A More Sustainable Dishwasher

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Abstract:
Conveyor-type commercial dishwashers consume 115 trillion BTUs annually in the United States. There is great potential for new sustainable design through reducing energy usage in dishwashers. While there is not a viable way to eliminate the need for dishwashers at the present time, incorporating ultraviolet light sanitization and thermoelectric cooling can reduce energy consumption by nearly 10,000 kWh per year when compared to the most efficient machines on the market, eliminating approximately 10 tons of annual CO2 emissions at a savings of $2,300.

Executive Summary

We initially identified the university cafeteria system as the target for our sustainable design project, as they serve thousands of students every day, and require a significant amount of resources to operate. Specifically, we recognized that commercial dishwashers account for a disproportionate amount of water consumption and consume a large amount of energy to heat the water they use. We investigated opportunities for consolidating various kitchen tasks, reusing the water and energy that goes into dish cleaning, and minimizing the amount of dishes that need to be cleaned. We received input from dishwashing staff, dining administrators, and design representatives at dishwasher manufacturing companies. The primary stakeholder for this product is the administrator responsible for overseeing cafeteria operations and procuring the necessary equipment. We identified stakeholder priorities as resource usage, safety, capacity, and working environment and learned that there is a trend in the dishwasher industry towards energy- and water-efficiency. We then developed a list of requirements for our design concepts and translated those requirements into specifications. We identified three broad design categories that could help make cafeteria dishwashing more sustainable: resource-saving dishwasher accessories, new dishwasher designs, or other, non-dishwasher concepts. We developed multiple design ideas for each of these categories and scored them against our design requirements.

The baseline competitor for our project is the Meiko K-400 LPW K-Tronic Multi-Tank Rack Conveyor Dishwasher, one of the most water- and energy-efficient conveyor-style commercial dishwashers on the market today. Our product sanitizes dishes using ultraviolet light rather than hot water and chemical sanitizers, and uses thermoelectric coolers to reduce the time and energy needed to dry dishes. These technologies reduce energy consumption by nearly 10,000 kWh per year when compared to our competitor, eliminating approximately 10 tons of annual CO_2 emissions at a savings of $2,300. We attempted to identify a technology that would recycle the wash water used by the machine, but were unable to devise a solution that was environmentally friendly and cost-effective.

Sustainable design revolves around the “triple bottom line;” a new design must address economic, environmental, and social sustainability. Additionally, the design must be revolutionary in some way, changing the industry as a whole or influencing the way in which people behave. While sustainable design is the standard that we strive towards, we often have to settle for eco-efficiency. This is the case with our project. While we have improved the environmental impact of the top-of-the-line commercial dishwashers on the market today, the steps made are not revolutionary. We have not changed the way people view the need to wash dishes nor have we come up with an idea that will cause a paradigm shift in the dishwasher manufacturing industry. We believe that we can market our product at a price relatively close to the existing competition, but we did not tunnel through the cost barrier to achieve an exceptionally affordable solution. Finally, there is almost no social aspect to this design. While we believe that using less hot water and steam during the dishwashing process will make the working environment around the dishwasher more pleasant, it is not what we would consider to be radical social improvement.

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Introduction

We initially identified the cafeteria system as the target for our sustainable design project. We performed a literature survey on this topic and quickly realized that there are many areas of the system that could benefit from sustainable design, including the sourcing of food, cleanliness of the dishes, generation of waste, etc. We used the information obtained from the literature and our initial observations to focus our efforts on the dish cleaning aspect of the cafeteria. University cafeterias serve thousands of students every day, and require a significant amount of resources to operate. Commercial dishwashers account for a disproportionate amount of water consumption, but currently are a vital part of the cafeteria system. There are a wide variety of dishwashers available on the market today, and some of them are more efficient than others. We plan to identify opportunities for consolidation of various kitchen tasks, new ways of reusing the energy that goes into dish cleaning, and looking for ways to minimize the amount of dishes that need to be cleaned. We plan to receive input from the dishwashing staff, members of the university administration who are responsible for the procurement of kitchen equipment, and the manufacturers of current commercial dishwashers. The primary stakeholder is the member of the administration because they will be the one purchasing our product. Identifying, weighing, and balancing the preferences and priorities of the various stakeholders while conserving resources will be essential to developing a successful design.

Product Functional Status

There are many aspects of cafeteria-style dining that are potential areas for improvement when considering sustainability. One of these areas is ensuring that foods delivered to the dining facility are organic, sustainably farmed, and locally-sourced. For example, Yale University has a "Sustainable Food Project [that] manages an organic farm on campus and runs diverse educational programs that support exploration and academic inquiry related to food and agriculture" [1]. Another area is constructing the cafeterias in accordance with the Leadership in Energy & Environmental Design (LEED) principles. For example, the National Renewable Energy Laboratory cafeteria received a LEED Platinum rating and incorporates many energy efficiency features such as daylighting, motion-sensing LED lights in walk-in refrigerators and freezers, low-flow water valves, and demand-controlled ventilation exhaust hoods [2]. A third area of concern is minimizing the energy lost during food prep and service. For example, repeatedly opening refrigerator or freezer doors, keeping larger quantities of food hot on the serving line, and cooking frozen (not thawed) vegetables all increase the energy demand of the food preparation process. Fourth, the disposal of waste generated throughout the cafeteria can be an issue; because much of the trash is food-based and biodegradable, composting is a good option, and many of the universities that have taken an interest in purchasing organic foods have also made the effort to institute widespread composting programs in their dining facilities. Also, "[a]ccording to a July [2008] report released by [Aramark], students waste 25% to 30% less food when they aren't carrying a tray" [3].

The final area of cafeteria sustainability is reducing water usage. Commercial dishwashers "can account for more than one-third of the overall water use in a commercial kitchen" [4]. Commercial dishwasher manufacturers offer a wide array of sizes and styles, suited for various businesses with different throughput demands. Some of the available products are ENERGY STAR qualified, and can "use 25 percent less water than conventional models, on average" [4]. Conveyor-type dishwashers are commonly used in hotels, hospitals, and universities, where between 500 and 2,000 meals are served per hour [5]. Conveyor-type dishwashers generally operate as follows: "The conveyor carries the dishes through different sections of the machine…. The wash section usually has a single tank to hold water and detergent at a set temperature. In a typical machine, the wash solution from the tank is pumped through multiple spray arms that run constantly once the machine is turned on…. Some conveyor washers have multiple wash sections or multiple rinse sections progressively cleaning dishes. In the rinse section the machine sprays fresh water on the dishes, this water then flows to the wash tanks displacing some of the wash water…. In machines with multiple washing sections, water is recycled in a cascading method… ultimately draining after the first wash section" [5].

According to a 2009 study, conveyor-type dishwashers in the United States consume 115 trillion BTUs annually [5]. The report also identified that there was the potential to reduce energy consumption by 33.8 trillion BTUs in both high- and low-temperature conveyor-type machines through the implementation of existing technology [5]. In 2008, there were over 310,000 conveyor-type dishwashers installed in the U.S., with annual sales totaling 19,100 units [5]. The most efficient high-temperature conveyor dishwashers used 0.28 gallons/rack, with the median dishwashers using 0.90 gallons/rack [5]. Table 1 includes water and electricity consumption figures (and corresponding annual costs) as well as retail prices for a variety of dishwashers available on the market today, all of which are in the upper half of dishwasher performance. The average utility costs in the U.S. are $0.11/kWh for electricity and $1.50/1000 gallons of water [6,7].

