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SUSTAINABLE WASTE MANAGEMENT IN SCHOOLS

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SUSTAINABLE WASTE MANAGEMENT IN SCHOOLS

BY

EMILY ORR

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

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OF

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ABSTRACT

A school district was interested in making sustainable changes in their cafeterias to lower their environmental impact. To determine their current state, weight and dimensions of their waste were taken, lunch observations and spaghetti diagrams were developed, and the purchasing process of lunch trays was determined. This was all used to create a current state map, a common industrial engineering tool used in lean manufacturing to display the flow of a system and label problem areas. From there, a life cycle assessment made with Umberto NXT LCA software was created for four lunch trays systems: disposable paper boats, compostable trays if sent to a composting facility, compostable trays if disposed of in a landfill, and reusable plastic trays. This was used to calculate the environmental impact and the results were compared for each tray. After this, a cost analysis was completed. One portion was developed to determine the expense or savings involved in switching to a different tray and/or dishwasher unit than what was already in place at each school level (elementary, middle, and high school). Another involved comparing the estimated amount of trash accumulated over a year with the annual volume of the dumpsters the schools were paying for. Lastly, a future state map was developed to lay out changes that could improve the system of the cafeterias.

The current state showed some areas in need of improvement such as recycling behavior, cafeteria layout of the waste bins, and educational signage. In terms of the weight and volume data collected, the high school had the largest tray contribution to trash when comparing the total weight and volume of the trash with the trays. For the life cycle assessment, reusable trays had the lowest environmental impact based on the

impact categories studied. The tray types with the highest impact were the compostable trays if sent to a landfill and the disposable trays. Once the cost analysis was completed, it was determined that while the reusable trays would be the best choice to lower environmental impact, it would be costly for any school level to switch to using them at that time. Switching to new dishwasher units, however, would save the schools money if the initial purchase could be covered. Finally, the future state map created incorporated changes that would resolve the problems noted in the current state map such as the positioning of waste bins and better signage.

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CHAPTER 1: INTRODUCTION

1.1 Background

Numerous studies have pointed out the issues that are arising in terms of the environment which is why there was motivation to complete this study. For instance, the Intergovernmental Panel on Climate Change (IPCC) discusses that climate change has adversely impacted weather changes, terrestrial ecosystems, land degradation, and food security. They have also mentioned attempts that have been done to resolve these problems or at least mitigate them including sustainable food production, improved and sustainable forest management, soil organic carbon management, ecosystem conservation and land restoration, reduced deforestation and degradation, and reduced food loss and waste (IPCC, 2019). As schools are such large organizations, they contribute large amounts of waste, electricity usage, and food loss all generating a great environmental impact which the IPCC is striving to reduce. While not all actions can be taken within the school systems, any change to lower environmental impact will help.

1.2 Context

With the exponential rise of concern regarding environmental impact from Rhode Island residents, in part caused by the predicted closing date for the Johnston Landfill which is operated by the Rhode Island Resource Recovery Corporation (RIRRC, 2015), a Rhode Island school district has been looking for ways to make sustainable changes within their schools, especially in their cafeteria handling of trash, recycling, and compost. Once this landfill closes, options include building another

landfill or waste being sent to another state which is costly (incineration is not an option in Rhode Island as this is prohibited). There is difficulty in determining what changes would be best and how to fit this within a certain budget.

1.3 Purpose

The goal of this research was to provide the school district with options that would benefit the environment while keeping in mind the amount of money they have to put towards this area of expense. This was done by first laying out the current state of the systems in the cafeterias, making note of sustainable behaviors and possible problems. Then, a future state was developed to depict what the system could look like, should certain recommendations be implemented. The questions associated with this are:

- What is the current state of the cafeteria systems?
- What are the environmental, economic, and social impacts of the systems?
- What changes can be suggested that will lower environmental impact?
- How would these changes affect the school financially?

1.4 Significance & Scope

This problem was selected not only because of the needs of the schools and the community but because it provides an opportunity to exercise multiple methods from the industrial and systems engineering discipline and present this appropriately to others who do not have expertise in this area. At the end of this study, the findings were summarized and shown to the Superintendent, Chief Financial Officer,

principals, as well as other members of the school district. Educating students on this topic and demonstrating sustainable behavior within schools is a growing concern among numerous school districts and this can be made into an example for others to follow. In other words, supporting sustainable habits in a school system can greatly impact the community over time in terms of positive environment related behaviors (GSA, n.d.). Collecting and working with data and observations as well as facilitating how changes can be made by people working in multiple levels of hierarchy is a critical role industrial and systems engineers must take on. Students spend a major portion of their developmental years in school and if they are educated about sustainability issues in the classrooms and the cafeterias, there is great potential that this will aid in extending the life of the landfill as well as maintaining these good habits in their community in the future.

1.5 Definitions

1.51 Current State / Future State Map:

A value stream map is a process mapping tool often used in lean manufacturing to display how a system is currently run with problems labeled (current state map) and how it can appear should the problems be resolved (future state map) (EPA, 2016). The problems are pointed out with a label known as a Kaizen Burst which can be seen in Chapter 4. Kaizen, also known as continuous improvement, “focuses on eliminating waste, improving productivity, and achieving sustained continual improvement in targeted activities and processes of an organization” (EPA, 2019). In this case, these will be used in the form of what is known as a sustainable value stream map. This method focuses on pointing out areas that can be improved to

benefit the environment and reduce waste (Faulkner & Badurdeen, 2014). For this study, the school cafeterias with sustainable changes have been labeled on the maps. The recommended flow of the cafeteria systems that is shown in the future state map was designed in a way that considers sustainable routing.

1.52 Sustainable Routing:

This has previously been used as a tool for manufacturing facilities. The process of sustainable routing is to send manufactured parts through the system to determine which path leads to lowering environmental impact and costs by reducing the amount of usage in areas such as water and electricity. In terms of the schools, recommendations from observing the current state have been formed to suggest what would lower certain wastes based the paths or layout chosen. A case study on this method shows that while making certain sustainable changes may not result in the cheapest outcome, it would aid in coming closer to what is known as the Triple Bottom Line (Gerdes and Maier-Sperdelozzi, 2018).

1. 53 Sustainable Development and the Triple Bottom Line:

The concept of sustainable development was first released in the Brundtland Report, *Our Common Future*, in 1987 by the World Commission on Environment and Development and accepted by the United Nations. It is defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987, p.41). This report was a source of inspiration for the Triple Bottom Line (TBL), which was terminology defined by John Elkington, (Elkington, 1998). It is a theory often used in businesses to assess its

performance. The term “bottom line” is often used to describe profit as a measure of success. While profit is important, it is not the only area that should be considered, as Elkington points out. The TBL is divided into three sections. These are economic, environment, and social equity which are elaborated on in the Brundtland report and necessary in order to be considered sustainable. This is also known as the three pillars of sustainability. The economic or profit section represents the financial portion as in the original “bottom line” term. Environment, or planet, is focused on how a company or organization impacts the environment such as a carbon footprint. Lastly, social equity or people is regarding how fair or well the community is treated such as when education or healthcare are considered (Elkington, 1998). In terms of a school district, economic restrictions exist as there is a limited budget provided. Concerns regarding the environment must be a focus when educating children that will become the next generation of citizens. Finally, social issues impact the school as there is not always agreement on the level of importance of sustainability among such a large body of people.

1.54 Life Cycle Assessment:

A life cycle assessment (LCA) is used to determine the total environmental impact of a product throughout its lifetime from raw materials to a complete design that will eventually be disposed. The main steps to complete an LCA include the definition of the goal and scope, an inventory analysis, and an impact assessment which will be elaborated on in Chapter 3. These steps are also outlined in Figure 1. Within an LCA, there is a functional unit, which is the measure used to compare products and list the inputs and outputs as well as system boundaries which define the

processes that will be accounted for in measuring impact. (Baumann & Tillman, 2014). In this study, the goal was to provide the schools with the most sustainable and economical tray option. A comparative LCA has been completed with the functional unit being one tray for the disposable, compostable, and reusable option. Once this was complete, the trays were compared for both the lowest environmental impact in all categories and the cost.

Figure 1 - The LCA Procedure (Baumann & Tillman, 2014)

1.55 Level

In this paper, the term “level” refers to either the elementary schools, the middle schools, or the high school. The elementary schools were individually named as Elementary School (ES) A, B, C, and D. The middle schools were named Middle

School (MS) A and B. As there was only one high school (HS) in this study, it did not have a letter associated with its name.

1.6 Outline

The outline of the following chapters begins with Chapter 2 which is a review of literature related to this study. Chapter 3 covers the methodology to gather the information used and Chapter 4 includes the results using these methods. Chapter 5 is an analysis of the results followed by Chapter 6, which discusses conclusions and the associated risks, assumptions, and final thoughts.

CHAPTER 2: REVIEW OF LITERATURE

2.1 Environmental Impact

The United Nations developed an action plan titled “Transforming Our World: the 2030 Agenda for Sustainable Development”. This agenda laid out seventeen main goals toward sustainable development designed for people, planet and prosperity. These goals are listed in Table 1 below (United Nations, 2015). A number of these goals relate to the issue of sustainability in school districts. For example, Goal 4 (quality education) and Goal 12 (responsible consumption and production) are related to the objective of educating students and staff on proper trash and recycling habits. School sustainability also supports Goal 11 on sustainable cities and communities as schools are an essential element of local government. Finally Goal 13 regards climate action and environmental impacts within a cafeteria setting can have positive effects on reducing carbon footprint.

Goal 1	End poverty in all its forms everywhere
Goal 2	End hunger, achieve food security and improved nutrition and promote sustainable agriculture
Goal 3	Ensure healthy lives and promote well-being for all at all ages
Goal 4	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
Goal 5	Achieve gender equality and empower all women and girls
Goal 6	Ensure availability and sustainable management of water and sanitation for all
Goal 7	Ensure access to affordable, reliable, sustainable and modern energy for all
Goal 8	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
Goal 9	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
Goal 10	Reduce inequality within and among countries
Goal 11	Make cities and human settlements inclusive, safe, resilient and sustainable
Goal 12	Ensure sustainable consumption and production patterns
Goal 13	Take urgent action to combat climate change and its impacts*
Goal 14	Conserve and sustainably use the oceans, seas and marine resources for sustainable development
Goal 15	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
Goal 16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
Goal 17	Strengthen the means of implementation and revitalize the global partnership for sustainable development

Table 1 - Sustainable Development Goals (Adapted from United Nations, 2015)

One prevalent topic which has shown impacts on climate change is the treatment of organic waste. Food waste, for instance, has been a concern for many years due to its negative effects on the environment. A study completed by the Food and Agriculture Organization of the United Nations looked into the global impact of food waste in terms of carbon footprint, water and land biodiversity. Globally, food waste is estimated to produce a total of 3.3 gigatons of carbon dioxide equivalent per year without including the greenhouse gas emissions from the land usage. It also depletes surface and groundwater resources by an annual estimate of 250 cubic kilometers (FAO, 2013). While it is not ideal to have any unnecessary organic waste, there must be a decision made on how to handle any such waste that is generated.

Some examples of waste in this category include the composting of food in schools as well as the use of compostable trays.

A similar study has been completed on three Florida schools. Waste audits were made at each cafeteria location to determine the highest contribution of the waste streams. This resulted in the average student generating over one hundred grams of waste per day with food waste making up roughly fifty one percent of this. With other organic waste included such as paper added, this amounted to about eighty one percent of the overall waste daily. Given this information, the recommendation was to find a way to properly recycle and compost to reduce their environmental impact (Wilkie, Graunke, & Cornejo, 2015).

There has been skepticism over whether composting is a better method than landfilling this type of waste. When organic matter is placed in a landfill, it goes through a process of anaerobic decomposition. In other words, this waste is deprived of oxygen and produces what is known as methane. Should this same waste be composted, it goes through an aerobic decomposition process which produces carbon dioxide rather than methane (EPA, 2020). Neither of these emissions are beneficial to the environment, however, composting has a much lower environmental impact.

Methane is a type of greenhouse gas. It makes up about fifty percent of the landfill gasses that are produced. Over one hundred years, it traps heat in the atmosphere about twenty-eight to thirty-six times more effectively than carbon dioxide (IPCC, 2014). Figure 2 represents the pathways for greenhouse gas emissions from a landfill with carbon dioxide represented as CO₂ and methane represented as

CH₄ (Bogner et al., 2007). The methane gas could be used as an energy source should it be captured and treated properly (see the gas well in Figure 2) which would reduce the environmental impact.

Figure 2 - Landfill Greenhouse Gas Pathways (Bogner et al., 2007)

2.2 Sustainable Changes in Schools

The Center for Green Schools at the US Green Building Council provided what is known as the “Whole-School Sustainability Framework”. The aim of the framework was to demonstrate how sustainable practices could be integrated in a school organization. A diagram of the three main components is shown in Figure 3. The component, Organizational Culture, is defined as the “the shared values, social norms, and practices within an organization” (Barr, Cross, & Dunbar, 2014). This framework has also been used by other groups in the support of sustainable changes in schools. One example is the organization, Green School Alliance, which guides school communities to implement sustainable changes through programs for students, school professionals and district professionals. For instance, they host what is known as a Green Cup Challenge which has students win points for recycling properly over the

span of four weeks (Green Cup Challenge, 2017). To implement lasting change in a school system it is imperative to find ways to empower the members of the community.

