reduce its environmental impact. The largest component of the manufacturing stage appears to be the veneer drying process. A continuation of this study should explore other "environmentally friendly" cutlery alternatives such as BSI cutlery. More research has to be done to quantify the impact of plastic cutlery on human health, water resources required and eco system impact to make a better educated decision.

Overall, the production of 2.6 g plastic cutlery and 5 g plastic cutlery results in an approximate increase of 24% and 60% kg CO_2 emissions per piece of cutlery, respectively, when compared to Aspenware. Plastic cutlery is about 43% less expensive than Aspenware. The end-of-life impacts of Aspenware cutlery will have broader implications than simple reductions in carbon dioxide emissions. Plastic may not degrade for hundreds of years and this was not quantified in the report's data (Cruise). Aspenware's wooden cutlery composts in less than 49 days, making it a more viable option (Aspenware, 2013). Overall, it is recommended that Aspenware be purchased over plastic cutlery due to the reduced greenhouse gas emissions and its compostable nature which results in less space requirements for on campus composting.

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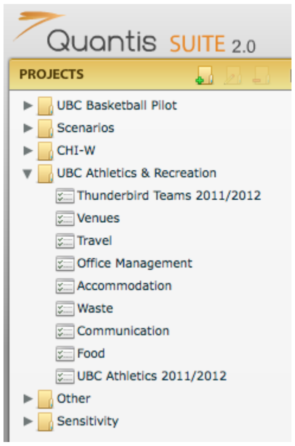
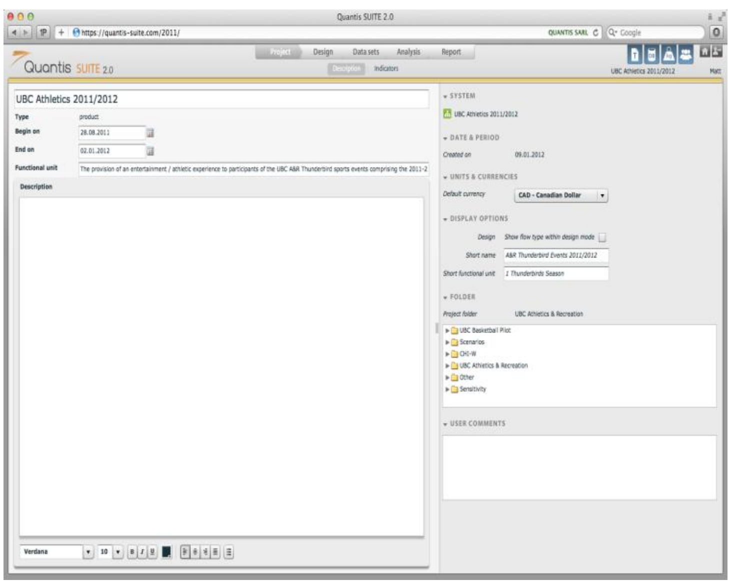
Appendix

Quantis Suite

1. Create a new project, or select a current project.



2. Add in the details of the project



3. Setup the project by creating and embedding elements.

4. Add input-output “flows” (e.g. materials) to the elements by dragging them from the pre-defined menu items on the bottom left screen.

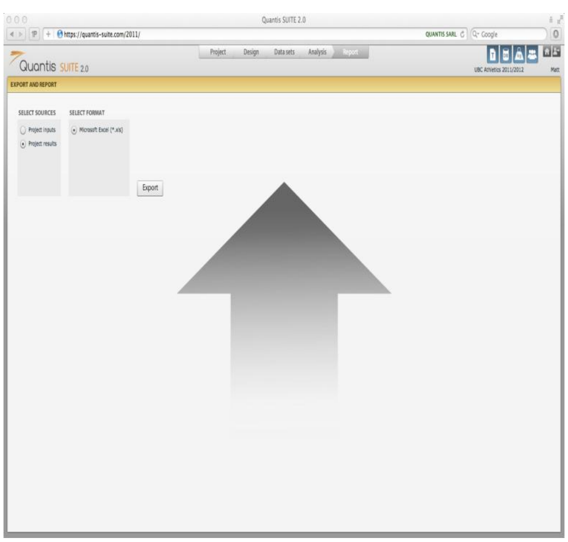
5. Assignment environmental factors (EF’s) to your flows. Clicking on the grey ‘EF’ button takes you to the ecoinvent database (first picture). Here you can filter through the 4,000 EFs and also compare impacts by selecting two or more at the same time. Double clicking assigns the EF and it will then appear on the flow (second picture).