Table 1. Commercial Dishwasher Prices and Utility Consumption and Costs

Dishwasher Model	Retail Price	Water Usage (gal/rack)	Electricity Usage (kWh/day)	Water per week (gal)	Electricity per week (kWh)	Water utility cost per year	Electricity utility cost per year
Meiko K-Tronic [8]	$35,558	0.28	198	353	1185	$21	$5,085
Jackson 208 Crew 44 [9]	$16,940	0.32	226	403	1355	$24	$5,812
Jet Tech FX44 [10]	$12,317	0.43	303	542	1820	$32	$7,810
CMA Dishmachines EST-44 [11]	$14,536	0.49	346	617	2074	$36	$8,899
Insinger Speeder 86-3 [12]	$36,849	0.52	367	655	2201	$38	$9,444
Champion 44 DR [13]	$22,340	0.54	381	680	2286	$40	$9,808
Hobart CL44e [14]	$16,191	0.62	437	781	2625	$46	$11,261
Insinger Admiral 44-4 [15]	$22,297	0.63	445	794	2667	$46	$11,442
Jackson AJX-54 [16]	$21,678	0.78	550	983	3302	$57	$14,166

There were several assumptions made to achieve these numbers. First, it was assumed that during peak meal times (lunch and dinner), the cafeteria would serve approximately 250 diners per hour for 3 hours, with a total of 2000 diners per day [17]. Cafeterias will always have different capacities, and it would be ideal to design a range of products to cover a variety of sizes, from relatively small to relatively large. However, we chose these numbers as a starting point for this project, and we will use them for our design requirements and decisions. From personal experience, we assumed that each person would use two dishes and one cup, on average. The dishwasher racks can fit an average of 25 dishes or 40 cups [14]. We thus assume that for flight-type dishwashers, 1.6 cups is equivalent to 1 dish, in terms of capacity. Our final dish usage assumption was that weekends would have half the diners of a weekday, and that the cafeteria would operate at this capacity for an average of 9 months a year, to account for vacations and the summer term, when there are fewer students on campus. As a result, we estimated a need to clean 5250 pieces of tableware (210 racks) each day, with a peak capacity of 26 racks per hour. In order to come up with an energy usage figure, we assumed that all water enters the heating tank at 60°F and is heated by electricity to a temperature of 150°F. From thermodynamics, 3.36kWh is required to heat 1 gallon of water 90 degrees [18]. While this is not an entirely accurate assumption, because some of the newer commercial dishwashers are able to recapture some of the heat used during the dishwashing process, there are inevitably other heat losses; for example, when the water tank is not being constantly used, the water will start to cool down and additional heat will have to be added.

Because water is a relatively inexpensive utility service, reducing water usage by itself will not result in any relevant cost savings to the operator. However, if the water heating requirements are the same, cutting the electricity in half has the potential to provide several thousands of dollars of annual savings. There are several publications detailing ways to minimize the energy used by commercial dishwashers, such as keeping the water pressure and hot water tank temperature at the manufacturer's recommended settings, using a pre-rinse sprayer to remove food before loading tableware in the dishwasher, and employing an water booster heater [19]. However, these measures were already taken into account when the water- and electricity-usage numbers in Table 1 were calculated. Assuming that a new $40,000 dishwasher reduces the best water usage figure (and related heating cost) by 50%, the reduced utility cost will pay back the entire value of the machine in 16 years. We understand that this number is not earth-shatteringly good, but it is significant to note that the expected payback time is within the 20-plus-year lifespan of a typical conveyor or flight-type commercial dishwasher [20]. However, because the payback period is so long, and it is expected that a more sustainable dishwasher might cost more than the competition, it would need to offer additional benefits, such as having a higher throughput or taking up less space or costing less, in order to be commercially attractive. Also, because commercial dishwashers are large, expensive, and semi-permanent, most institutions would not be likely to replace their current model with a new product until their dishwasher died or they were given some sort of financial incentive by the government or could be persuaded to promote their company's "green" image.

Design Ethnography

We developed our design ethnography plan using the six-question worksheet provided by Professor Shanna Daly. We wanted to determine what features of a dishwasher's functionality were most important or the biggest nuisance to the relevant stakeholders, namely the dishwashing staff, the cafeteria manager, and the institution's procurement division. We felt that the other stakeholders would not provide us with as valuable information, and that the bulk of our design work would benefit from these few critical stakeholders. We decided to initially observe day-to-day activities in the cafeteria in a non-intrusive manner, but were unable to gain access to the necessary parts of the cafeteria. Instead, we relied on interviews with the dishwashing staff to receive input on the specifics of the dishwashing process. Additionally, we sought information about what the institutional bureaucracy valued when selecting a commercial dishwasher, because the dishwashers themselves have no say in what dishwasher is purchased. We also attempted to contact executives at commercial dishwasher manufacturing companies who were responsible for design decisions and production of new dishwasher models to benefit from their customer research and knowledge and experience in the field. Our existing background knowledge is described in detail in the Product Functional Status section, above.

We quickly ran into problems with our original design ethnography plan because of the restrictions placed on our ability to observe and interact with the cafeteria staff. University of Michigan Housing personnel informed us that they were short-staffed in the cafeterias and that we would not be allowed to interview any employees other than perhaps the managers. We attempted to work around this major obstacle in two ways. First, Masiha made personal observations while having dinner at one of the cafeterias on Central Campus. Second, Niket knows several people who work in the cafeterias, and was able to interview them about their experiences. Gaurav currently works in the Bursley cafeteria and was able to make his own observations and talk to several of his coworkers as well. Hanyi interviewed his friends who work in the University of Minnesota dining halls to obtain more detailed observations and information on another university's dining facilities. We were able to receive some valuable input from the University of Michigan Director of Dining and one of the dining facility managers. Additionally, we spoke briefly with a representative from Hobart Corporation's dishwasher design division.

The Bursley dining hall has a lot of natural lightning and the use of electric lighting is kept to a minimum during daylight hours. Plastic trays for student use are stacked near the entrance of the facility, which allows the diners to get all of their food in one trip and they do not have to go back again to the food stations and wait. As noted in the literature survey, there is lot of food that is wasted because of the use of trays; during our observations, approximately 60% of trays had uneaten food left on them when diners were done eating. Trash bins are located on one side of the hall, and people dispose of their napkins, straws, and other primarily plastic waste here; there is no option to recycle waste. The temperature in the dishwashing room is higher than the rest of the kitchen and dining facility, and is very humid, which appears to be caused by steam escaping through the entrance and exit of the dishwashing machine. In the University of Minnesota Centennial Hall dining facility, it was noted that the cleaning staff seldom have a chance to get in touch with the manager during working hours, even if they want to talk about problems encountered during their job. The dishwashing machine employs a conveyor belt, and the dishwashing staff is responsible for loading dirty dishes into dish racks and then running the dishes through the machine. During the busiest hours of operation, it is impossible for only two persons to keep the dish racks full, meaning that the machine operates with less-than-full loads of dishes. This makes the washing machine less efficient and requires more water and energy to clean the same number of dishes. At the University of Michigan, students are not allowed to take food out of the dining hall, but at the University of Minnesota, students sometimes take food back into their dorms to eat, but frequently forget to bring them back to the dining hall. This results in some tableware being thrown away outside of the dining facility and a shortage of dishes during meal time. Appendix IV contains our observations in their entirety.

The Michigan Director of Dining informed us that the University has implemented programs and policies that encourage sustainable behavior at the institutional level, and that they accept and value feedback from students. He also stated that most of their dishwashers last between 15 and 22 years before being replaced, and that they value capacity, manufacturer's reputation, resource consumption, and contribution to the working environment when selecting a new machine. We did not gain much insight into Hobart's design process, but we learned that there has been a significant trend towards efficiency over the past 20 years or so, that new models are sometimes slow in coming, and that add-ons are often developed to improved dishwasher performance without the need to replace the entire machine.

Project Description

We decided to focus our design efforts on reducing water and energy usage in the cafeteria, specifically within the dishwashing process, because we believe it to be an area of large potential savings. While there are many other aspects of commercial kitchen operations that account for a larger portion of energy usage, we feel that we would have a much more difficult time innovating a way to make grills, ovens, etc. more energy-efficient. And even though commercial dishwashers are becoming more efficient, they can still account for a third of the kitchen's entire water demand. Making an improvement in this area would translate to improving the cafeteria's overall sustainability by a similar amount. Additionally, with annual sales of nearly 20,000 conveyor-type dishwashers and a potential nationwide savings of over 30 trillion BTUs by simply implementing existing technology, dishwashers are a commercially viable area for sustainable design. There are two general approaches we can take to making dishwashers more efficient. The first is to design an add-on or accessory that will attach to existing dishwashers to improve water and/or energy usage. This product would be marketed to institutions as an item to be purchased immediately, regardless of dishwasher age; as there are over 300,000 conveyor-type dishwashers in service today, there would be a large market for this kind of product. The second approach is to design an entirely new dishwasher or other system to replace the functionality of a dishwasher. This concept would not be a "rip-out-your-current-dishwasher-and-install-this-thing-now" type of product; instead, it would be marketed as something that can replace a dishwasher nearing the end of its service life. While this would greatly reduce annual sales, it could make a large impact, and the payback cost of the machine would only be the difference between its price and the price of its major competitors; this makes the design of an entirely new product a viable option.