Figure 3 - The Whole-School Sustainability Framework (Barr, Cross, & Dunbar, 2014)

A study done at an elementary school aimed to minimize the amount of waste produced with initiatives geared towards educating the children on proper recycling/composting behaviors. To display the issue of mismanaged waste, a trash audit was completed in the cafeteria on three garbage bins chosen at random. The results included that of every item placed in the trash, 93% was either recyclable or compostable and that recyclable milk/juice cartons as well as Styrofoam trays

contributed most to garbage consumption (James, 2017). This was helpful to lay out this problem area within the school.

2.3 Life Cycle Assessment

The International Organization for Standardization (ISO), formed in 1947, “brings together experts to share knowledge and develop voluntary, consensus-based, market relevant International Standards that support innovation and provide solutions to global challenges” with 23,126 international standards defined (ISO, 2020). Within this, the ISO has a series of standards designed for Life Cycle Analysis, or LCA. These standards are defined in the ISO 14000 Family, titled “Environmental Management” (ISO, 2020). Specifically, these standards can be found in ISO 14040 to ISO 14044. More details about the specific steps and model building using these standards are in Methodology section 3.2.

One example of an LCA that followed the ISO standards was completed on multiple crockery types used in the United States. The three scenarios considered were non-patient meals in hospital cafeterias, school lunches, and breakfasts for hotel guests. The two systems observed and evaluated for potential ecological impacts in each scenario were reusable and disposable crockery. Their audience was intended for experts along with responsible decision makers working in the commercial kitchen field. Their functional unit was defined as “Provision of dishes for the hygienic delivery of X portions of food a day within a year in a stationary out-of-home cafeteria in the USA” (Antony & Gensch, 2017, p. 23). The impact categories considered were ozone depletion, global warming, fossil depletion, acidification and terrestrial acidification, eutrophication, photochemical oxidation, agricultural land occupation,

natural land transformation, cumulative energy demand, and water depletion. The software tool, Umberto NXT LCA, was used to carry out their assessment.

The results of Antony & Gensch (2017) showed that for most of the impact categories tested, reusable crockery had a lower impact than disposable. For the disposable crockery, the production and disposal contributed most to the environmental impacts in all scenarios. For reusable crockery, the use of washing the dishes contributed the most to the overall environmental impact. Given these results even with a higher water demand for the reusable system, the conclusion for all three scenarios after completing the life cycle assessment was that reusable crockery would have the lowest environmental burdens and should be used over disposable for this reason. This being stated, to improve upon this analysis, it would be beneficial to consider the costs of each system.

2.4 Lean Manufacturing Techniques

In lean manufacturing, the main goal is to eliminate wastes in a system. Waste is considered any process that does not add value. These wastes have been divided into specific categories. The first seven, known as the Seven Deadly Wastes were identified in the Toyota Production System. These include defects, overproduction, waiting, transportation, inventory, motion, and excess or extra-processing. The eighth waste, added later, is known as unused talent, or not using resources efficiently.

Defects refer to products that do not meet customer needs. Overproduction occurs when more is made than needed to meet the demand. Waiting is when time is spent not adding value to the system. Transportation refers to unnecessary movement from parts of the system such as the people or inventory. Inventory refers to having more

than is needed of a product on hand that is taking up valuable space. Motion is the unnecessary movements done by people that can cause ergonomic issues. Excess processing is completing more than is needed in terms of work, equipment, or steps in a process. Lastly, not using resources efficiently refers to human or natural resources (The Lean Way, 2020).

In “The Lean and Environmental Toolkit” by the Environmental Protection Agency, some of these wastes are related to environmental impacts. For Defects, this can relate to raw material and energy consumption that goes into making the defective product as well as the disposal of the product. Overproduction requires more raw materials and energy than is needed to complete the task. Waiting can involve a waste of energy from the electricity used during this time. Transportation that is not needed causes unnecessary emissions if it is referring to vehicle transports. Inventory that is taking up space can result in more energy used in terms of electricity for heating, cooling, and lighting. Lastly, excess processing can be connected with the consumption of more raw materials and energy for extra steps completed or products made (EPA, 2019).

CHAPTER 3: METHODOLOGY

3.1 Current State

The research began by connecting with each individual school and meeting with key personnel such as the principal and/or assistant principal as well as the head custodian. The purpose of this introductory meeting was to gather information on the school's current state and procedures regarding the how waste was handled in the cafeteria as well as the schedule for the trash and recycling pickups. In addition, the lunch period times were noted and another visit to each school was arranged to observe the lunches. Because this project involved some observation of human subjects, it was approved by the Institutional Review Board of the University of Rhode Island.

A lunch period observation took place once at each school to determine how the system was run. Notes were taken on the layout of the cafeteria, including the location of the serving stations, tables for the students to eat, as well as the trash, recycling, and compost barrels. Additionally, sustainable behaviors of the students were tracked to assess their familiarity with the trash and recycling regulations of Rhode Island. The flow of the lunch period was determined by creating spaghetti diagrams of the students' processes to learn the functionality of the layout. After these observations, weight and dimension data of the trash and recycling was measured at the end of each of the lunch periods. A sample of the trays used at each level was collected, measured, and weighed to calculate how much the trays contribute to the cafeteria trash.

The bags of waste were weighed using a standard scale and the trays were weighed with an electronic food scale. This information was used to determine the estimated daily tray contribution to trash. All trash bags were weighed at each school after the lunch periods and added together for each level to make the estimated daily weight of trash. To determine the daily weight of the trays, the annual number of trays purchased was divided by the number of school days in a year (assumed to be 180 days) and multiplied by the unit weight of the tray for each level. The dimensions of the trash and trays were taken with a standard ruler and used to determine the volume. The volume of each trash bag was calculated by assuming the shape was a cylinder. After the volumes were determined, they were added together to make the daily volume of trash per level.

Like the trash, the different tray volumes were determined by volume calculations of shapes that were most similar to the trays. The compostable tray used the volume of a rectangular prism, the disposable tray used the volume of a trapezoidal prism (see Figure 12 for reference), and the styrofoam plate used the volume of a cylinder. An assumption was made that the trays were stacked before throwing them away so for all cases, when multiplying the number of trays needed per day by the volume of the tray, the height is calculated by adding together the height of one tray with the product of the thickness and number of trays needed per day to create a total height. The contribution the trays to the trash per day was calculated by taking its daily weight or volume and dividing it by the weight or volume of the trash. For the compostable trays, this scenario assumed that the trays were being thrown into the landfill which was occurring at the time of this study. This information was then used

along with the price and frequency of the trash collection service to support the cost analysis of the current systems in place.

3.2 Environmental & Economic Comparison LCA

The following sections, 3.21 to 3.23, define the processes followed in the life cycle assessment which will be connected with this study in Chapter 4, the results section. The costs of all products mentioned will also be determined and further discussed in the next section, 3.3 - Options and Cost Analysis.

3.21 Goal & Scope

In the ISO 14040:2006, Principles and framework, the goal and scope of a life cycle assessment are defined. The goal of an LCA should state the purpose or reason for the study to be completed, the audience that it is intended for, and whether it is being used for comparison purposes. The scope of an LCA should state the products of the system, the functional unit, the choice of impact categories, the type of LCA, and the system boundaries (ISO, 2016). The products of the system refer to what items are being studied.

The functional unit is defined as a “quantified performance of a product system for use as a reference unit”. There are a number of resources to determine the choice of impact categories such as TRACI and ReCiPe (GmbH, 2016). Some examples of impact categories include carbon emissions, global warming potential, and human health carcinogens. Two main types of LCA, accounting and change-oriented. An accounting LCA focuses on the environmental impact associated with the product. A

change-oriented LCA looks at the consequences of switching to alternative options in terms of environmental impact. Finally, the system boundaries define what the particular study will include and what will not be considered. The system boundaries are broken into four main categories: boundaries in relation to natural systems, geographical boundaries, time horizon, and boundaries in relation to other product's life cycles (Baumann & Tillman 2014).

Natural systems refer to the beginning and end of the life cycle and what is being considered in the study. Geographical boundaries define what part of the world are included in the study. The time horizon boundary defines the period from which the study will extend to for its consequences (example: 5 years). The boundaries in relation to other product's life cycles considers production capital and allocation of other life cycles linked with the product.

3.22 Inventory Analysis

An inventory analysis involves a flowchart of the process, data collection of the product and associated processes, as well as the results of the environmental loads. The collection of data is laid out to show what was determined and what sources were used as well as how it is represented in the results. This includes sections such as the product name, the quantity, material type, dimensions, environmental loads in relation to the functional unit, and mass (Baumann & Tillman 2014). Once this is determined, an impact assessment on the results can be completed.

3.23 Impact Assessment

The impact assessment includes three mandatory elements. The first involves defining the impact category. This includes the selection of impact categories, category indicators, and characterization models. The next element is classification, where the results based on impact categories are listed. The last element is characterization. This is where the environmental impact per product or category is determined (ISO, 2016).

3.3 Options and Cost Analysis

The information gathered from the current state and life cycle assessment allowed for many options to be considered and an engineering economic analysis to be completed. A cost analysis was completed for the elementary schools, middle schools, and high schools to determine which tray option would be recommended on the basis of cost alone. The data on the number of trays needed was based on the trays purchased the previous year. This information as well as the cost of the trays and labor information was provided by the purchasing department. For the reusable trays, the school and cafeteria supplies provider estimated that thirty percent of the trays would need to be replaced each year due to loss or theft. In addition, the dishwasher units of certain schools were noted and compared with other units to calculate the potential savings or loss involved in switching to a different model. The data related to the dishwashers was provided by a dishwashing equipment company that performed energy audits, although only some schools had the audits completed during this study, due to unanticipated access restrictions (Kittredge, personal communication,

2020). Costs of trash collection and recycling through various providers were also gathered.

3.4 Future State

Finally, once all the data had been collected, recommendations were completed. This was to lay out what changes could be made to lower environmental impact while remaining conscious of cost. To go along with the current state map, a future state map was created to display the flow of the systems should certain recommendations be considered.

CHAPTER 4: RESULTS

4.1 Current State

4.1.1 Lunch Observations

To develop the current state map of the lunch periods, each school was visited, and the cafeteria system was observed during these times. The layout, as well as spaghetti diagrams depicting the paths students walked during this time, was recorded. In addition, sustainable behavior was noted. These spaghetti diagrams are shown in Figures 4 to 10. The colors symbolize the path of different students. The waste bins are labeled with circles with “T” being trash, “R” being recycling, and “C” being compost.

In the elementary schools, in most cases for the lower grades, students lined up to throw away their waste. The upper grades were able to use the bins as needed. There were several observations of students that hesitated at the bins unsure which was the correct one to dispose of their waste and many ended up using the incorrect bin. To help with this, a few of the schools had signs educating the students on the proper rules of recycling and compost. Two of the schools had bins that were color coded (trash was grey, recycling was blue, compost was red) to also help in this situation. In addition, at the end of the lunches, most schools had the trays stacked to save space before they were thrown away. The middle school and high school students were able to use the bins whenever needed. There were a large amount of milk and water bottles thrown in the trash. The paper boats and styrofoam plates were not stacked before disposal.

Figure 4 - Spaghetti Diagram of Elementary School A

Figure 5 - Spaghetti Diagram of Elementary School B

Figure 6 - Spaghetti Diagram of Elementary School C

Figure 7 - Spaghetti Diagram of Elementary School D

Figure 8 - Spaghetti Diagram of Middle School A

Figure 9 - Spaghetti Diagram of Middle School B

Figure 10 - Spaghetti Diagram of the High School

4.1.2 CSM

After observing lunches and taking note of the layouts and processes in each school, a current state map was created as shown in Figure 11. The beginning of the process occurred when the purchasing department ordered lunch trays from a supplier, labeled as Cafeteria Supplier. The information on how the trays were ordered came directly from the purchasing department of the school. Next, the delivery truck dropped off the trays to each school. The teal triangle labeled “Trays Delivered” is known as an inventory symbol to show the trays sitting in the cafeteria for an amount of time before they were provided to the students. The student then ate their lunch and walked over to the waste bins to either throw away, recycle, or compost what was left. Composting was only an option for some of the elementary schools at this time, with

pickups which occurred once a week by volunteers from the community. Recycling was picked up once a week in every school. Trash for the landfill was picked up three times per week at each building. The first kaizen burst (the blue pointed icon) is labeled for when the student walked to the waste bins titled “Transportation” referring to the unnecessary distance traveled to reach the locations of certain waste bins. The next is at the point of disposal with a “Waste” label due to improper throwing away of trash or recycling and therefore materials sent to a landfill that could have been recycled. The last kaizen burst is located where there are trucks symbolizing the delivery of waste to its appropriate destination labeled “Emissions” referring to the emissions required to transport the waste to its disposal location when alternatives might provide less travel.