6. Enter the activity data. The example below shows spectator car travel. Data can be entered directly into the “Quantity” field or, as in the case here, parameters can be used to set up a “Formula”. In all cases the “Units” must match up with that required by the EF (e.g. passenger kilometers - pkm). Note that data can be added at enter the element or flow level.

7. The “Analysis” tab shows the impacts through an interactive graphical interface.

8. A custom database of environmental factors can also be created.

9. The “Report” section can be used to export results to Excel.



(Quantis Intl)

Plastic cutlery Impact

The following GHG emissions were assumed for plastic cutlery:

Injection Molded General Purpose Polystyrene (GPPS)

Process	GHG emissions in kg CO_2E per kg polymer	Energy demand in MJ NCV per kg polymer
Production (cradle-to-polymer)	3.53	81.00
Injection molding	1.27	25.30
Forward logistics	0.15	2.10
Landfill	0.09	0.31
Cradle-to-grave	5.04	108.71
Collection	0.07	0.99
Transport to processor (500 km)	0.08	1.13
Reprocessing into polymer (incl. processing waste landfill)	0.49	7.10
Collection-to-gate	0.64	9.22

(CalRecycle, 2012)

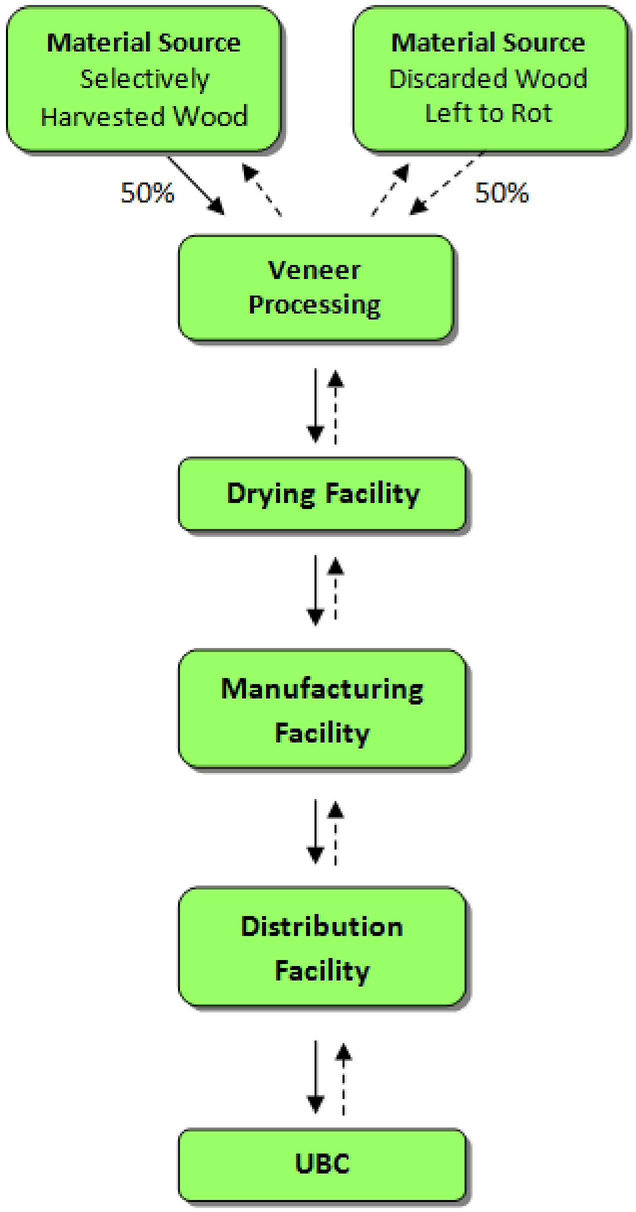


Figure 8: Different Stages of Transportation