Also, there are connections between this and other areas of potential sustainable improvement. For example, the steam generated by the dishwashers makes the surrounding area exceptionally hot and humid, increasing the ventilation and air conditioning demand for the space. The removal of food waste from the tableware and its subsequent disposal can be made more efficient or facilitate composting. The heat and water used during dishwashing could potentially be used to assist another aspect of the cafeteria's operations. However, making improvements to the efficiency of dishwashers that rely on water to clean tableware can only take us so far; a whole-systems approach and outside-the-box thinking is the key to a breakthrough improvement in terms of sustainability. We believe that universities are some of the more progressive institutions around, and would be more likely to accept new environmentally-friendly processes or technology, even if the cost savings are not substantial. Additionally, there is a pressure from students at many universities to adopt "green" technology. Making a more sustainable piece of equipment that also improves the process and saves the owner money is sure to be a smash hit with institutions of higher learning.

Description of Persona

The persona that our product caters to is Jane, a 47-year-old mother of three. Her children are aged 14, 11, and 9, and lives in a middle-class neighborhood about a 30 minute commute away. She enjoys listening to classic rock or news reports during her drive. She works a 9-5 job and is an upper-level administrator responsible for managing the residential facilities at a university with over 10,000 enrolled students. A large number of these students live on campus and eat in the dining facilities. Jane is not involved in the day-to-day operation of the dining facilities… her office is located in a separate building and she hardly ever goes to the facilities except to perform periodic inspections. She is satisfied with her career and personal accomplishments, but was never that ambitious; she valued taking the time to raise a family and was out of the workforce between the birth of her first child and the time her third was four years old. She has been promoted once in the past five years, and plans to continue working for the university until retirement. Jane has the most leverage among the stakeholders for reviewing, acquiring and implementing new technologies and systems in the dining halls. She works with a procurement committee and the cafeteria managers to identify the best equipment to use, but she likes to exercise her authority and because of her managerial experience (16 years) and placement within the university bureaucracy, her opinions dominate this process. Her job performance is measured by the economic performance of the facilities, so she is primarily interested in the bottom line; however, there is an institution-wide agenda to help the university appear "green" because the highest levels of management believe that it will help attract idealistic young students. Jane has been specifically instructed by her boss to favor eco-friendly options (within reason) when remodeling facilities, procuring new appliances, and evaluating bids for new contracts.

We identified two other stakeholders worth thinking of as personas to help us determine which design requirements to focus on. Jim is 32 years old and has been on the job for 8 years. He is well-versed with the dining facility, having worked his way up through the kitchen ranks to become the floor manager. He employs an aggressive management style and deals firmly with his employees; he would rather force results out of them than work with them to achieve his goals because he believes that the employees are generally unmotivated. He also is defensive when interacting with his boss, whom he believes is unaware of the challenges of his job, and attempts to prevent what he sees as "meddling" in his business. He does not appreciate unsolicited advice and is not concerned with saving water or energy because he does not see the utility bills; rather, he is concerned with efficiency and minimizing complaints. Jim takes pride in ensuring the quality of the cafeteria food and cleanliness of the facilities. The only time he interacts with the dishwashing staff is when students complained about new dishes not being clean or if the dishwashing machine needs repairs. He is happy with the staff as long as everything operates smoothly.

Leslie is a junior working part-time to help pay off her bills and earn some spending money. Her parents are helping pay for her tuition, but she still has had to take on student loans and now that she is living in a house off-campus and old enough to go to the bars, she has additional expenses and her parents don't have the money to fund her social activities. She is a member of the cafeteria dishwashing staff, is unmotivated to excel at her job, and believes that being placed on the cleaning crew is a stroke of bad luck. She is not concerned with performing her job well; she works enough to avoid drawing the negative attention of her managers, but no more. She dislikes the heat and humidity in the dishwashing room, and spends much of her time on the job daydreaming about her boyfriend and thinking about upcoming school assignments. While she has no part in process of acquiring new dishwashing machines, Leslie uses the product on a daily basis and has to live with whatever decisions the school administration make.

Project Requirements and Specifications

A list of requirements was created through a brainstorming process, taking into account the information that we had collected from our interviews with dishwashing staff, dining facility management, and commercial dishwasher manufacturers. We came up with three general categories: safety, practicality and functional requirements. The bulk of our requirements fell under safety and included limiting the heat, humidity, and noise in the dishwashing room, preventing steam or hot water from scalding the user, keeping floors dry and limiting other slip or trip hazards, enclosing moving or dangerous parts, preventing exposure to harmful chemicals, ensuring electrical and natural gas safety, and providing an emergency shutdown feature. Practicality considerations led us to develop requirements for adequate throughput to meet demand, adequate lifespan and durability, limiting the size of the product, and ensuring that the cost would not be prohibitive. Our functional decomposition led us to general requirements for removing waste from, washing, sanitizing, drying, and cooling the tableware. We then researched existing regulations and surveyed current dishwasher models to assist us in mapping our requirements to specifications, which can be seen in detail in Appendix V.

We then surveyed the relevant stakeholders to determine which requirements were most important to them. Our notes can be found in Appendix IV. The dining facility management stated that they were concerned with capacity, manufacturer's reputation, resource consumption, noise, and working conditions. Industry representatives informed us that they focused on resource usage and ensuring the cleanliness of the tableware when they exit the dishwasher. We also examined our specifications from the viewpoint of the sustainable designer (the "Mother Nature" stakeholder), and prioritized limiting water and electricity usage, not using harmful chemicals, durability, and the proper disposal of solid waste. There was a general consensus among the dishwashing staff that the most important specifications were those dealing with safety and comfort in the work environment. In addition to interviewing dishwashing staff, we conducted a failure mode and effects analysis (FMEA) on the specifications having to do with operator safety; the entire FMEA can be found in Appendix VI. This analysis was used along with the input we received during our interviews to objectively rank the specifications. Table 2 contains a comprehensive list of the specifications, scored 1 (don't forget about this), 3 (worth considering), or 9 (essential to success).

Table 2. Scored design specifications

Limit heat index in space to less than 91 deg F [21]	1
Limit noise production to 75 dB while machine is in operation [22]	3
Enclose water while machine is in operation	3
Enclose steam while machine is in operation	9
Enclose moving parts while machine is in operation	3
Vent steam before user can open machine	9
Machine must be thermally insulated to limit surface temperature to 140 deg F [23]	9
Provide overflow drain piping to prevent water overflow	1
Utility lines cannot be horizontal on the floor and exposed [24]	1
Utility lines must be insulated with non-absorbent material [24]	1
Do not use chemicals requiring protective clothing (OSHA standards) in the dishwashing process [25]	1
Electrical units close to sinks have to be watertight and washable [24]	3
If natural gas heating is used, comply with all safety regulations [26]	1
Provide mechanical and electrical emergency stops	3
Provide emergency stop feature if machine is opened during operation or maintenance is being conducted	3
Must have a maximum cleaning capacity of at least 625 disher per hour	9
If machine requires electricity, must be adaptable to 208V, 240V, or 480V power [27]	1
Dimensions must be equal to or less than 3.5 x 2.0 x 2.5m or take up less than 17 cubic meters	3
Retail cost of $40,000 or less	1
Product pays back capital cost with energy savings in <5 years	9
Solid waste must be removed and disposed of prior to entering dishwashing stage	3
Water temps between 150-165 deg F while washing [24]	3
Water temps above 120 deg F while washing (with sanitizing solution) [24]	3
Water temps between 165-180 deg F while sanitizing (no sanitizing solution) [24]	3
Chemical sanitizer must contain chlorine, iodine, or quaternary ammonium [28]	1
Must use less than 0.005 gallons of water to clean each plate	9
Must consume less than 100 kWh/day	9
Ensure materials used can withstand 165 deg F w/ sanitizing solution or 180 deg F w/out sanitizing solution	1
Ensure materials used can withstand operating pressures	1
Withstand 1,000,000 cycles with only minor replacements or repairs (Dishwasher only)	3
Drain line cannot be connected directly to sewer line (Dishwasher only) [24]	1
A visual or audible sanitizing agent flow indicator must be installed in a conspicuous location (Dishwasher only) [24]	1
Detergent and sanitizing solution tank caps must be easily accessible (Dishwasher only)	1
Dishes must cool to 133 deg F within 3 seconds of leaving machine (Dishwasher only) [23]	9

A few of our specifications are worth discussing in greater detail. First, the heat index depends on both the temperature and humidity of the workspace, so reducing the heat transfer to the atmosphere and containing moisture inside the machine are both beneficial [29]. Second, the OSHA-recommended maximum noise level for an 8-hour workday is 85dB; we selected 75dB as our maximum allowable machine noise to account for the fact that there will be other sources of noise in the dishwashing space. The two requirements regarding maximum material temperatures are based on the minimum duration of contact before burns occur; scalding occurs after 5 seconds of contact with a 140°F surface and after 15 seconds of contact with a 133°F surface and we deemed these to be reasonable amounts of time where the machine operators would quickly realize that they were touching something very hot and would be able to avoid being scalded. The throughput requirement is based off of our assumed peak capacity. The flexibility in power source compatibility is to ensure that our product is not commercially limited by institutions not having the appropriate electrical connection. The size and commercial cost limitations are based off of competing dishwashers; we do not want to provide a product that will not fit inside existing dishwashing rooms or that will be prohibitively expensive. The waste removal requirement is to allow for proper sorting of compostable and recyclable waste materials, and the 1,000,000-cycle lifespan is based off of the assumed throughput of approximately 200 dish racks per day over an expected 20-year service life. The water and power usage limits are based on our goal to reduce utility consumption by 50% over our leading competitor, as seen in Table 1. Finally, the maximum payback period of 5 years was identified as the threshold for commercial success based on our feedback from one of the dining facility managers on campus; potential customers would be alienated by the prospect of tying up additional capital in a product that would not return to them in a reasonable amount of time.