Figure 11 - Current State Map: Lunch Period and Ordering of Trays

4.1.3 Weight Data

The calculations for the volumes of the trays are shown in Table 2. Table 3 shows the tray contribution to trash by level for both weight and volume. Figure 13 and 14 show a graph of the tray contribution by weight and volume as a percentage of the trash, respectively. Based on weight, the high school lunch trays contributed to 42.910% of cafeteria trash. The middle school trays were 10.539% and the elementary schools were 20.756% of the trash weight. Based on volume, the high school trays made up to 6.915% of the trash, the middle school trays were 1.687% and the elementary school trays were 21.821% of the trash.

Tray Calculations & Dimensions				
Compostable Tray				
Volume Calculation: Rectangular Prism (Length x Width x Height)				
	Length	Width	Height	Thickness
inches	10.375	8.250	1.000	0.150
yards	0.288	0.229	0.028	0.004
Unit Volume	0.002 yd ³			Total cubic yds / day (stacked)
Est. # of Trays per day	408.078			0.114
Disposable Paper Boat				
Volume Calculation: Trapezoidal Prism (0.5 x Length x (Width of a + Width of b) x Height)				
	Length (l)	Width (a+b)	Height (h)	Thickness
inches	4.750	13.438	2.000	0.016
yards	0.132	0.373	0.056	4.340E-04
Unit Volume	0.001 yd ³			Total cubic yds / day (stacked)
Est. # of Trays per day (Middle Schools)	328.850 trays			0.005
Est. # of Trays per day (High School)	285.661			0.004
Disposable Styrofoam Plate				
Volume Calculation: Cylinder (Pi x Radius squared x Height)				
	Radius	Height	Thickness	
inches	4.500	1.000	0.039	
yards	0.125	0.028	0.001	
Unit Volume	0.001 yd ³			Total cubic yds / day (stacked)
Est. # of Trays per day	285.661 trays			0.017

Table 2 - Tray Type Calculations and Dimensions for Volume per Day

Figure 12 - Volume of a Trapezoidal Prism

Tray Contribution to Trash by Weight						
Level	Trash Weight per day (lb)	Tray Type	Weight Per Tray (lb)	Est. # Trays per Day	Est. Tray Weight per day (lb)	Contribution to Trash
Elementary Schools	99.692	Compostable	0.051	408.078	20.692	20.756%
Middle Schools	89.425	Disposable Paper Boat	0.029	328.850	9.425	10.539%
High School	52.836	Disposable Paper Boat & Styrofoam Plate	0.040	571.322	22.672	42.910%
Tray Contribution to Trash by Volume						
Level	Trash Volume per day (yd^3)	Tray Type			Tray Volume Per day (yd^3)	Contribution to Trash
Elementary Schools	0.523	Compostable			0.114	21.821%
Middle Schools	0.289	Disposable Paper Boat			0.005	1.687%
High School	0.305	Disposable Paper Boat & Styrofoam Plate			0.021	6.915%

Table 3 - Tray Contribution to Trash

Figure 13 - Tray Contribution to Trash by Weight

Figure 14 - Tray Contribution to Trash by Volume

4.2 Environmental & Economic Comparison LCA

4.2.1 Goal & Scope

The goal and scope of the LCA are listed as:

1. To compare different tray options in terms of their environmental impact in each category
2. To compare the associated costs with these trays
3. To determine which tray is “best” in terms of having the lowest overall environmental impact and in terms of costs
4. To provide recommendations based on these findings

The research question associated with this LCA was: What are the effects of changing the material of the tray currently being used in the school in terms of the impact categories and expenses? The intended audience was the school district being studied but could also be an example for other schools to follow. In addition, the LCA

was designed for locations in the United States alone as this was where all data was retrieved.

As for the functional unit, this assessment had a functional unit of one tray. This is in terms of one reusable tray that is washed in a dishwasher, one compostable tray sent to a composting plant, one compostable tray sent to a landfill, and one disposable paper boat sent to a landfill. These are considered the four main systems of the LCA study. The reason for the types of trays chosen is because of what was being used in the schools. The elementary schools served lunch on compostable trays, whereas the middle schools and high schools served lunch on disposable paper boats. The high school also served lunch on styrofoam plates which were not included in the LCA portion of the study. As for the two versions of a compostable tray, at the time of the study, the trays were disposed of in the trash and sent to the landfill, however there were options being investigated for composting these trays. Therefore, an LCA was completed considering all possible outcomes.

After speaking with various members of the school district, it was apparent that the majority believed disposable trays would have the most harmful environmental impact but were unsure whether reusable or compostable trays was the best choice in terms of the environment. For these reasons, all tray types were tested to determine the outcome. Along with this, the school district needed to be able to afford any changes made so a cost analysis on these trays was also completed in section 4.3. The impact categories are shown in Table 4, Listing the Life Cycle Inventory Analysis (LCIA) databases used, impact category, unit and unit description for each category as well as the source of the data which was derived from Umberto ("Umberto NXT LCA",2016).

LCIA Database	Impact Category	Unit	Unit Description	Data Source & Description (Umberto)
TRACI	Global Warming	kg CO ₂ -Eq	Stratospheric ozone depletion	Tool for the Reduction and Assessment of Chemical and other environmental Impacts. A midpoint-oriented methodology developed specifically for the US. http://www.epa.gov/nmr/std/traci/traci.html see Bare 2004; Bare J. C. et al. 2007 and ecoinvent report No. 3 (2010), pp. 149-155. Note: The ecoinvent implementation of TRACI excludes the impact categories 'fossil fuel depletion', 'land use' and 'water use'.
	Ozone Depletion	kg CFC-11-Eq	Ozone layer depletion	
	Acidification	Moles of H ⁺ -Eq	Moles of Hydrogen	
	Ecotoxicity	kg 1, 4-D-Eq	1,4-Dioxane: Freshwater ecotoxicity	
	Eutrophication	kg N	Nitrogen	
	Human health (air pollutants) respiratory effects average	kg PM _{2.5} -Eq	Atmospheric particulate matter	
ReCiPe Midpoint (H) w/o LT	Fossil Depletion w/o LT, FDP w/o LT	kg Oil-Eq		ReCiPe LCIA Method, results on midpoints level (H) = Humanitarian. see Goedkoop et al. 2009 and ecoinvent report No. 3 (2010), pp. 143-148
	Water depletion w/o LT, WDP w/o LT	m ³	Cubic meters	
USEtox	USEtox human toxicity, total	CTU	Comparative Toxic Units	LCIA Method that comprises primarily human toxicity and ecotoxicity effects: see Rosenbaum et al. 2008 and ecoinvent report No. 3 (2010), pp.156-160.
	USEtox ecotoxicity, total	CTU		

Table 4 - Impact Categories

This LCA was labeled as change oriented. In other words, this LCA compared alternatives to what was already in place to see the impact on the environment. There are a number of system boundaries associated with this study. The systems were defined for the reusable, compostable, and disposable tray options. The natural system was broken up into two sections. The first included the only use and end-of-life phases. The second included raw material extraction, manufacturing, use, and end-of-life phases. The reason for this is there were many assumptions made when considering the raw material extraction and manufacturing life phases, and thus, the natural system that considers only the use phase and end-of-life phase will have more accurate results. For all systems being observed, transportation/distribution was not included in the study. The geographical boundary is in the United States alone. The time horizon was based on the replacement rates of reusable trays. The schools provided that thirty percent of the trays would need to be replaced each year, giving

them a lifetime of 3.3 years. Alternatives should this be able to be reduced were also provided. These were a ten percent replacement rate (10-year life estimate) and a twenty percent replacement rate (five-year life estimate). This was also chosen as the life span of the trays would vary depending on the usage and, therefore, was not be provided by the manufacturers. In terms of production capital, if an alternative tray is recommended, this would require the purchase of the tray type and may impact labor hours. Other life cycles that are linked with this include oil extraction, deforestation, and landfill leachate associated with each functional unit.

4.2.2 Inventory Analysis

For all systems studied, reusable trays, compostable trays, and disposable paper boats, the flowchart shown in Figure 15 displays the simplified process from “cradle” to “grave” (or start to end) of the life of the products. The functional unit for each system is listed in Table 5 along with the dimensions and weight. The weight was used in the LCA throughout the models in Umberto. The disposable and compostable trays were measured with a ruler and food scale and the data on the reusable tray was retrieved ("School Trays: Cambro"). The two scenarios for each system modeled in Umberto were the Use to End-of-Life Phases and the Raw Materials to End-of-Life Phases. The process, description, and source of these are shown in Tables 6 and 7, respectively. The source listed as “ecoinvent 3 v3” is pulled directly from the software and the created sources were made using materials created of the functional units with the weight data included (GmbH, 2016). The compostable tray system includes the two additional scenarios should the trays be sent to a landfill.

Figure 15 - Basic Flow Chart of All Systems

Functional Unit	Dimensions (in)	Weight (lb)
1 Disposable Paper Boat	Length: 4.75, Top width: 5.438, Bottom width: 8, Height: 2	0.029
1 Compostable Tray	Length: 10.375, Width: 8.25, Height: 1	0.051
1 Reusable Tray	Length: 13.875, Width: 10.689	0.47

Table 5 - Functional Unit Dimensions and Weight

Use to End-of-Life Phases Modeled in Umberto			
Product	Process Label	Description	Source
Disposable Paper Boat	Use	Used in School Cafeteria	Created
	Disposal	Thrown in trash bin	Created
	Treatment of waste graphical paper, sanitary landfill [RoW]	Landfilled	ecoinvent 3 v3
Compostable Tray - Composted	Use	Used in School Cafeteria	Created
	Disposal	Thrown in compost bin	ecoinvent 3 v3
	treatment of biowaste, industrial composting [RoW]	Composted	ecoinvent 3 v3
Compostable Tray - Landfilled	Use	Used in School Cafeteria	Created
	Disposal	Thrown in trash bin	Created
	Treatment of waste paperboard, sanitary landfill [RoW]	Landfilled	ecoinvent 3 v3
Reusable Tray	Market for sodium tripolyphosphate [GLO]	Dishwashing Components	ecoinvent 3 v3 and Oeko-Institut e.V.
	Market for potassium hydroxide [GLO]	Dishwashing Components	
	Market for sodium silicate, solid [GLO]	Dishwashing Components	
	Market for water, deionised, from tap water, at user [RoW]	Dishwashing Components	
	Market for sodium perborate, monohydrate, powder [GLO]	Dishwashing Components	Created
	Dishwashing	Trays Cleaned	
	Disposal	Thrown in trash bin	
	Treatment of waste polypropylene, sanitary landfill [CH]	Landfilled	
			ecoinvent 3 v3

Table 6 - Use to End-of-Life Phases Modeled in Umberto

Raw Materials to End-of-Life Phases Modeled in Umberto			
Product	Process Label	Description	Source
Disposable Paper Boat	Market for kraft paper, bleached [GLO]	Paper pulp bleached	ecoinvent 3 v3
	Manufacturing of Paper Boat	Paper boat formed	created
	Use	Used in School Cafeteria	Created
	Disposal	Thrown in trash bin	Created
	Treatment of waste graphical paper, sanitary landfill [RoW]	Landfilled	ecoinvent 3 v3
Compostable Tray - Composted	market for folding boxboard/chipboard [GLO]	Fiber pulp made	ecoinvent 3 v3
	Manufacturing	Compostable tray molded	Created
	Use	Used in School Cafeteria	Created
	Disposal	Thrown in compost bin	ecoinvent 3 v3
	treatment of biowaste, industrial composting [RoW]	Composted	ecoinvent 3 v3
Compostable Tray - Landfilled	market for folding boxboard/chipboard [GLO]	Fiber pulp made	ecoinvent 3 v3
	Manufacturing	Compostable tray molded	Created
	Use	Used in School Cafeteria	Created
	Disposal	Thrown in compost bin	ecoinvent 3 v3
	Treatment of waste paperboard, sanitary landfill [RoW]	Landfilled	ecoinvent 3 v3
Reusable Tray	Market for polypropylene, granulate [GLO]	Polypropylene for trays made	ecoinvent 3 v3
	Thermoforming of plastic sheets [RoW]	Polypropylene made into sheets	ecoinvent 3 v3
	Tray Manufacturing	Reusable trays formed	Created
	Market for sodium tripolyphosphate [GLO]	Dishwashing Components	ecoinvent 3 v3 and Oeko-Institut e.V.
	Market for potassium hydroxide [GLO]	Dishwashing Components	ecoinvent 3 v3 and Oeko-Institut e.V.
	Market for sodium silicate, solid [GLO]	Dishwashing Components	ecoinvent 3 v3 and Oeko-Institut e.V.
	Market for water, deionised, from tap water, at user [RoW]	Dishwashing Components	ecoinvent 3 v3 and Oeko-Institut e.V.
	Market for sodium perborate, monohydrate, powder [GLO]	Dishwashing Components	ecoinvent 3 v3 and Oeko-Institut e.V.
	Dishwashing	Trays Cleaned	Created
	Disposal	Thrown in trash bin	Created
	Treatment of waste polypropylene, sanitary landfill [CH]	Landfilled	ecoinvent 3 v3

Table 7 - Raw Materials to End-of-Life Phases Modeled in Umberto

Figures 16 to 23 are screenshots of the models made in Umberto. The two scenarios are considered for all systems. For the compostable tray system, the additional scenarios showing the trays sent to a composting facility and a landfill are also shown.

Figure 18 - Use to End-of-Life Phases Modeled in Umberto: Compostable Tray
(Composted)

Figure 19 - Raw Materials to End-of-Life Phases Modeled in Umberto: Compostable Tray (Composted)

Figure 20 - Use to End-of-Life Phases Modeled in Umberto: Compostable Tray
(Landfilled)

Figure 21 - Raw Materials to End-of-Life Phases Modeled in Umberto: Compostable Tray (Landfilled)

Figure 22 - Use to End-of-Life Phases Modeled in Umberto: Reusable Tray

Figure 23 - Raw Materials to End-of-Life Phases Modeled in Umberto: Reusable Tray

4.2.3 Impact Assessment

The impact results of the LCA for both scenarios of the use to end-of-life phases as well as the raw materials to end-of-life phases are displayed in Tables 8 and 9, respectively. In each table, the LCIA data source/group, category of impact assessment, results by system, and unit of impact category are listed. The four systems were listed as Disposable - disposable paper boats, Compostable - sent to a composting plant, Compostable (Landfilled) - sent to a landfill, and Reusable.

LCIA Source	Category	Results by System				Unit
		Disposable	Compostable	Compostable (Landfilled)	Reusable	
TRACI	Global Warming	0.99	0.06	2.79	0.04	kg CO ₂ -Eq
	Ozone Depletion	3.02E-09	3.83E-09	6.53E-09	1.17E-09	kg CFC-11-E
	Acidification	0.01	0.04	0.03	1.74E-03	Moles of H ⁺ -Eq
	Ecotoxicity	0.03	0.27	0.02	7.82E-04	kg 1, 4-D-Eq
	Eutrophication	2.20E-03	7.86E-05	4.12E-03	1.75E-05	kg N
	Human health (air pollutants) respiratory effects average	6.59E-05	7.70E-05	1.53E-04	6.95E-06	kg PM _{2.5} -Eq
ReCiPe Midpoint (H) w/o LT	Fossil Depletion w/o LT, FDP w/o LT	9.36E-03	0.01	0.02	2.50E-03	kg Oil-Eq
	Water depletion w/o LT, WDP w/o LT	8.42E-05	8.54E-03	1.68E-04	1.21E-05	m ³
	USEtox human toxicity, total	2.22E-07	6.43E-08	2.67E-07	2.31E-07	CTU
USEtox	USEtox ecotoxicity, total	4.32	0.57	5.3	17.91	CTU

Table 8 - Use to End-of-Life Phases Impact Results

LCIA Source	Category	Results by System				Unit
		Disposable	Compostable	Compostable (Landfilled)	Reusable	
TRACI	Global Warming	2.65	1.59	4.32	2.75	kg CO ₂ -Eq
	Ozone Depletion	1.38E-07	8.70E-08	8.97E-08	3.36E-08	kg CFC-11-E
	Acidification	0.48	0.45	0.45	5.10E-01	Moles of H ⁺ -Eq
	Ecotoxicity	2.22	1.75	1.5	1.90E-01	kg 1, 4-D-Eq
	Eutrophication	4.08E-03	8.44E-04	4.89E-03	6.60E-04	kg N
	Human health (air pollutants) respiratory effects average	3.79E-03	2.60E-03	2.68E-03	2.53E-03	kg PM _{2.5} -Eq
ReCiPe Midpoint (H) w/o LT	Fossil Depletion w/o LT, FDP w/o LT	5.00E-01	0.43	0.44	1.75E+00	kg Oil-Eq
	Water depletion w/o LT, WDP w/o LT	5.26E-03	1.28E-02	5.69E-03	3.32E-03	m ³
	USEtox human toxicity, total	8.12E-07	6.68E-07	8.71E-07	7.77E-07	CTU
USEtox	USEtox ecotoxicity, total	10.22	6.02	10.76	44.66	CTU

Table 9 - Raw Materials to End-of-Life Phases Impact Results

Once the results were calculated, the carbon footprint of each system was determined for each scenario. Figure 24 shows the carbon footprint results of each system from use to end-of-life phases. Figure 25 shows the carbon footprint results for the same four systems, extended to show the raw material extraction to end-of-life phases.

Figure 24 - Use to End-of-Life Phases: Carbon Footprint

Figure 25 - Raw Materials to End-of-Life Phases: Carbon Footprint

Once these results were determined, the annual impact for each system was calculated for all scenarios as seen from Tables 10 to 17. These tables include the database source, impact category unit and results per functional unit (one tray) per system. The results per functional unit were multiplied by the estimated number of functional units per year (based on the number of trays purchased the year before) to determine the estimated annual impact per category.

The reusable systems, in Tables 13 and 17, for all scenarios differ when determining the annual impact per category as the first year requires an initial purchase of the tray followed by smaller replacement purchases the years following. To estimate the impact for this, the percentage of trays needing replacement was shown for ten percent, twenty percent, and thirty percent of the original purchase amount. Originally, the amount of thirty percent was given by the schools from the foodservice providers as their estimation of loss or theft. The ten and twenty percent

replacement rates were also shown in the event that the schools would be able to reduce this. All of these were calculated by multiplying the original purchase amount (estimated number of functional units for the initial year) by the percentage. This number was then multiplied by the results per functional unit for each category.

Annual Impact Calculations Use to End-of-Life: Disposable System					
LCIA Source	Category	Unit	Result per Functional Unit	Est. # of Functional Units per Year	Est. Annual Impact
TRACI	Global Warming	kg CO2-Eq	0.99	110612	109505.88
	Ozone Depletion	kg CFC-11-E	3.02E-09	110612	3.34E-04
	Acidification	Moles of H+-Eq	0.01	110612	1106.12
	Ecotoxicity	kg 1, 4-D-Eq	0.03	110612	3318.36
	Eutrophication	kg N	2.20E-03	110612	243.35
	Human health (air pollutants) respiratory effects average	kg PM2.5-Eq	6.59E-05	110612	7.29
	Fossil Depletion w/o LT, FDP w/o LT	kg Oil-Eq	9.36E-03	110612	1035.33
ReCiPe Midpoint (H) w/o LT	Water depletion w/o LT, WDP w/o LT	m³	8.42E-05	110612	9.31
USEtox	USEtox human toxicity, total	CTU	2.22E-07	110612	2.46E-02
	USEtox ecotoxicity, total	CTU	4.32	110612	477843.84

Table 10 - Annual Impact Calculations for Use to End-of-Life: Disposable System

Annual Impact Calculations Use to End-of-Life: Compostable System					
LCIA Source	Category	Unit	Result per Functional Unit	Est. # of Functional Units per Year	Est. Annual Impact
TRACI	Global Warming	kg CO2-Eq	0.06	74880	4492.80
	Ozone Depletion	kg CFC-11-E	3.83E-09	74880	2.87E-04
	Acidification	Moles of H+-Eq	0.04	74880	2995.20
	Ecotoxicity	kg 1, 4-D-Eq	0.27	74880	20217.60
	Eutrophication	kg N	7.86E-05	74880	5.89
	Human health (air pollutants) respiratory effects average	kg PM2.5-Eq	7.70E-05	74880	5.77
ReCiPe Midpoint (H) w/o LT	Fossil Depletion w/o LT, FDP w/o LT	kg Oil-Eq	1.00E-02	74880	748.80
	Water depletion w/o LT, WDP w/o LT	m³	8.54E-03	74880	639.48
	USEtox human toxicity, total	CTU	6.43E-08	74880	4.81E-03
USEtox	USEtox ecotoxicity, total	CTU	0.57	74880	42681.60

Table 11 - Annual Impact Calculations for Use to End-of-Life: Compostable System (Composted)

Annual Impact Calculations Use to End-of-Life: Compostable System (Landfilled)					
LCIA Source	Category	Unit	Result per Functional Unit	Est. # of Functional Units per Year	Est. Annual Impact
TRACI	Global Warming	kg CO2-Eq	2.79	74880	208915.20
	Ozone Depletion	kg CFC-11-E	6.53E-09	74880	4.89E-04
	Acidification	Moles of H+-Eq	0.03	74880	2246.40
	Ecotoxicity	kg 1, 4-D-Eq	0.02	74880	1497.60
	Eutrophication	kg N	4.12E-03	74880	308.51
ReCiPe Midpoint (H) w/o LT	Human health (air pollutants) respiratory effects average	kg PM2.5-Eq	1.53E-04	74880	11.46
	Fossil Depletion w/o LT, FDP w/o LT	kg Oil-Eq	2.00E-02	74880	1497.60
	Water depletion w/o LT, WDP w/o LT	m³	1.68E-04	74880	12.58
USEtox	USEtox human toxicity, total	CTU	2.67E-07	74880	2.00E-02
	USEtox ecotoxicity, total	CTU	5.3	74880	396864.00

Table 12 - Annual Impact Calculations for Use to End-of-Life: Compostable System (Landfilled)

Annual Impact Calculations Use to End-of-Life: Reusable System							
LCIA Source	Category	Unit	Result per Functional Unit	Est. # of Functional Units: Initial Purchase (Year 1)	Est. Annual Impact After Year 1		
					10% Replaced	20% Replaced	30% Replaced
TRACI	Global Warming	kg CO2-Eq	0.04	1650	6.60	13.20	19.80
	Ozone Depletion	kg CFC-11-E	1.17E-09	1650	1.93E-07	3.86E-07	5.79E-07
	Acidification	Moles of H+-Eq	0.00174	1650	2.87E-01	5.74E-01	8.61E-01
	Ecotoxicity	kg 1, 4-D-Eq	0.000782	1650	1.29E-01	2.58E-01	3.87E-01
	Eutrophication	kg N	1.75E-05	1650	2.89E-03	5.78E-03	8.66E-03
	Human health (air pollutants) respiratory effects average	kg PM2.5-Eq	6.95E-06	1650	1.15E-03	2.29E-03	3.44E-03
ReCiPe Midpoint (H) w/o LT	Fossil Depletion w/o LT, FDP w/o LT	kg Oil-Eq	2.50E-03	1650	4.13E-01	8.25E-01	1.24E+00
	Water depletion w/o LT, WDP w/o LT	m³	1.21E-05	1650	2.00E-03	3.99E-03	5.99E-03
	USEtox human toxicity, total	CTU	2.31E-07	1650	3.81E-05	7.62E-05	1.14E-04
USEtox	USEtox ecotoxicity, total	CTU	17.91	1650	2955.15	5910.30	8865.45

Table 13 - Annual Impact Calculations for Use to End-of-Life: Reusable System

Annual Impact Calculations Raw Materials to End-of-Life: Disposable System					
LCIA Source	Category	Unit	Result per Functional Unit	Est. # of Functional Units per Year	Est. Annual Impact
TRACI	Global Warming	kg CO2-Eq	2.65	110612	293121.80
	Ozone Depletion	kg CFC-11-E	1.38E-07	110612	1.53E-02
	Acidification	Moles of H+-Eq	0.48	110612	53093.76
	Ecotoxicity	kg 1, 4-D-Eq	2.22	110612	245558.64
	Eutrophication	kg N	4.08E-03	110612	451.30
	pollutants) respiratory effects average	kg PM2.5-Eq	3.79E-03	110612	419.22
ReCiPe Midpoint(H) w/0 LT	FDP w/o LT	kg Oil-Eq	5.00E-01	110612	55306.00
	Water depletion w/o LT,	m ³	5.26E-03	110612	581.82
USEtox	USEtox human toxicity, total	CTU	8.12E-07	110612	8.98E-02
	USEtox ecotoxicity, total	CTU	10.22	110612	1130454.64

Table 14 - Annual Impact Calculations for Raw Materials to End-of-Life: Disposable System

Annual Impact Calculations Raw Materials to End-of-Life: Compostable System					
LCIA Source	Category	Unit	Result per Functional Unit	Est. # of Functional Units per Year	Est. Annual Impact
TRACI	Global Warming	kg CO2-Eq	1.59	74880	119059.20
	Ozone Depletion	kg CFC-11-E	8.70E-08	74880	6.51E-03
	Acidification	Moles of H+-Eq	0.45	74880	33696.00
	Ecotoxicity	kg 1, 4-D-Eq	1.75	74880	131040.00
	Eutrophication	kg N	8.44E-04	74880	63.20
	pollutants) respiratory effects average	kg PM2.5-Eq	2.60E-03	74880	194.69
ReCiPe Midpoint(H) w/0 LT	Fossil Depletion w/o LT, FDP w/o LT	kg Oil-Eq	0.43	74880	32198.40
	Water depletion w/o LT,	m ³	1.28E-02	74880	955.47
	USEtox human toxicity,	CTU	6.68E-07	74880	5.00E-02
USEtox	USEtox ecotoxicity, total	CTU	6.02	74880	450777.60