As identified in Table 2, the specifications that are most critical to the success of our project are:

1. Ensuring the (additional) capital cost of the product is paid back through energy savings in less than 5 years.
2. Ensuring water consumption is reduced to 0.005 gallons per plate.
3. Ensuring energy consumption does not exceed 100 kWh per day.
4. Ensuring that steam is enclosed during operation and properly vented before the user can open the machine.
5. Ensuring the exterior surface of the machine does not exceed 140°F.
6. Ensuring that dishes are cooled to below 133°F within 5 seconds of leaving the machine.
7. Ensuring that the maximum cleaning capacity of the system is at least 625 dishes per hour.

The first requirement is the most essential to the viability of this product as it is a go/no-go criterion for the design's commercial success. The next two requirements deal with reducing resource consumption, a priority for Mother Nature and the persona. Requirements four through six cater primarily to the dishwashing staff, as they are designed to reduce the risk of burns to the machine operator. However, they also have a positive impact on the priorities of the persona and "Mother Nature"; reducing the heat given off by the machine to the space corresponds to a reduction in required ventilation, leading to reduced power consumption. The fifth requirement is to ensure that performance is not degraded by the introduction of energy-saving features, which caters to the cafeteria managers who are concerned with productivity and slow-downs and the users who would then experience the negative effects of their manager's displeasure.

Sustainability Evaluation Process

We performed an initial sustainability evaluation based on the first four steps described in *Environmental Improvement through Product Development*.

Step 1: Describe the use context

This product should be used to process used trays, plates, utensils, cups, etc. (henceforth referred to as "tableware") in a large-scale cafeteria setting. The main functions to be performed will be cleaning food residue off of the tableware and sanitizing said tableware to meet regulations. This product will be designed to be used by cafeteria staff, specifically those who currently wash the used tableware (see Stakeholder B in Step 4), but will be marketed to the institutions that own and operate the cafeterias (Stakeholder E). The product is expected to clean approximately 5000 dishes and cups, plus utensils. The cafeterias we are designing this product for are located in the United States, with possible implementation in other "developed" countries pending regulatory exploration and technical conversion (to account for different power grids, etc.). The dining facilities are primarily part of colleges and universities, where the dishwashers are paid low wages, only work in the cafeteria for a year or two, and are not motivated to perform their job exceptionally well. The dishwashing staff will have to interact with this product for several hours every day, and designing something that is user-friendly and safe is important to the success of this product. However, even more critical to its success is its marketability to the people in charge of procuring kitchen equipment. While they typically do not frequently have to buy a new commercial dishwasher, they are the only people who would potentially buy this product. The leadership of the university is concerned with profits, but is more likely to sacrifice money for a "green" image than another institution in industry.

Step 2: Create an overview of the environmental impacts
Our brainstorming yielded the following list of potential environmental impacts:

1. Chemicals: detergent & sanitizing solution in waste water
2. Energy: power required to heat steam
3. Materials: food is disposed of with waste water
   Energy: embodied energy in food
   Other: food is not being consumed
4. Materials: non-biodegradable/recyclable waste in waste water/landfill
5. Materials: water required to clean tableware
   Other: potable water is not being consumed
6. Energy: power required to operate all parts of product
7. Materials: non-renewable resources used in production of product
   Energy: power required to manufacture product
   Chemicals: toxic chemicals used during production of product
8. Materials: non-renewable resources used in production of detergent & sanitizing solution
   Energy: power required to manufacture detergent & sanitizing solution
   Chemicals: toxic chemicals used during production of detergent & sanitizing solution
9. Materials: non-recyclable materials entering landfill
   Energy: power required to recycle metal construction
   Chemicals: toxic chemicals used to reprocess recycled materials
10. Materials: non-renewable resources used in production of replacement parts
    Energy: power required to manufacture replacement parts
    Chemicals: toxic chemicals used during production of replacement parts
11. Energy: power required to transport product, detergent/sanitizing solution, and replacement parts from manufacturing plant to warehouse to customer
12. Chemicals: vulcanization process to produce rubber parts
13. Energy: power required to operate ventilation fans and air conditioning units to remove heat and steam from dishwashing space
    Other: uncomfortable work environment for employees
14. Materials: warm waste water enters the environment
    Energy: heat is lost to warm waste water disposal
15. Materials: non-renewable resources are used to manufacture the product

Step 3: Create your environmental profile and find root causes
We sorted the environmental impacts listed above into the five product life stages (raw materials, manufacture, transport, use, and disposal) and four general categories (materials, energy, and other). The resulting "MECO-matrix" is shown in Table 3 below.

Table 3. MECO-matrix for our tableware-cleaning product

	Materials	Manufacture	Transport	Use	Disposal
Materials	15	7,8		3,4,5,10,14	9
Energy		7,8	11	2,3,6,10,13,14	9
Chemicals		7,8,12		1,10	9
Other				3,5,13	

It is apparent that the areas with the largest number of brainstormed environmental impact are the material and chemical concerns during the manufacturing process as well as the material and energy concerns during the product's use. We agreed that our top focus areas are:

1. Materials during the use phase
2. Energy during the use phase

The major material involved in the use phase that we hope to address is water consumption. Water is used to wash and sanitize dishes because it is common practice and government regulations call for certain temperatures to be used to achieve a sanitizing effect so that the dishes can be reused. They are reused because there is not a disposable alternative that is cost-effective and/or more environmentally-friendly than reusable tableware. Tableware is necessary because cafeterias serve food that require the use of tableware to serve, transport, and consume it. Cafeterias serve this food because it is the traditional and practical way to feed thousands of customers. Institutional cafeterias exist because some customers do not have the means to prepare their own food, they find it more convenient than bringing their own food from home, or it is less expensive than eating elsewhere. We believe that we are not going to change the way cafeterias operate on a fundamental level, so the most basic changes we can make are to the need to clean reusable tableware or the need to use water to do so. The major energy involved in the use phase is the combusted fuel and/or electricity used to heat the water used in the dishwasher. Energy is needed to heat water to clean tableware because government regulations specify a minimum water temperature to sanitize dishes. Government regulations specify a certain minimum temperature because the most commonplace way to sanitize dishes is with heat. There is potential room for change by developing a sanitizing solution that works sufficiently well without heat. Additionally, we could attempt to find a better way to retain heat within the system or heat the water in the first place. Additionally, we created a root cause brainstorming diagram for both the act of washing dishes and the function of the dishwasher in particular, shown in Figures 1 and 2.

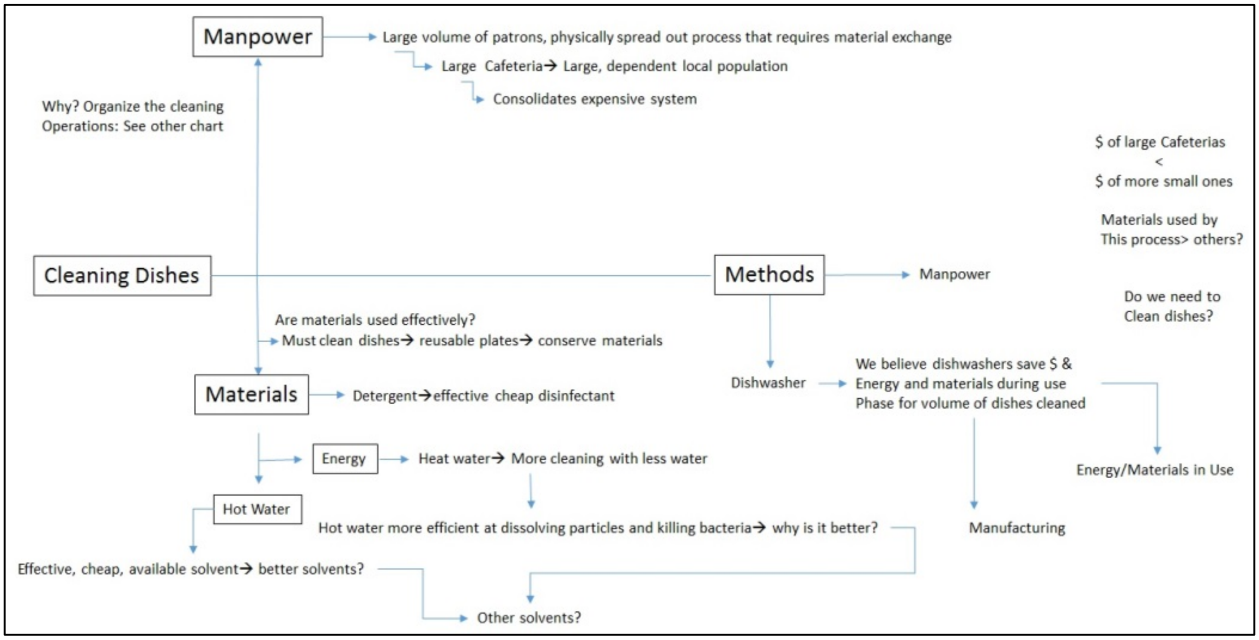

Figure 1. Root cause diagram for washing dishes

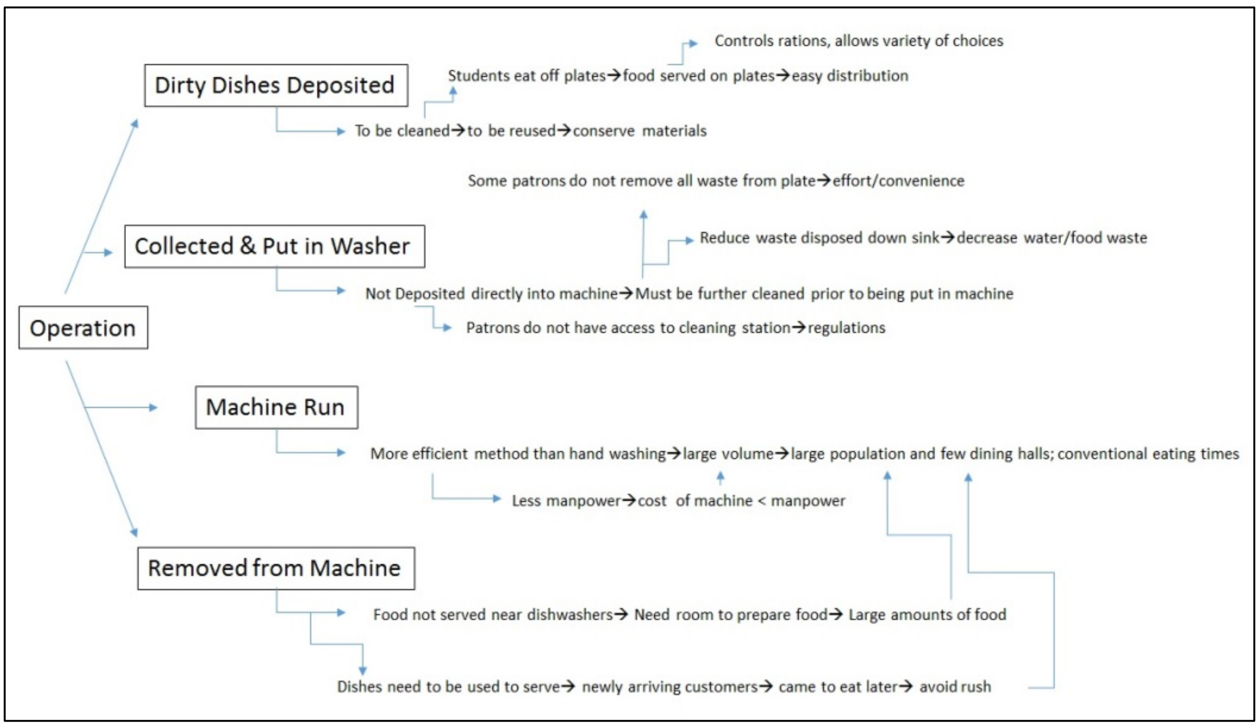

Figure 2. Root cause diagram for dishwashers

Step 4: Sketch the stakeholder network

We identified the following stakeholders for our product:

A. People eating in the cafeteria
B. Cafeteria staff responsible for cleaning the tableware
C. Cafeteria staff responsible for serving food
D. Cafeteria managers/coordinators
E. Institutions - the cafeteria owners/operators
F. Dishwasher manufacturers
G. Detergent/sanitizing solution manufacturers
H. Dishwasher maintenance/repair staff

The stakeholder network is shown in Figure 3 below.

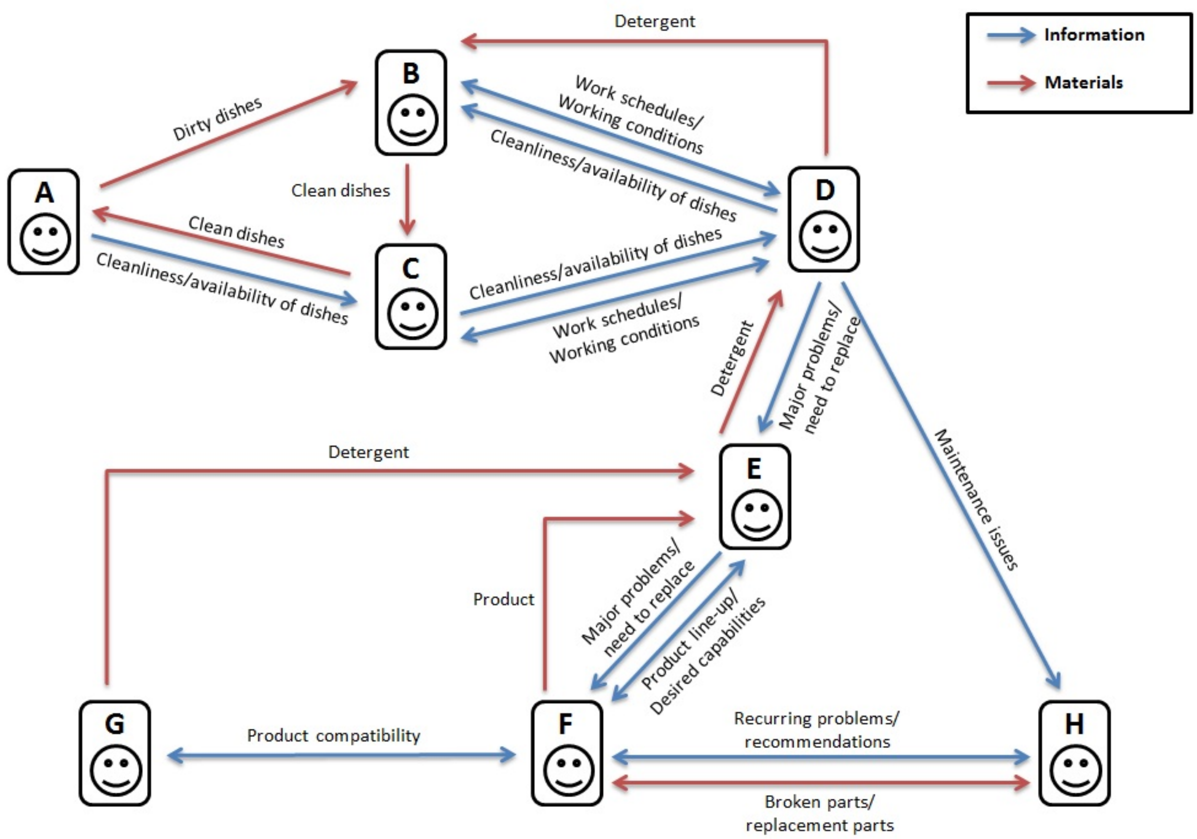

Figure 3. Stakeholder network

We identified the most important information and material exchanges, which are listed below:

1. The exchange of tableware between the diners, the dish cleaners, and the food servers.
2. The exchange of information between the diners, the food servers, the cafeteria managers, and the dish cleaners regarding the cleanliness and availability of dishes.
3. The exchange of information between the cafeteria managers and the owners and repair staff regarding maintenance issues.
4. The exchange of information between the cafeteria owners and the dishwasher manufacturers regarding desired capabilities.
5. The exchange of information between the repair technicians and dishwasher manufacturers regarding recurring problems and recommended fixes.