Table 15 - Annual Impact Calculations for Raw Materials to End-of-Life: Compostable System (Composted)

Annual Impact Calculations Raw Materials to End-of-Life: Compostable System (Landfilled)					
LCIA Source	Category	Unit	Result per Functional Unit	Est. # of Functional Units per Year	Est. Annual Impact
TRACI	Global Warming	kg CO2-Eq	4.32	74880	323481.60
	Ozone Depletion	kg CFC-11-E	8.97E-08	74880	6.72E-03
	Acidification	Moles of H+-Eq	0.45	74880	33696.00
	Ecotoxicity	kg 1, 4-D-Eq	1.5	74880	112320.00
	Eutrophication	kg N	4.89E-03	74880	366.16
	pollutants) respiratory effects average	kg PM2.5-Eq	2.68E-03	74880	200.68
ReCiPe Midpoint(H) w/0 LT	Fossil Depletion w/o LT, FDP w/o LT	kg Oil-Eq	0.44	74880	32947.20
	Water depletion w/o LT,	m ³	5.69E-03	74880	426.07
	USEtox human toxicity,	CTU	8.71E-07	74880	6.52E-02
USEtox	USEtox ecotoxicity, total	CTU	10.76	74880	805708.80

Table 16 - Annual Impact Calculations for Raw Materials to End-of-Life: Compostable System (Landfilled)

Annual Impact Calculations Raw Materials to End-of-Life: Reusable System							
LCIA Source	Category	Unit	Result per Functional Unit	Est. Annual Impact After Year 1			
				Est. # of Functional Units: Initial Purchase (Year 1)	10% Replaced	20% Replaced	30% Replaced
TRACI	Warming	kg CO2-Eq	2.75	1650	453.75	907.50	1361.25
	Depletion	kg CFC-11-E	3.36E-08	1650	5.54E-06	1.11E-05	1.66E-05
	Acidification	Moles of H ⁺ -Eq	0.51	1650	84.15	168.30	252.45
	Ecotoxicity	kg 1, 4-D-Eq	0.19	1650	31.35	62.70	94.05
	n	kg N	6.60E-04	1650	1.09E-01	2.18E-01	3.27E-01
	(air pollutants)	kg PM2.5-Eq	2.53E-03	1650	4.17E-01	8.35E-01	1.25E+00
ReCiPe Midpoint(H) w/0 LT	Depletion w/o	kg Oil-Eq	1.75	1650	288.75	577.50	866.25
	Water	m ³	3.32E-03	1650	0.55	1.10	1.64
USEtox	USEtox human	CTU	7.77E-07	1650	1.28E-04	2.56E-04	3.85E-04
	USEtox ecotoxicity	CTU	44.66	1650	7368.90	14737.80	22106.70

Table 17 - Annual Impact Calculations for Raw Materials to End-of-Life: Reusable System

Using the annual impact results, Table 18 and 19 were made, showing the projection of the impact per category over ten years for both the Use to End-of-Life scenario and Raw Materials to End-of-Life scenario comparing all systems. The disposable and two compostable systems were calculated by multiplying their annual impact by ten for each category. The reusable system was broken down by the ten, twenty, and thirty percent replacement rates. These were calculated by first multiplying the estimated number of functional units for the initial purchase of the trays by the impact category per functional unit to determine the first-year impact per category. This number was then added with the annual impact after the first year multiplied by nine (the number of years left after the first year). The tables highlight the value with the highest impact per category in red and the value with the lowest impact per category in green.

10 Year Outlook: Total Accumulated Impact for Use to End-of-Life Phases								
LCIA Source	Category	Unit	Disposable	Compostable	Compostable (Landfilled)	Reusable (10% Replaced)	Reusable (20% Replaced)	Reusable (30% Replaced)
TRACI	Global Warming	kg CO2-Eq	1095058.80	44928.00	2089152.00	125.40	184.80	244.20
	Ozone Depletion	kg CFC-11-E	3.34E-03	2.87E-03	4.89E-03	3.67E-06	5.41E-06	7.14E-06
	Acidification	Moles of H+-Eq	11061.20	29952.00	22464.00	5.45	8.04	10.62
	Ecotoxicity	kg 1, 4-D-Eq	33183.60	202176.00	14976.00	2.45	3.61	4.77
	Eutrophication	kg N	2433.46	58.86	3085.06	0.05	0.08	0.11
	Human health (air pollutants) respiratory effects average	kg PM2.5-Eq	72.89	57.66	114.57	0.02	0.03	0.04
ReCiPe Midpoint (H) w/o LT	Fossil Depletion w/o LT, FDP w/o LT	kg Oil-Eq	10353.28	7488.00	14976.00	7.84	11.55	15.26
	Water depletion w/o LT, WDP w/o LT	m³	93.14	6394.75	125.80	0.04	0.06	0.07
USEtox	USEtox human toxicity, total	CTU	2.46E-01	4.81E-02	2.00E-01	7.24E-04	1.07E-03	1.41E-03
	USEtox ecotoxicity, total	CTU	4778438.40	426816.00	3968640.00	56147.85	82744.20	109340.55

Table 18 - 10 Year Outlook: Total Accumulated Impact for Use to End-of-Life Phases

10 Year Outlook: Total Accumulated Impact for Raw Materials to End-of-Life Phases								
LCIA Source	Category	Unit	Disposable	Compostable	Compostable (Landfilled)	Reusable (10% Replaced)	Reusable (20% Replaced)	Reusable (30% Replaced)
TRACI	Global Warming	kg CO2-Eq	2931218.00	1190592.00	3234816.00	8621.25	12705.00	16788.75
	Ozone Depletion	kg CFC-11-E	0.15	0.07	0.07	1.05E-04	1.55E-04	2.05E-04
	Acidification	Moles of H+-Eq	530937.60	336960.00	336960.00	1598.85	2356.20	3113.55
	Ecotoxicity	kg 1, 4-D-Eq	2455586.40	1310400.00	1123200.00	595.65	877.80	1159.95
	Eutrophication	kg N	4512.97	631.99	3661.63	2.07	3.05	4.03
	Human health (air pollutants) respiratory effects average	kg PM2.5-Eq	4192.19	1946.88	2006.78	7.93	11.69	15.45
ReCiPe Midpoint (H) w/o LT	Fossil Depletion w/o LT, FDP w/o LT	kg Oil-Eq	553060.00	321984.00	329472.00	5486.25	8085.00	10683.75
	Water depletion w/o LT, WDP w/o LT	m³	5818.19	9554.69	4260.67	10.41	15.34	20.27
USEtox	USEtox human toxicity, total	CTU	0.90	0.50	0.65	2.44E-03	3.59E-03	4.74E-03
	USEtox ecotoxicity, total	CTU	11304546.40	4507776.00	8057088.00	140009.10	206329.20	272649.30

Table 19 - 10 Year Outlook: Total Accumulated Impact for Raw Materials to End-of-Life Phases

In addition to the impact categories, the results for annual impact were also determined by carbon footprint in kilograms of carbon dioxide. Table 20 and Table 22 show the Reusable System based on the initial purchase (year 1) and all subsequent years, respectively, for all scenarios. The carbon footprint for the first year was calculated by multiplying the carbon footprint results per functional unit by the number of functional units needed in the first year (estimated by the number of trays purchased the year before as mentioned earlier). Table 21 and Table 23 show the annual carbon footprint calculations which were completed by multiplying the carbon

footprint per functional unit by the estimated annual quantity. As done previously, the reusable trays display calculations based on a ten, twenty, and thirty percent annual replacement by multiplying the percentage by the number needed in the initial year and the carbon footprint per functional unit.

Carbon Footprint (kg CO2-Eq) Impact Calculations: Reusable System Initial Purchase Year 1 Use to End-of-Life			
System	Carbon Footprint per Functional Unit (kg CO2-Eq)	Year 1 Est. # of Functional Units	Year 1 Carbon Footprint (kg CO2-Eq)
Reusable Initial Purchase	0.04	1650	66

Table 20 - Carbon Footprint (kg CO2-Eq) Impact Calculations: Use to End-of-Life of Reusable System for Initial Purchase

Annual Carbon Footprint (kg CO2-Eq) Impact Calculations Use to End-of-Life				
	System	Functional Unit (kg CO2-Eq)	Est. Annual Quantity	Annual Carbon Footprint (kg CO2-Eq)
	Disposable	0.96	110612.00	106187.52
	Compostable	0.07	74880.00	5241.60
	Compostable (Landfilled)	2.70	74880.00	202176.00
Reusable (After Year 1)	10% Replaced	0.04	165.00	6.60
	20% Replaced	0.04	330.00	13.20
	30% Replaced	0.04	495.00	19.80

Table 21 - Annual Carbon Footprint (kg CO2-Eq) Impact Calculations: Use to End-of-Life

Carbon Footprint (kg CO2-Eq) Impact Calculations: Reusable System Initial Purchase Year 1 Raw Materials to End-of-Life			
System	Carbon Footprint per Functional Unit (kg CO2-Eq)	Year 1 Est. # of Functional Units	Year 1 Carbon Footprint (kg CO2-Eq)
Reusable Initial Purchase	2.79	1650.00	4603.50

Table 22 - Annual Carbon Footprint (kg CO2-Eq) Impact Calculations: Raw Materials to End-of-Life of Reusable System for Initial Purchase

Annual Carbon Footprint (kg CO2-Eq) Impact Calculations Raw Materials to End-of-Life				
	System	Carbon Footprint per Functional Unit (kg CO2-Eq)	Est. Annual Quantity	Annual Carbon Footprint (kg CO2-Eq)
	Disposable	2.63	110612.00	290909.56
	Compostable	1.61	74880.00	120556.80
	Compostable (Landfilled)	4.25	74880.00	318240.00
Reusable (After Year 1)	10% Replaced	2.79	165.00	460.35
	20% Replaced	2.79	330.00	920.70
	30% Replaced	2.79	495.00	1381.05

Table 23 - Annual Carbon Footprint (kg CO2-Eq) Impact Calculations: Raw Materials to End-of-Life

Using the annual carbon footprint results that were calculated, a table of the estimated annual carbon footprint per system projected over a ten year period was created for the Use to End-of-Life Phases (Table 24) and the Raw Materials to End-of-Life Phases (Table 25). The totals for both scenarios are added together at the bottom representing the total accumulated carbon footprint over the ten years. The highest impact result is highlighted in red and the lowest is highlighted in green

10 Year Outlook: Carbon Footprint (kg CO2-Eq) Impact for Use to End-of-Life Phases						
Year	Disposable	Compostable	Compostable (Landfilled)	Reusable		
				Reusable (10% Replaced)	Reusable (20% Replaced)	Reusable (30% Replaced)
1	106187.52	5241.60	202176.00	66.00	66.00	66.00
2	106187.52	5241.60	202176.00	6.60	13.20	19.80
3	106187.52	5241.60	202176.00	6.60	13.20	19.80
4	106187.52	5241.60	202176.00	6.60	13.20	19.80
5	106187.52	5241.60	202176.00	6.60	13.20	19.80
6	106187.52	5241.60	202176.00	6.60	13.20	19.80
7	106187.52	5241.60	202176.00	6.60	13.20	19.80
8	106187.52	5241.60	202176.00	6.60	13.20	19.80
9	106187.52	5241.60	202176.00	6.60	13.20	19.80
10	106187.52	5241.60	202176.00	6.60	13.20	19.80
Total	1061875.20	52416.00	2021760.00	125.40	184.80	244.20

Table 24 - 10 Year Outlook: Carbon Footprint (kg CO2-Eq) Impact for Use to End-of-Life Phases

10 Year Outlook: Carbon Footprint (kg CO ₂ -Eq) Impact for Raw Materials to End-of-Life Phases						
Year	Disposable	Compostable	Compostable (Landfilled)	Reusable (10% Replaced)	Reusable (20% Replaced)	Reusable (30% Replaced)
1	290909.56	120556.80	318240.00	4603.50	4603.50	4603.50
2	290909.56	120556.80	318240.00	460.35	920.70	1381.05
3	290909.56	120556.80	318240.00	460.35	920.70	1381.05
4	290909.56	120556.80	318240.00	460.35	920.70	1381.05
5	290909.56	120556.80	318240.00	460.35	920.70	1381.05
6	290909.56	120556.80	318240.00	460.35	920.70	1381.05
7	290909.56	120556.80	318240.00	460.35	920.70	1381.05
8	290909.56	120556.80	318240.00	460.35	920.70	1381.05
9	290909.56	120556.80	318240.00	460.35	920.70	1381.05
10	290909.56	120556.80	318240.00	460.35	920.70	1381.05
Total	2909095.60	1205568.00	3182400.00	8746.65	12889.80	17032.95

Table 25 - 10 Year Outlook: Carbon Footprint (kg CO₂-Eq) Impact for Raw Materials to End-of-Life Phases

4.3 Options and Cost Analysis

4.3.1 Trays & Dishwashers

The elementary school tray information is shown in Table 26. At the time, all schools at this level were using compostable trays at a total cost of \$7,188.48 per year. The initial cost of the reusable trays would be \$2374.46. If the reusable trays were to be purchased, additional labor was required at 1440 hours per year with an estimated salary of \$15.60 per hour. This resulted in a total of \$22,464 annual increase in labor. Finally, the annual cost of operating the dishwashers was estimated to be \$10,729.78. Tables 27 to 29 show the total expenses of the reusable tray compared with the compostable tray for the first year and the years following at ten, twenty, and thirty percent replacement rates for the reusable trays. The table assumes no increases due to inflation. The reusable tray expenses column for year one was calculated by adding the total initial cost of the tray with the labor costs and dishwasher costs. The following years included the same information but adjusted the cost of reusable trays to account for an estimated loss that would need to be replenished each year. The

compostable tray expenses were the same every year based on the total annual cost of compostable trays. The savings/loss column subtracted the compostable tray (current system) by the cost of the reusable tray. A positive value indicated money would be saved if the schools switched to reusable trays and a negative value indicated money would be lost. In this case, the switch to reusable trays would result in a loss of \$28379.76 in the first year. The annual amount after the first year resulted in a loss of \$26242.75 for ten percent replacement, \$26480.19 for twenty percent replacement and \$26717.64 for thirty percent replacement. This table calculates the expenses with the current dishwasher in place and the following tables consider a new dishwasher option.