Environmental Impacts of the Baseline

We selected our baseline competitor to be the Meiko K-400 LPW K-Tronic Multi-Tank Rack Conveyor Dishwasher. It incorporates state-of-the-art technology to improve its performance and reduce its water and electricity usage, and had the lowest water use per plate of any commercially available conveyor-type dishwasher that we could find. Life Cycle Thinking (LCT) was applied to establish the sources of environmental impacts of the K-400, and SimaPro was used to identify quantitative values for these impacts. As shown in Table 3, the most important areas of the life cycle of our product are the materials and energy consumed during the "use" phase. Because of this, we limited our analysis to this portion of the baseline's life. The major upstream and downstream environmental impacts of this product were found to be the quantity and type of materials used in the product's manufacture and the way in which the product is disposed of at the end of its service life. The best way to address these concerns is to employ recycled metals in the production of the machine and to ensure that many of its components can be recycled at the end of its useful life.

We decided to apply the SimaPro software to quantify the environmental impacts of our baseline model. Before doing the simulations, we agreed to make proper assumptions for the full dishwasher. First, we assumed the whole commercial dishwasher weighs 1000kg, extrapolated from the 600kg weight of the K-200 model and is transported an average of 200 miles via US rail freight [30]. In terms of materials, we assumed 85% of the weight is steel used in the body construction of dishwasher, 10% is copper used to produce heat exchangers and other electrical components, and 5% is injection molded- polypropylene used to form the conveyor belt and other plastic parts. The LCI and Eco-Indicator 99 millipoint assessment network for the Meiko dishwasher and its detailed energy flow can be found in Appendix VII.

The results of our impact analysis are shown in Figures 4 and 5 below. The majority of impacts are categorized as fossil fuels, respiratory inorganics, and climate change. In order to further analyze the impact of energy use on the environment, the Eco-Indicator 99 method for life cycle analysis was simulated. 93% of the environmental impacts are due to electricity usage (shown in blue in Figure 5) while 6.8% are due to deionized water consumption (shown in green in Figure 5). The fact that electricity consumption dominates the environmental impact during the use phase came as a surprise because we were assuming that water consumption had a substantial enough impact to focus on. According to the Eco-Indicator network, we also find that thermal power generation plays an important role in the electricity generation process; since large amounts of bituminous coal are used for power generation in the U.S., it has a large impact on the environment.

Figure 4. Meiko K-400 impact assessment: single score results

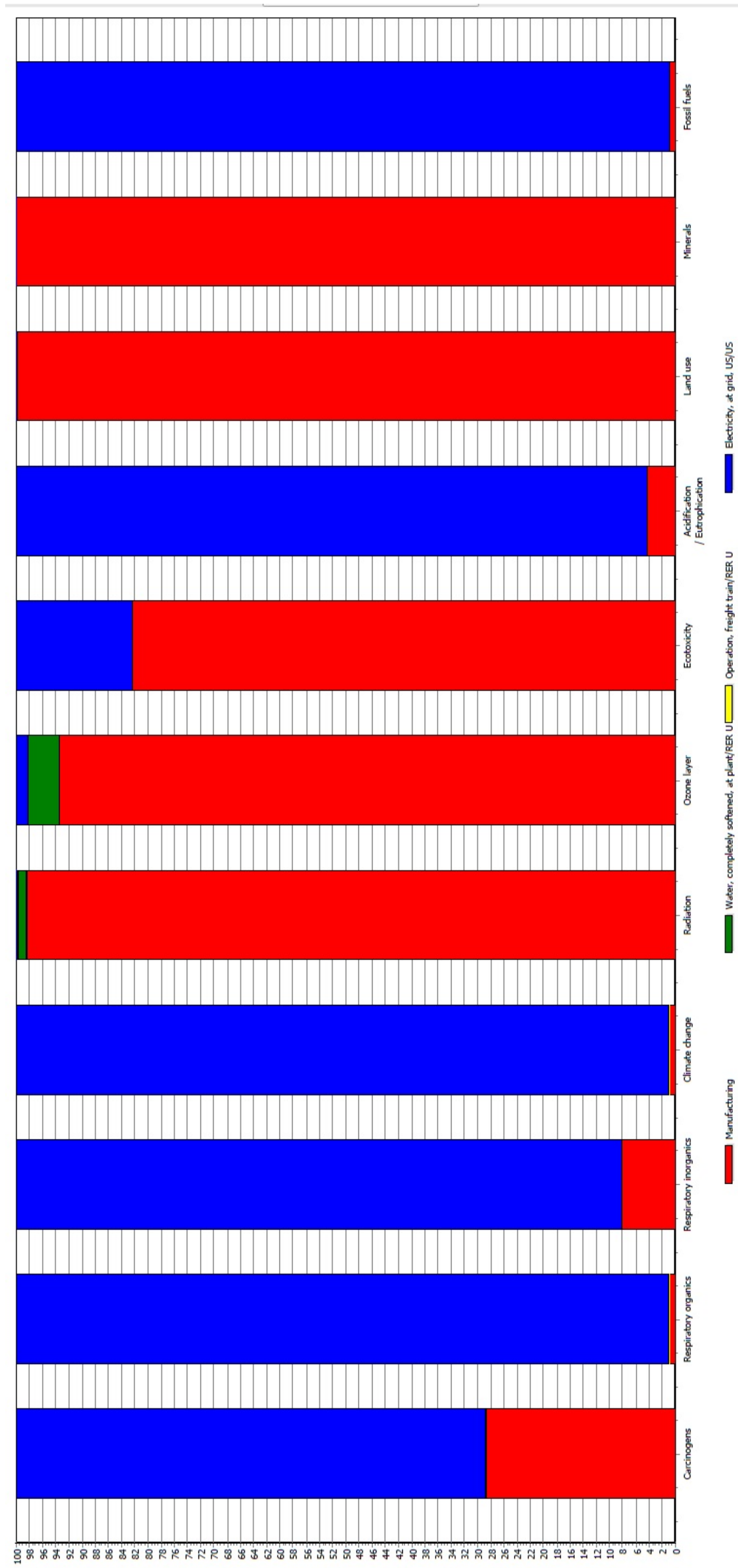

Figure 5. Meiko K-400 impact assessment: damage assessment results

Concept Generation for Improving Baseline Impacts

We performed an initial brainstorm to generate ideas for how to improve the functionality of the baseline; a comprehensive list can be found in Appendix VIII. A go/no-go test was applied to each idea and certain concepts were removed from future consideration (indicated in the Appendix by the use of red text) due to technological impossibilities or exceptionally unreasonable violations of size or cost constraints. The remaining ideas were translated into design concepts, described in greater detail in Appendix IX. The three general categories of concepts were accessories for existing dishwashers, new dishwashers, and new systems other than dishwashers. Two of the accessories we developed are a wash water recovery unit and better dish rack. We investigated ways of reusing water within the dishwasher to eliminate the need to continuously pump water into the machine and developed a design to pass dirty wash water through a filter and purification system that would then return the water to the hot water tank. Returning this warm water significantly reduces the energy needed to provide water at an acceptably hot temperature during the wash cycle and cuts down on the total amount of water consumed by the dishwasher. This unit would be retrofitted to existing dishwashers; the drain piping would be rerouted into the unit, whose discharge would be directed into the hot water tank. The design requiring the lowest capital cost that we developed was an improved version of the standard dish rack used in commercial dishwashers. Current dish racks result in dishes blocking each other from direct spray from the water jets. Redesigning the rack so that the dish orientation permits the maximum surface area to be exposed to the jets would result in shorter wash cycles and corresponding reductions in water and energy consumption.

One of the new dishwasher concepts we generated incorporates the use of thermoelectric coolers during the drying cycle, inspired by a conversation we had with Professor Steve Skerlos. While there is the potential for developing this as another accessory, we felt that with the wide array of commercial dishwashers on the market, it would be difficult to develop a product that would adapt to a large number of them. This dishwasher has a segmented design, where the washing/sanitizing compartment is separated from the drying compartment. As the dishes pass into the drying area, the coolers activate to pull condensation onto the walls, reducing the amount of water on the tableware. This reduces the amount of energy and time needed to effectively dry the dishes. One of the non-dishwasher solutions we came up with is the use of biodegradable plates. Biodegradable plates eliminate the need for dishwashing and thus rid us of all the impacts related to the dishwasher; however, a ceramic reusable plate undergoing at least 50 washes will have less environmental impact than an equivalent number of disposable biodegradable plates [31]. Ceramic dishes are expected to last much longer than this, so the environmental impact of compostable plates is higher than washing reusable plates. The environmental impacts can be significantly decreased by composting cutlery rather than sending it to a landfill or incinerating it, but extra effort would have to be expended by the cafeteria staff, which seems improbable when considering our persona of a cafeteria dishwashing staff member [32]. Another type of "biodegradable plate" is banana leaves which have very little environmental impact because they grow naturally [33]. The problem here is that these are not good enough to carry food, and would require cafeterias to bring food to the dining tables rather than using serving lines, requiring several changes to cafeteria operations.

Concept Selection

Each concept was scored on a scale from 1-5 against the critical specifications identified in Table 3. A score of 1 represented that the concept entirely failed to meet the specification, a score of 3 indicated that the concept barely met the goal, and a score of 5 was awarded to those concepts that surpassed the requirement by a large margin. In addition to generating our initial 18 ideas, we created three new designs by combined the functionality of some of the more compatible individuals, typically involving one dishwasher concept and two accessories. The thought was that if a new dishwasher was going to be designed and manufactured, you might as well pack it full of cost-effective sustainable ideas.

In order to achieve a final score that we could use to compare designs, we assigned different weights to the various specifications. We used the same 1-3-9 system that we used during our initial identification of critical specifications, but with a slight modification. The payback time was most important, given that a design that is not commercially viable is a waste of time, so it was given a weight of 9. The sustainability specifications were given a weight of 6: not as important as the commercial aspect, but more important that routine criteria such as safety and performance, which are more easily met through small design modifications. Safety received a weight of 3 and capacity received a weight of 1 for this reason. This concept scoring is shown in Appendix IX. Table 4 shows the evaluation of prospective designs receiving a total score of 90 or above.

Table 4. Selected concept scores

Design Concept ==>	UV Sanitizing System	Wash Water Recovery and Reuse	Better Dish Rack	Sponges for Dish Drying	Biodegradable Plates	Inclined Conveyor Dishwasher with Better Dish Rack and Waste Heat Recovery System	Thermoelectric Cooling System for Dish Drying	UV Sanitizing, Wash Water Recovering, and Thermoelectric Cooling Dishwasher
The (additional) capital cost of the product is paid back through energy savings in less than 5 years	4	3	5	3	4	5	5	4
Water consumption is reduced to 0.005 gallons per plate.	2	4	2	1	1	2	1	4
Energy consumption does not exceed 100 kWh per day.	3	3	2	3	1	2	3	5
Steam is enclosed during operation and properly vented before the user can open the machine.	3	3	3	5	5	5	4	4
The exterior surface of the machine does not exceed 140 deg F.	3	3	3	5	5	3	4	4
Dishes are cooled to below 133 deg F within 5 seconds of leaving the machine.	1	1	1	4	5	1	3	3
The maximum cleaning capacity of the system is at least 625 dishes per hour.	3	3	3	2	5	4	4	4
Total score ===>	90	93	93	95	98	100	106	127

It is important to note that each of these designs is expected to be commercially viable; that is, each one will pay back its capital cost (or the additional capital cost in the case of the entire dishwasher designs) with energy savings within 5 years. The steam containment and surface temperature requirements were met or exceeded by all designs, and the capacity was sufficient in all cases except the sponge-drying design. The real difference was seen in the dish-cooling and resource usage requirements. First and foremost, the use of biodegradable plates performed admirably in every category except for the sustainable categories. While the fact that they are biodegradable is a huge improvement over typical paper or Styrofoam, the amount of water and energy that goes into producing them is significant enough that while it might make commercial sense for the institution, it is not eco-friendly, much less eco-efficient. The sponge and thermoelectric drying designs were not designed to reduce water usage, but instead offered significant reductions in energy consumption. The use of UV sanitizing and better dish rack designs promise to reduce water consumption, but not by half. The wash water recovery system is the only design that is really effective at reducing water usage, but its higher capital cost reduces its economic incentive.

The first combined design takes advantage of an inclined (rather, declined) conveyor belt to allow gravity to assist the dish racks move through the machine as well as an improved rack design to reduce the resource consumption and time spent washing each rack. Furthermore, the tendency for steam to rise toward the elevated end of the machine is utilized to more effectively collect and recapture the heat given off during the wash cycle, allowing the wash water to be pre-heated before entering the heating unit. The majority of the cost of this design above and beyond the competition would be the heat recovery unit, but the added efficiency and heating energy reduction should pay for the difference in less than 5 years. The highest-scoring concept we generated combined major water- and energy-saving features. The use of UV sanitization eliminates the need to use very hot water and/or sanitizing solution, reducing water and energy consumption. The thermoelectric coolers significantly reduce the amount of energy needed to dry the plates. And the wash water recovery system is able to reuse much of the water that is used during the wash phase. With this design, there is the potential need to work with governmental regulating bodies to ensure that a UV sanitizing system meets applicable health codes or rewriting the regulations to recognize the validity of UV sanitization within the commercial dishwasher market and develop reasonable standards. The biggest question about this concept is the feasibility of designing an acceptable water filtration and purification system and making it small and cheap enough to be used in a commercial dishwasher.

Alpha Design

As mentioned above, a new dishwasher design combining UV sanitization, thermoelectric cooling during drying, and wash water recovery scored the highest during our concept evaluation. For this reason as well as the high chance of significantly reducing water and energy usage, this is our alpha design. The highest energy consumption occurs during the water-heating and dish-drying processes. A major source of water saving in the new design is through wash water recovery. This involves a unit hooking up to the drain line of the dishwasher which then filters the dirty wash water using reverse osmosis. The recovered water is then supplied to the hot water tank. The advantage of using this method is that it significantly reduces water usage since the water being drained has minimal solid particle impurities and much of the water can be recovered. Also since the recycled water would be at a higher temperature than the incoming water from the utility line, this recycles heat as well and reduces energy consumption. The conveyor belt is permeable, allowing water to drain into the drain-back pipes, which transport it to the water recycling unit. The disadvantage of this system is that an additional tank and pumping arrangement may be required if the diffusion rate in the reverse osmosis unit is low. However, this can be offset by gains in energy reduction in other areas. If filtering is to be accomplished mechanically, then additional maintenance would be required. Because the sanitizing water must be heated above 120°F when using a chemical sanitizer, or above 165°F without the use of a sanitizer, employing UV light to sanitize the dishes reduces both water and, more importantly, energy consumption. UV lamps have been installed by LG in their home use dishwashers, and the company claims that this technology removes 99% of germs [34]. By using thermoelectric coolers along the walls of the dishwasher, we can reduce the amount of moisture that condenses on the plates, lowering the heating requirement during the drying phase and hence the energy consumption.