ES Cost Estimates

Compostable Tray		
Number of Trays Needed	Unit Cost	Total Cost
74880	\$0.10	\$7,188.48
Reusable Tray		
Number of Trays Needed	Unit Cost	Total Cost
700	\$3.39	\$2,374.46
Labor		
Hours per Year	Estimated Salary	Total Cost
1440	\$15.60	\$22,464.00
Dishwashers		
Water	\$ 894.07	
Energy	\$ 4,900.05	
Chemicals	\$ 4,935.66	
Total		\$ 10,729.78

Table 26 - ES Cost Estimates of Tray Types

ES Cost Estimate: Reusable Tray (10% Replacement) and Current Dishwasher			
	Reusable Expenses	Compostable Expenses	Savings/Loss (+/-)
Year 1	\$35,568.24	\$7,188.48	-\$28,379.76
After Year 1	\$33,431.23	\$7,188.48	-\$26,242.75

Table 27 - ES Cost Estimate: Reusable Tray with 10% Replacement and Current Dishwasher

ES Cost Estimate: Reusable Tray (20% Replacement) and Current Dishwasher			
	Reusable Expenses	Compostable Expenses	Savings/Loss (+/-)
Year 1	\$35,568.24	\$7,188.48	-\$28,379.76
After Year 1	\$33,668.67	\$7,188.48	-\$26,480.19

Table 28 - ES Cost Estimate: Reusable Tray with 20% Replacement and Current Dishwasher

ES Cost Estimate: Reusable Tray (30% Replacement) and Current Dishwasher			
	Reusable Expenses	Compostable Expenses	Savings/Loss (+/-)
Year 1	\$35,568.24	\$7,188.48	-\$28,379.76
After Year 1	\$33,906.12	\$7,188.48	-\$26,717.64

Table 29 - ES Cost Estimate: Reusable Tray with 30% Replacement and Current Dishwasher

Elementary School A had an up to date dishwasher and an energy audit provided.

Elementary School B also had an energy audit but a new machine was recommended which was the same machine that is already in use at Elementary School A.

Elementary Schools C and D did not have energy audits completed so the assumption was made that the information matched that of Elementary School B. For all

Elementary schools besides Elementary School A, an installation cost estimate was provided by the dishwashing equipment company. All cost information is shown in Table 30 as well as estimated environmental impact. Based on this information, new cost estimates, as seen in Tables 31 to 33, were made considering the expenses should

the schools invest in the new dishwashers that were recommended. If the new dishwasher were purchased and the schools switched to reusable trays, they would lose \$4740.85 in the first year. The annual amount after the first year resulted in a loss of \$22869.84 for ten percent replacement, \$23107.28 for twenty percent replacement and \$23344.73 for thirty percent replacement.

ES Dishwasher Comparisons

Elementary School A			
No new dishwasher needed			
Operating Costs			
Water	\$ 125.60		
Energy	\$ 789.23		
Chemicals	\$ 652.75		
Total	\$ 1,567.58		
Environmental Impact			
Water (gal)	20935.38		
Electricity (kWh)	6679.29		
Gas (therms)	136.98		
Carbon Emissions (metric tons)	0.67		
Elementary School B			
	Current	New	Difference
Purchase & Installation		\$ 9,900.54	\$ (9,900.54)
Operating Costs			
Water	\$ 256.15	\$ 125.60	\$ 130.55
Energy	\$ 1,370.27	\$ 789.23	\$ 581.04
Chemicals	\$ 1,427.64	\$ 652.75	\$ 774.89
Total	\$ 3,054.07	\$ 1,567.58	\$ 1,486.48
Environmental Impact			
Water (gal)	42685.71	20935.38	21750.33
Electricity (kWh)	11254.95	6679.29	4575.66
Gas (therms)	279.40	136.98	142.42
Carbon Emissions (metric tons)	1.13	0.67	0.46
Elementary Schools C & D			
	Current	New	Difference
Purchase & Installation		\$ 6,825.00	\$ (6,825.00)
Operating Costs			
Water	\$ 256.15	\$ 125.60	\$ 130.55
Energy	\$ 1,370.27	\$ 789.23	\$ 581.04
Chemicals	\$ 1,427.64	\$ 652.75	\$ 774.89
Total	\$ 3,054.07	\$ 1,567.58	\$ 1,486.48
Environmental Impact			
Water (gal)	42685.71	20935.38	21750.33
Electricity (kWh)	11254.95	6679.29	4575.66
Gas (therms)	279.40	136.98	142.42
Carbon Emissions (metric tons)	1.13	0.67	0.46

Table 30 - ES Dishwasher Comparisons

ES Cost Estimate: Reuseable Tray (10% Replacement) and New Dishwasher			
	Reusable Expenses	Compostable Expenses	Savings/Loss (+/-)
Year 1	\$54,659.33	\$7,188.48	-\$47,470.85
After Year 1	\$30,058.32	\$7,188.48	-\$22,869.84

Table 31 - ES Cost Estimate: Reusable Tray with 10% Replacement and New Dishwasher

ES Cost Estimate: Reuseable Tray (20% Replacement) and New Dishwasher			
	Reusable Expenses	Compostable Expenses	Savings/Loss (+/-)
Year 1	\$54,659.33	\$7,188.48	-\$47,470.85
After Year 1	\$30,295.76	\$7,188.48	-\$23,107.28

Table 32 - ES Cost Estimate: Reusable Tray with 20% Replacement and New Dishwasher

ES Cost Estimate: Reuseable Tray (30% Replacement) and New Dishwasher			
	Reusable Expenses	Compostable Expenses	Savings/Loss (+/-)
Year 1	\$54,659.33	\$7,188.48	-\$47,470.85
After Year 1	\$30,533.21	\$7,188.48	-\$23,344.73

Table 33 - ES Cost Estimate: Reusable Tray with 30% Replacement and New Dishwasher

Similar to the Elementary Schools, Tables 34 shows the cost estimates for the lunch tray that the middle schools had in place at the time of the study (disposable) and the cost estimates should they switch to either compostable or reusable trays. Unlike the elementary schools, an energy audit was not completed so the dishwasher expenses were determined by information on the estimated number of cycles per year and chemical cost per cycle provided by the schools. The results of this table show a total of \$2071.76 per year for disposable paper boats, \$5682.53 per year for compostable trays, an initial reusable tray cost of \$1526.44 with labor as \$16,848 per year and dishwasher expenses as \$3150 per year. Tables 35 to 37 show the expenses for year one and the following years comparing disposable and reusable trays for each replacement rate and Table 38 shows the annual expenses comparing the disposable and compostable trays. Switching to reusable trays results in a loss of \$19452.68 in the first year. The annual amount after the first year resulted in a loss of \$18078.89 for ten percent replacement, \$18231.53 for twenty percent replacement and \$18384.18 for

thirty percent replacement. Switching to compostable trays results in an annual loss of \$3610.77.

MS Cost Estimates

Disposable Tray		
Number of Trays Needed	Unit Cost	Total Cost
59,193	\$0.04	\$2,071.76
Compostable Tray		
Number of Trays Needed	Unit Cost	Total Cost
59,193	\$0.10	\$5,682.53
Reusable Tray		
Number of Trays Needed	Unit Cost	Total Cost
450	\$3.39	\$1,526.44
Labor		
Hours	Salary	Total Cost
1080	\$15.60	\$16,848.00
Dishwashers		
Cycles per year	Cost per cycle	Total Cost
9,000	\$0.35	\$3,150.00

Table 34 - MS Cost Estimates of Tray Types

MS Cost Estimate: Reusable Tray (10% Replacement)			
	Reusable Expenses	Disposable Expenses	Savings/Loss (+/-)
Year 1	\$21,524.44	\$2,071.76	-\$19,452.68
After Year 1	\$20,150.64	\$2,071.76	-\$18,078.89

Table 35 - MS Cost Estimate: Reusable Tray with 10% Replacement

MS Cost Estimate: Reusable Tray (20% Replacement)			
	Reusable Expenses	Disposable Expenses	Savings/Loss (+/-)
Year 1	\$21,524.44	\$2,071.76	-\$19,452.68
After Year 1	\$20,303.29	\$2,071.76	-\$18,231.53

Table 36 - MS Cost Estimate: Reusable Tray with 20% Replacement

MS Cost Estimate: Reusable Tray (30% Replacement)			
	Reusable Expenses	Disposable Expenses	Savings/Loss (+/-)
Year 1	\$21,524.44	\$2,071.76	-\$19,452.68
After Year 1	\$20,455.93	\$2,071.76	-\$18,384.18

Table 37 - MS Cost Estimate: Reusable Tray with 30% Replacement

MS Cost Estimate: Compostable Tray			
	Compostable Expenses	Disposable Expenses	Savings/Loss (+/-)
Annual Amount	\$5,682.53	\$2,071.76	-\$3,610.77

Table 38 - MS Cost Estimate: Compostable Tray

Finally, the high school tray expenses are shown in Table 39. An energy audit was completed, and the dishwasher information was incorporated into the analysis. According to the schools and contracted food service provider, the high school would not require additional labor for the switch to reusable trays. The cost estimates for the disposable tray (the system in place) versus the compostable tray are shown in Table 40 and the cost estimates comparing the disposable tray and reusable tray with the current dishwasher for each replacement rate is shown in Tables 41 to 43. Switching to the compostable trays would result in an annual loss of \$3136.56. Switching to the reusable trays would result in a loss of \$2432.30 in the first year. The annual amount after the first year resulted in a loss of \$905.86 for ten percent replacement, \$1075.47 for twenty percent replacement and \$1245.07 for thirty percent replacement.

HS Cost Estimates

Disposable Tray		
Number of Trays Needed	Unit Cost	Total Cost
51,419	\$0.04	\$1,799.67
Compostable Tray		
Number of Trays Needed	Unit Cost	Total Cost
51,419	\$0.10	\$4,936.22
Reusable Tray		
Number of Trays Needed	Unit Cost	Total Cost
500	\$3.39	\$1,696.04
Dishwasher		
Water	\$ 198.69	
Energy	\$ 1,486.38	
Chemicals	\$ 850.85	
Total		\$ 2,535.92

Table 39 - HS Cost Estimates of Tray Types

HS Cost Estimate: Compostable Tray			
	Compostable	Disposable Expenses	Savings/Loss (+/-)
Annual Amount	\$4,936.22	\$1,799.67	-\$3,136.56

Table 40 - HS Cost Estimate: Compostable Tray

HS Cost Estimate: Reusable Tray (10% Replacement) and Current Dishwasher			
	Reusable Expenses	Disposable Expenses	Savings/Loss (+/-)
Year 1	\$4,231.96	\$1,799.67	-\$2,432.30
After Year 1	\$2,705.53	\$1,799.67	-\$905.86

Table 41 - HS Cost Estimate: Reusable Tray with 10% Replacement and Current Dishwasher

HS Cost Estimate: Reusable Tray (20% Replacement) and Current Dishwasher			
	Reusable Expenses	Disposable Expenses	Savings/Loss (+/-)
Year 1	\$4,231.96	\$1,799.67	-\$2,432.30
After Year 1	\$2,875.13	\$1,799.67	-\$1,075.47

Table 42 - HS Cost Estimate: Reusable Tray with 20% Replacement and Current Dishwasher

HS Cost Estimate: Reusable Tray (30% Replacement) and Current Dishwasher			
	Reusable Expenses	Disposable Expenses	Savings/Loss (+/-)
Year 1	\$4,231.96	\$1,799.67	-\$2,432.30
After Year 1	\$3,044.74	\$1,799.67	-\$1,245.07

Table 43 - HS Cost Estimate: Reusable Tray with 30% Replacement and Current Dishwasher

A new dishwasher was recommended, and the comparison of both dishwashers are shown in Table 44 along with the cost of installation and environmental impacts.

Using this information, a new cost estimate was completed comparing the disposable tray with the reusable tray at each replacement rate and the new dishwasher in Tables 45 to 47. This resulted in a loss of \$14385.92 in the first year. The annual amount after the first year resulted in a savings of \$265.52 for ten percent replacement and \$95.92 for twenty percent replacement. As for the thirty percent, the annual amount after the first year resulted in a loss of \$73.69.

HS Dishwasher Comparison

	Current	New	Difference
Purchase & Installation		\$ 13,125.00	\$ (13,125.00)
Operating Costs			
Water	\$ 198.69	\$ 100.38	\$ 98.31
Energy	\$ 1,486.38	\$ 889.62	\$ 596.77
Chemicals	\$ 850.85	\$ 374.54	\$ 476.31
Total	\$ 2,535.92	\$ 1,364.54	\$ 1,171.38
Environmental Impact			
Water (gal)	33156.69231	16697.07692	16459.61538
Electricity (kWh)	12924	8329.846154	4594.153846
Gas (therms)	217.3846154	57.46153846	159.9230769
Carbon Emissions (metric tons)	1.294615385	0.830769231	0.463846154

Table 44 - HS Dishwasher Comparison

HS Cost Estimate: Reusable Tray (10% Replacement) and New Dishwasher			
	Reusable Expenses	Disposable Expenses	Savings/Loss (+/-)
Year 1	\$16,185.58	\$1,799.67	-\$14,385.92
After Year 1	\$1,534.14	\$1,799.67	\$265.52

Table 45 - HS Cost Estimate: Reusable Tray with 10% Replacement and New Dishwasher

HS Cost Estimate: Reusable Tray (20% Replacement) and New Dishwasher			
	Reusable Expenses	Disposable Expenses	Savings/Loss (+/-)
Year 1	\$16,185.58	\$1,799.67	-\$14,385.92
After Year 1	\$1,703.75	\$1,799.67	\$95.92

Table 46 - HS Cost Estimate: Reusable Tray with 20% Replacement and New Dishwasher

HS Cost Estimate: Reusable Tray (30% Replacement) and New Dishwasher			
	Reusable Expenses	Disposable Expenses	Savings/Loss (+/-)
Year 1	\$16,185.58	\$1,799.67	-\$14,385.92
After Year 1	\$1,873.35	\$1,799.67	-\$73.69

Table 47 - HS Cost Estimate: Reusable Tray with 30% Replacement and New Dishwasher

4.3.2 Dumpsters

During the school year, the trash is picked up three times per week and the recycling is picked up once per week. In Table 48, the volumes and expenses of the dumpsters are listed. Using this information, the total volume of trash and recycling picked up per year was estimated, assuming that the bins are completely full. To calculate this, the number of pickups per week was multiplied by the number of weeks in the school year (41.429 with vacations included) to find the estimated number of pickups per year. This value was then multiplied by the total volume of the dumpsters for trash and recycling to have the estimated total annual volume of the trash/recycling

dumpsters. The annual costs of these bins are also shown in Table 48 (Republic Services, personal communication, 2020).

Dumpster Volumes & Expenses					
Elementary Schools					
	Total Volume (yd³)	# Pick Ups per Week	Est. # Pick ups per year	Total Volume per year (yd³)	Annual Cost
Trash	26	3	124	3231.429	\$15,654.25
Recycling	24	1	41	994.286	\$4,194.48
Middle Schools					
	Total Volume (yd³)	# Pick Ups per Week	Est. # Pick ups per year	Total Volume per year (yd³)	Annual Cost
Trash	14	3	124	1740.000	\$8,429.21
Recycling	14	1	41	580.000	\$2,431.29
High School					
	Total Volume (yd³)	# Pick Ups per Week	Est. # Pick ups per year	Total Volume per year (yd³)	Annual Cost
Trash	20	3	124	2485.714	\$12,402.98
Recycling	8	1	41	331.429	\$1,382.67
All Schools					
	Total Volume (yd³)			Total Volume per year (yd³)	Annual Cost
Trash	60			7457.143	\$36,486.44
Recycling	46			1905.714	\$8,008.44

Table 48 - Dumpster Volumes and Expenses

Using the information from Table 48, a comparison was made between the annual volumes of the dumpsters and the amount of trash and recycling coming from the cafeterias. As mentioned earlier, the dimensions of the full trash and recycling bags at each building were measured. This was used to calculate the volumes (using the volume of a cylinder) to find the daily estimated volume of trash and recycling per level. The annual volumes were determined by multiplying the daily volumes by the assumed 180 days in the school year. Table 49 shows the comparison between the

estimated volume of trash and recycling accumulated in the cafeteria over the school year versus the annual volume of trash and recycling the schools are paying for.

Annual Volume Comparisons (yd³)		
Elementary Schools		
Trash	Dumpster (Trash)	% of Container
94.146	3231.429	2.913%
Recycling	Dumpster (Recycling)	% of Container
49.603	994.286	4.989%
Middle Schools		
Trash	Dumpster (Trash)	% of Container
52.093	1740.000	2.994%
Recycling	Dumpster (Recycling)	% of Container
15.676	580.000	2.703%
High School		
Trash	Dumpster (Trash)	% of Container
54.978	2485.714	2.212%
Recycling	Dumpster (Recycling)	% of Container
16.015	331.429	4.832%
All Schools		
Trash	Dumpster (Trash)	% of Container
201.216	7457.143	2.698%
Recycling	Dumpster (Recycling)	% of Container
81.294	1905.714	4.266%

Table 49 - Annual Volume Comparisons

4.4 Future State

After all the results were gathered, a future state map of the cafeteria process was completed, as shown in Figure 28. This was influenced by all portions of the study, especially the observations. The changes and additions include the repositioning of the waste bins, the elementary schools having new bin stands and lower liquid drain stations as well as the compost bins and clearly defined locations to drain liquids added to other schools.

Figure 26 - Future State Map

4.5 Alternative Case Scenarios

It was determined by the cafeteria supplier that fifty reusable trays could be added to the elementary and middle schools without adding any additional labor costs to the expenses. Therefore, an alternative scenario was created showing the results of having a mix between the current tray in place and the fifty reusable trays per school. Tables 50 to 55 display the total expenses comparing this alternative with the tray in place at the elementary and middle schools. In the elementary schools, switching to this alternative results in savings after the first year for each replacement rate of the reusable trays. For the middle schools, there is a loss for each replacement rate when switching to the alternative option.

ES Alternative Case: No Added Labor, Reusable with 10% Replacement			
Current Dishwasher			
	Reusable & Compostable Expenses	Compostable Expenses Only	Savings/Loss (+/-)
Year 1	\$7,476.55	\$7,188.48	-\$288.07
After Year 1	\$6,865.97	\$7,188.48	\$322.51
New Dishwasher			
	Reusable & Compostable Expenses	Compostable Expenses Only	Savings/Loss (+/-)
Year 1	\$29,752.96	\$7,188.48	-\$22,564.48
After Year 1	\$5,591.84	\$7,188.48	\$1,596.64

Table 50 - ES Alternative Case: Reusable Tray with 10% Replacement

ES Alternative Case: No Added Labor, Reusable with 20% Replacement			
Current Dishwasher			
	Reusable & Compostable Expenses	Compostable Expenses Only	Savings/Loss (+/-)
Year 1	\$7,476.55	\$7,188.48	-\$288.07
After Year 1	\$6,933.81	\$7,188.48	\$254.67
New Dishwasher			
	Reusable & Compostable Expenses	Compostable Expenses Only	Savings/Loss (+/-)
Year 1	\$29,752.96	\$7,188.48	-\$22,564.48
After Year 1	\$5,659.69	\$7,188.48	\$1,528.79

Table 51 - ES Alternative Case: Reusable Tray with 20% Replacement

ES Alternative Case: No Added Labor, Reusable with 30% Replacement			
Current Dishwasher			
	Reusable & Compostable Expenses	Compostable Expenses Only	Savings/Loss (+/-)
Year 1	\$7,476.55	\$7,188.48	-\$288.07
After Year 1	\$7,001.66	\$7,188.48	\$186.82
New Dishwasher			
	Reusable & Compostable Expenses	Compostable Expenses Only	Savings/Loss (+/-)
Year 1	\$29,752.96	\$7,188.48	-\$22,564.48
After Year 1	\$5,727.53	\$7,188.48	\$1,460.95

Table 52 - ES Alternative Case: Reusable Tray with 30% Replacement

MS Alternative Case: No Added Labor, Reusable with 10% Replacement			
	Reusable & Disposable Expenses	Disposable Expenses Only	Savings/Loss (+/-)
Year 1	\$2,480.96	\$2,071.76	-\$409.21
After Year 1	\$2,175.68	\$2,071.76	-\$103.92

Table 53 - MS Alternative Case: Reusable Tray with 10% Replacement

MS Alternative Case: No Added Labor, Reusable with 20% Replacement			
	Reusable & Disposable Expenses	Disposable Expenses Only	Savings/Loss (+/-)
Year 1	\$2,480.96	\$2,071.76	-\$409.21
After Year 1	\$2,209.60	\$2,071.76	-\$137.84

Table 54 - MS Alternative Case: Reusable Tray with 20% Replacement

MS Alternative Case: No Added Labor, Reusable with 20% Replacement			
	Reusable & Disposable Expenses	Disposable Expenses Only	Savings/Loss (+/-)
Year 1	\$2,480.96	\$2,071.76	-\$409.21
After Year 1	\$2,243.52	\$2,071.76	-\$171.76

Table 55 - MS Alternative Case: Reusable Tray with 30% Replacement

Using this information, Table 56 was made. This shows the total accumulated expenses for the elementary schools and middle schools over ten years. The elementary schools section includes the current and new dishwasher expenses as well. For both levels, the reusable trays were considered for each of the replacement rates. Additionally, the carbon footprint was calculated for each level including this alternative case scenario for the Use to End-of-Life scenario and Raw materials to End-of-Life scenario.

This was combined with the expense information in Figures 27 to 30. The elementary schools compare the carbon footprint and expenses of the tray that was in place (the compostable tray sent to a landfill) with the alternative case scenarios of a mixture of reusable trays and compostable trays sent to a landfill. The middle schools compare the carbon footprint of the tray in place (disposable paper boats) with the alternative of a mix between disposable and reusable trays. In both cases, the reusable trays for each replacement rate is considered.

ES Alternative Case: 10 Year Outlook: Expenses				
	100% Compostable (Landfilled)	Compostable & Reusable Mixed (30% Replaced)	Compostable & Reusable Mixed (20% Replaced)	Compostable & Reusable Mixed (10% Replaced)
Current Dishwasher	\$71,884.80	\$70,491.46	\$69,880.88	\$69,270.31
New Dishwasher	\$71,884.80	\$81,300.71	\$80,690.13	\$80,079.56

MS Alternative Case: 10 Year Outlook: Expenses				
	100% Disposable	Disposable & Reusable Mixed (30% Replaced)	Disposable & Reusable Mixed (20% Replaced)	Disposable & Reusable Mixed (10% Replaced)
Current Dishwasher	\$20,717.55	\$22,672.62	\$22,367.33	\$22,062.05

Table 56 – Alternative Case 10 Year Outlook: Total Accumulated Expenses

Figure 27 - ES Alternative Case: Total Accumulated Carbon Footprint for Use to End-of-Life Phases

Figure 28 - MS Alternative Case: Total Accumulated Carbon Footprint for Use to End-of-Life Phases

Figure 29 - ES Alternative Case: Total Accumulated Carbon Footprint for Raw Materials to End-of-Life Phases

Figure 30 - MS Alternative Case: Total Accumulated Carbon Footprint for Raw Materials to End-of-Life Phases

CHAPTER 5: ANALYSIS

5.1 Current State

5.1.1 Lunch Observations

The lunch observations and spaghetti diagrams made it possible to determine the current state of each school. As expected, every school had a handful of students that did not throw away their waste properly. This being said, the schools that showed better results were those with the best signage. The signage that most students seemed to understand the best were when the rules of trash/recycling/compost were simplified and contained large fonts. One of the elementary schools had signage with physical pieces of the appropriate examples from that category stapled to a poster board which proved most effective. For instance, the trash had plastic sandwich bags and candy wrappers and the recycling had empty containers and milk cartons. Most of the other schools have the standard signage provided by RIRRC but the smaller font and mass list of instructions seemed to deter people from actually reading them.

Another school had a built-in stand for the bins to be placed underneath, color coded for the students to use. The stand was not in use during the observation, however, due to its large height and the younger students having difficulty seeing above it, so a shorter version would be preferred. This was also an issue for the liquid drain stations at some of the schools where students drain excess liquids such as milk out of the cartons before recycling. Outside of the elementary schools, there were no other liquid drain stations observed; however, some locations allowed the draining to

be done in the garbage bins. While this was a possibility, it was not often observed, and many recyclable containers were noticed to be thrown in the trash bins half full.

Another noted problem in some schools involved the placement of the trash and recycling bins. In Elementary School C, the lower grades had a trash bin that was moved from its location in the spaghetti diagram to the center in between the tables. While this made it easier for these younger students to get to, the recycling bins were not being used at all for this lunch period. Every piece of waste was observed to be thrown into the trash, recyclable products included. As seen in the spaghetti diagram for Middle School B, there is only one recycling bin which is placed away from the entry and exit doors in the back of the cafeteria. This resulted in a great deal of recyclable items being thrown in the trash. Those that did use the recycling bin appeared to be sitting closer towards the back of the room near its location. As for the other schools, the spaghetti diagrams depicted an expected path that students would take during lunch and all of these aided in the development of the current state map.

5.1.2 CSM

As described earlier, the current state map (CSM) shows the process of the lunch trays being ordered and the cafeteria process during a lunch period. The first kaizen burst, transportation, was noted due to the problem with certain bin locations mentioned above. The trash bin located in the center of the tables or the recycling bin in the back of the room required students to travel much farther to reach the required bin which resulted in improper recycling or trash disposal due to inconvenience. The next kaizen burst, waste, is often used when resources are not being used properly or

there is a decision being made that impacts the environment. In this case, the waste refers to the improper disposal of the trash, recycling, or compost that was occasionally noticed as well as the use of disposable trays and plates in the secondary schools when they could switch to more eco-friendly trays. The last kaizen burst, emissions, is meant for each of the truck symbols showing that more frequent pickups of waste result in more emissions that are created.

5.1.3 Weight Data

Based on the weight data of the trash and trays at each school, the high school has the largest tray contribution to trash at 42.910%. This was expected as there are two types of trays served, both of which are disposable whereas the other levels only serve lunch on one tray. The next largest value is from the elementary school compostable tray at 20.756% contribution to trash. This would be resolved should the schools find a composting plant willing to accept trays. The food that is composted is currently being taken by community members who have use for food scraps but do not accept trays. Finally, the lowest tray percent contribution to trash value is the middle school with a result of 10.539%.

Based on the volume data, the elementary schools had the largest tray contribution to trash at 21.821%. this was likely due to the fact that these trays were larger than the other two types of trays. The next largest value was the high school at 6.915%. Lastly, the middle schools had the lowest result with 1.687% contribution to trash.

5.2 Environmental & Economic Comparison LCA

5.2.1 Comparisons of Systems by Impact Category Results

Once the impact result for each system per functional unit of one tray was calculated, the projection of impact accumulated over ten years was created considering the number of trays that would be required for purchase every year. The purpose of this was to have a more accurate representation when comparing the systems with one another. For example, the impact appears to be high for the reusable system when comparing it with the other systems based on the impact of one tray, however, one must consider that these trays are purchased significantly less often than the other types of tray systems.

In both scenarios of Use to End-of-Life Phases and Raw Materials to End-of-Life Phases, the reusable tray with a ten percent replacement rate due to loss or theft had the lowest environmental impact results in every category. This was mainly due to the fact that it required the least amount of purchases of trays over the ten years. In addition, all impact results of the reusable trays for any of the three replacement rates showed a significantly lower impact than the other systems involving disposable or compostable trays.

For the Use to End-of-Life scenario, the disposable system had the highest impact for total human toxicity and ecotoxicity. The compostable system with the trays being composted showed the highest impact for acidification and ecotoxicity. Finally, the compostable system with trays being sent to a landfill had the largest number of highest impact results in the categories for global warming, ozone

depletion, eutrophication, human health respiratory effects average, and fossil depletion.

For the Raw Materials to End-of-Life Phases scenario, the disposable system had the largest number of highest impacts per category. These included every impact category besides global warming and water depletion. The compostable system with the trays composted resulted in the highest impact for water depletion. Lastly, the compostable system with the compost sent to the landfill resulted in the highest impact for global warming compared to other systems.

5.2.2 Comparisons of Systems by Carbon Footprint Results

Similar to the impact categories, the carbon footprint results included a total accumulated impact over a ten-year period. Figures 31 and 32 are charts based on the results from Tables 25 and 26. In both scenarios, the carbon footprint showed to be the highest for the compostable tray if it was sent to the landfill followed by the disposable tray. The reusable trays for all three replacement rates showed an impact that was significantly lower than the other systems.

Figure 31 - Carbon Footprint (kg CO₂-Eq) Total Accumulated Impact Over 10 Years: Use to End-of-Life Phases

Figure 32 - Carbon Footprint (kg CO₂-Eq) Total Accumulated Impact Over 10 Years: Raw Materials to End-of-Life Phases

5.3 Options and Cost Analysis

5.3.1 Trays and Dishwashers

At the elementary level, based on the cost estimates in Tables 27 to 29 with the reusable trays and current dishwasher values compared with the system in place (the compostable tray), switching to the reusable tray would result in the school losing over twenty thousand dollars per year for all replacement rates. This is mainly due to the additional dishwasher usage and labor that would be required to handle the increased workload that the reusable trays would create. When comparing dishwasher options for the three elementary schools that were provided alternatives, switching to a new dishwasher saves the school almost fifteen hundred dollars in annual costs. This being said, the purchase and installation fees need to also be considered. Tables 31 to 33 comparing the compostable tray to the reusable tray and new dishwasher expenses shows lower annual expenses after year one than with the old dishwasher. However, there is still a loss of over twenty thousand dollars per year following the first year for all replacement rates.

At the middle school level, when comparing the expenses of the system in place (disposable paper boats) to reusable tray expenses in Tables 35 to 37, there is an annual loss of roughly eighteen hundred dollars after the first year for all replacement rates. Similar to the elementary level, this is mainly due to dishwashing fees and labor hours. When compared with the compostable tray option in Table 38, the result is significantly better than with the reusable trays but is still showing a loss of over three thousand dollars a year.

Lastly, at the high school level, when the current disposable tray expenses are compared with compostable trays (Table 40), there is a loss of over three thousand dollars per year. Due to there being no labor added should the tray type switch to reusable trays, the expenses decrease significantly when compared with the other schools. With the current dishwasher in place, switching to the reusable tray results in an annual loss for all replacement rates of at least nine hundred dollars per year after the first year as seen in Tables 41 to 43. When comparing dishwasher expenses alone (Table 44), the switch to a new dishwasher would result in over one thousand dollars in savings per year along with the initial purchase and installation fee. When comparing the disposable expenses to the reusable tray expenses with the new dishwasher installed (Tables 45 to 47), after the first year, there is about a seventy-dollar loss annually for the thirty percent replacement rate. This outcome, however, changes when viewing the ten and twenty percent replacement rates. If the reusable tray replacement rate was twenty percent and the new dishwasher was installed, there would be a savings of about ninety-five dollars after the first year. If this was set to ten percent replacement, there would be a savings of over two hundred dollars after the first year. Should the initial fees of the reusable trays and dishwasher be covered by external funds, such as through a grant, and setting the reusable replacement rate to at least twenty percent, the schools would be saving money every year.

5.3.2 Dumpsters

When looking at the estimated amount of trash and recycling accumulated over the year in terms of the volume compared with the annual volume of dumpster pickups in (Table 49), the results show that for all cases, the cafeteria waste contributes to

less than ten percent of total school waste. The trash accumulation in the cafeterias for every level was calculated to be under three percent of the annual dumpster volume and the recycling was under five percent. The total annual contribution of cafeteria waste to dumpsters was 2.698% for trash and 4.266% for recycling. While there are other factors that contribute to filling these dumpsters in the schools such as classroom waste, it is very possible that the schools were paying for more pick-ups than was necessary.

5.4 Future State

The future state map is similar to the current state map but with additions or slight changes with the goal of resolving the kaizen bursts. The bins are suggested to be repositioned closer to entry/exit points where there were previously no bins in place for some schools. For the elementary schools, suggestions were made to add new bin stands and liquid drain stations that would be easier for the students to reach. In addition, the coloration of the bins as well as the posters with familiar examples of trash/recycling/compost would assist the students in knowing the proper bin to use. For all other schools, adding compost bins would be better for the environment and lower the amount of waste going into the trash which may save the schools money. Also, if throwing liquid waste such as coffee or milk in the trash is acceptable, adding signage may assist or remind the students to do so and recycle more.

5.5 Alternative Case Scenario

The alternative case scenarios allowed for the possibility of a combination of the tray in place and the reusable trays without adding labor costs. Based on the results

in Figures 27 and 29, the elementary schools would save over one thousand dollars switching to this alternative scenario for any reusable tray replacement rate without changing to the new dishwashers. This would also lower the carbon footprint in these schools by at least 971970.40 kilograms of carbon dioxide equivalent for the Use to End-of-Life scenario and 2554367.40 kilograms of carbon dioxide equivalent for the Raw Materials to End-of-Life scenario. The outcome that results in the lowest carbon footprint and expenses is the alternative scenario with reusable trays set to ten percent replacement every year.

For the middle schools, based on Figures 28 and 30, switching to the alternative scenario would lower the carbon footprint by at least 172785.20 kilograms of carbon dioxide equivalent for the Use to End-of-Life scenario and 1144296.90 kilograms of carbon dioxide equivalent for the Raw Materials to End-of-Life scenario. This being said, the expense of making this change would increase to a minimum of almost two thousand dollars.

CHAPTER 6: CONCLUSION

6.1 Environmental Perspective

One of the main reasons this study was completed with the school district was due to their high interest in lowering their impact on the environment. Some areas of improvement that were determined include updating the signage to better educate the students on proper waste handling as well as positioning the bins so that it is more convenient to not only dispose of trash but also to recycle or compost. Based on the life cycle assessment, reusable trays had the lowest environmental impact in all scenarios and therefore was the best option to cause the least amount of harm to the environment. In addition, switching to reusable trays would lower emissions caused by the delivery of waste to a disposal site as this would occur less often unlike the other options which was an issue pointed out in the current state map. After this, compostable trays would be the next best choice. That being said, this is only the case if the compostable trays are composted and not sent to a landfill. In many cases, the landfilled compostable trays resulted in a higher environmental impact than disposable trays. As for the alternative case scenarios of mixing reusable trays with the trays in place for the elementary and middle schools, in all cases, the environmental impact would be lowered in terms of the carbon footprint.

6.2 Cost Perspective

Based on the cost analysis, it was determined that making the switch to entirely reusable trays would be too costly of a decision for any school to make. This being said, if money could be raised or grants could be used towards the initial purchase of

the trays and new dishwasher, the high school would be able to not only afford this option, but save money doing so. Compostable trays would end up costing the middle and high schools more money than the disposable options each year, however, this amount is significantly less than the reusable trays. Based on the dishwasher information, if the schools switched to the newer versions that were listed, the money saved could be put towards either reusable or compostable trays. As for the alternative case scenarios, if the elementary schools are able to add fifty reusable trays to each school, they would save money doing so.

6.3 Risks, Assumptions, & Final Thoughts

To complete this study, there were assumptions that were made in the calculations. One assumption was that the school year was considered to be 180 days. Another assumption was that the weight and dimensions of the trash and recycling would be the same every day based on the measurements taken, which could have a great deal of variability. Also, the calculated volumes were completed based on the three-dimensional shapes that most resembled that object. For example, the compostable tray was rectangular, so a rectangular prism volume calculation was made. For the LCA, each tray included the use of the ecoinvent 3 database to assume the process of its life cycle, as shown in the inventory analysis.

Not every company or organization considers the environment to be a necessary concern and this school district's desire to improve made this study possible. One area that is crucial to focus on is educating the students from the early ages into adulthood. This would continuously engage them in this subject to better understand

the impact they have on the environment. In addition, the more they learn, the less likely they would be to make mistakes such as throwing trash in the recycling bin.

6.4 Future Work

Based on the results of this study, future work and recommendations have been made that can improve the school cafeterias' sustainability. In terms of the waste bins, it is recommended that every type of bin be positioned in more convenient locations based on the flow of traffic. Additionally, all schools should investigate adding compostable bins that do not yet have this in place, so the food is not going into the landfill and contributing to the volume and cost of trash. Based on the low volumes of cafeteria trash to the dumpsters, a trash audit should be completed daily for several weeks of normal school activity to see if these dumpsters are full three times per week. This would allow the schools to determine if they could lower the amount of trash pickups occurring at each location which would save money.

As reusable trays would be the best option from an environmental perspective, a time study should be done to determine if the added labor hours required at each level is lower than estimated as this was one of the largest contributors to reusable tray expenses. It would also be beneficial to determine how many trays can fit within the loads that are currently being run. This way, the schools could at least have some number of reusable trays in place without requiring added labor. In terms of the reusable tray replacement rate of thirty percent provided by the schools and cafeteria suppliers, one suggestion that may be able to reduce this would be labelling the trays

(i.e. “Property of the Cafeteria”) to decrease motivation of theft. Additionally, the schools should look into possible grant options that may cover some of the initial expenses for the trays and new dishwashers.

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