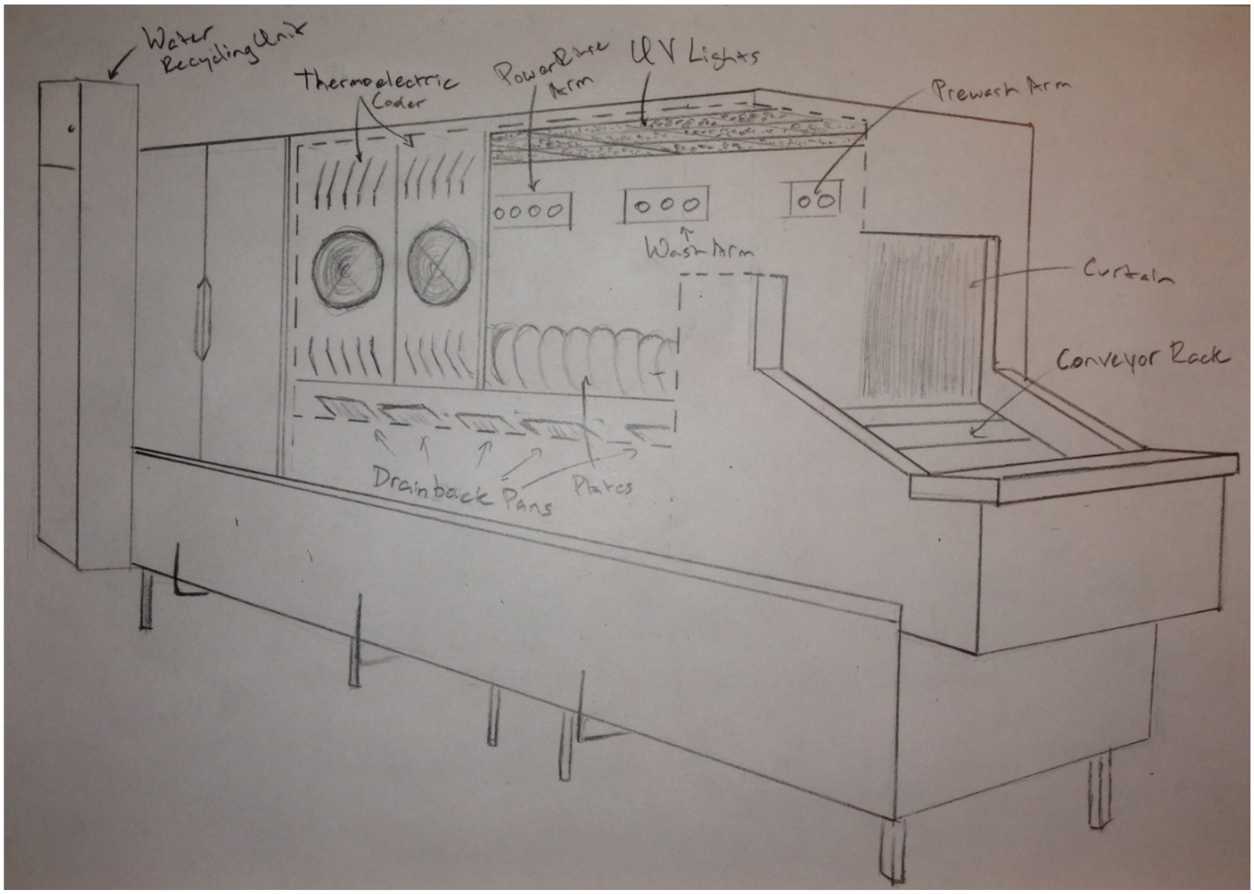

Figure 6. Sketch of alpha design

Benefits of Alpha Design

The streamlined LCA of the baseline model revealed that electricity consumption caused 93% of the environmental impacts, while water accounted for 6.8% in terms of the Eco-indicator 99 millipoint metric. The alpha design was selected to reduce the environmental impacts of the use phase. The major components of the alpha design - UV sanitizing, thermoelectric cooler and wash water recovery system; all work together to save water and reduce electricity consumption over the baseline. Ultraviolet germicidal irradiation kills microorganisms by exposure to UV light with a wavelength of approximately 250 nm [35]. The baseline product uses a sanitizing solution for the purpose, which involves constant power consumption to pump the sanitizing solution and water and maintain the water at an acceptably high temperature, on the order of 10kW. Our alpha design requires UV bulbs maintained at constant intensity during the operational period. The power consumption of the UV lamps is much lower, being on the order of 30-40W per bulb; the overall power consumption depends upon the surface area to be sanitized, and we have assumed an average exposure time of 5 seconds [36]. This results in reducing the electricity and eliminating the water consumption for sanitizing purposes. In the long run as it is evident from the preliminary LCA that electricity savings in the use phase would have a much higher positive impact on sustainability than the increase in manufacturing processes and safety measures to be employed in the manufacturing phase for using UV light. We expect that the total utilities savings will amount to $2,125 per year for electricity and $255 per year for water. The calculations to reach these numbers are shown in Appendix X.

The next major feature is the thermo electric coolers used during the drying process. The baseline product uses a heated dry cycle which relies purely on evaporation to dry the plates; this requires constant operation of the heating element and blower, which have a combined power draw of 4kW. The thermoelectric coolers in our design work by cooling the walls of the drying chamber, resulting in condensation of moisture on the walls rather than the plates. The power required for thermoelectric coolers to operate is based on heat removal rate and is approximately 300-400W [37]. While the blower and heater must still be used, they operate for a significantly shorter time, lowering the overall power consumption. We believe the environmental impact of the manufacturing phase is insignificant, when compared to the impacts due to the electricity savings over the life of the equipment. The third feature is the wash water recovery system. In our design, water is primarily consumed during the wash cycle. With the use of a reverse osmosis purification and recovery system, we aim to significantly reduce water wastage. The baseline product drains the wash water to the sewer, resulting in the disposal of all of the detergent-filled water. The wash water mostly contains detergents as an impurity and the solid particle size is also very low, making it relatively easy to purify the water through reverse osmosis. Due to the resulting water and energy savings, the environmental impacts of this product in the use phase would be reduced dramatically.

The initial environmental impacts of this product can be reduced by employing recycled metals during the fabrication process. The end of life scenario for this product is similar to the baseline. The stainless steel body can be completely recycled along with many of the components, including the heat exchangers. The plastic parts can be incinerated to regain some of the stored energy. The thermoelectric coolers can be partially recycled. The use of UV lamps would create an additional impact because they would likely need to be replaced multiple times during the life of the dishwasher.

Feedback on Alpha Design

We conducted interviews with several members of the dishwashing staff as well as the manager of one of the dining facilities at the University of Michigan. Details of our observations can be found in Appendix IV. It should be said that much more feedback is needed to obtain truly insightful information regarding the validity of our design. Our time and resource limitations permitted us to receive input from less than a half dozen dishwashing staff members and one cafeteria manager. While we hope that their opinions are typical of our potential customers, the only way to know for certain would be to survey more managers and administrators at a large number of colleges and universities. Also, getting input from members of industry could also be extremely beneficial, but we did not contact anyone who could help us.

The feedback we received from the dishwashing staff was fairly encouraging. We asked our subjects to rank several dishwasher features, including the three that we included in our alpha design, to determine what impressions they had; they ranked water recovery, waste heat recovery, and thermoelectric coolers most highly, with UV sanitation next, followed by compressed air and a declined conveyor belt as least desirable. Of course, our subjects have not performed any sort of analysis on the actual savings potential or environmental impact of these features. But, the fact that our design features were in the top and middle of the list was encouraging. They expressed valid concerns that the water recycling unit needed to meet appropriate sanitation standards and that the UV lighting used for sanitization would have to reach a certain minimum intensity. When asked for their opinion on other design features that they would like to see integrated into commercial dishwashers, they generally repeated concepts that we had developed in our brainstorming phase and ruled out because they performed poorly against our design criteria.

The information we gathered from the cafeteria manager generally reinforced our previous beliefs regarding what our potential customers find important when selecting a product. Certification as Energy Star compliant and validation by the National Sanitation Foundation (NSF) are extremely important. Additionally, we learned that a price difference of $10,000 to $15,000 over our competition would not be too concerning as long as the utility savings paid back the difference within four or five years. This is because of the large cost of kitchen equipment in general and the amount of money that would be tied up in equipment for several years is relatively insignificant. One interesting point that was brought up is the cost of filing paperwork and ordering replacement parts when a machine breaks or malfunctions; the manager stated that it can cost up to $2,000 in addition to the price of the parts to deal with breakdowns. The manager also stated that dishwasher add-ons are viewed as less efficient than their built-in counterparts, making a strong case for designing an entire dishwasher rather than a retrofitting attachment. They also mentioned that their primary safety concern would be the proper enclosure of the UV lights.

Final Design

The most controversial part of our design is the water wash recovery system. Because of the relatively low environmental impact of the industrial water purification process and the low cost of water utilities, it is difficult to identify a system that improves both the environmental and economic costs of simply letting the wash water go down the drain. We identified two options for purifying the recovered wash water: reverse osmosis, as described in our alpha design, or mechanical filtration. The reverse osmosis system is only able to recover around 20% of the water that runs through it. The filtration system can return around 90% of the water to the dishwasher. We conducted an environmental impact assessment of these two systems, which is summarized in Appendix XI [38,39]. We determined that the negative environmental impact of both the production of the water filters and the additional electricity required by the pump motor outweigh the positive environmental impact of reusing the wash water.

Our final design includes the same thermoelectric coolers and UV light sterilization system found in our alpha design, while completely eliminating the water recovery system. The coolers and lights are environmentally friendly when considering the amount of electricity they will save and will not substantially increase the cost of the dishwasher. The water filtration systems we examined were not actually environmentally beneficial, and the low cost of water utilities makes it highly unlikely that such a system would make economic sense. This final design will reduce electricity consumption by 19,100 kWh per year when compared to our baseline competitor, eliminating approximately 10 tons of annual CO_2 emissions at a savings of $2,300 [40]. Our final design is shown below in Figure 7.

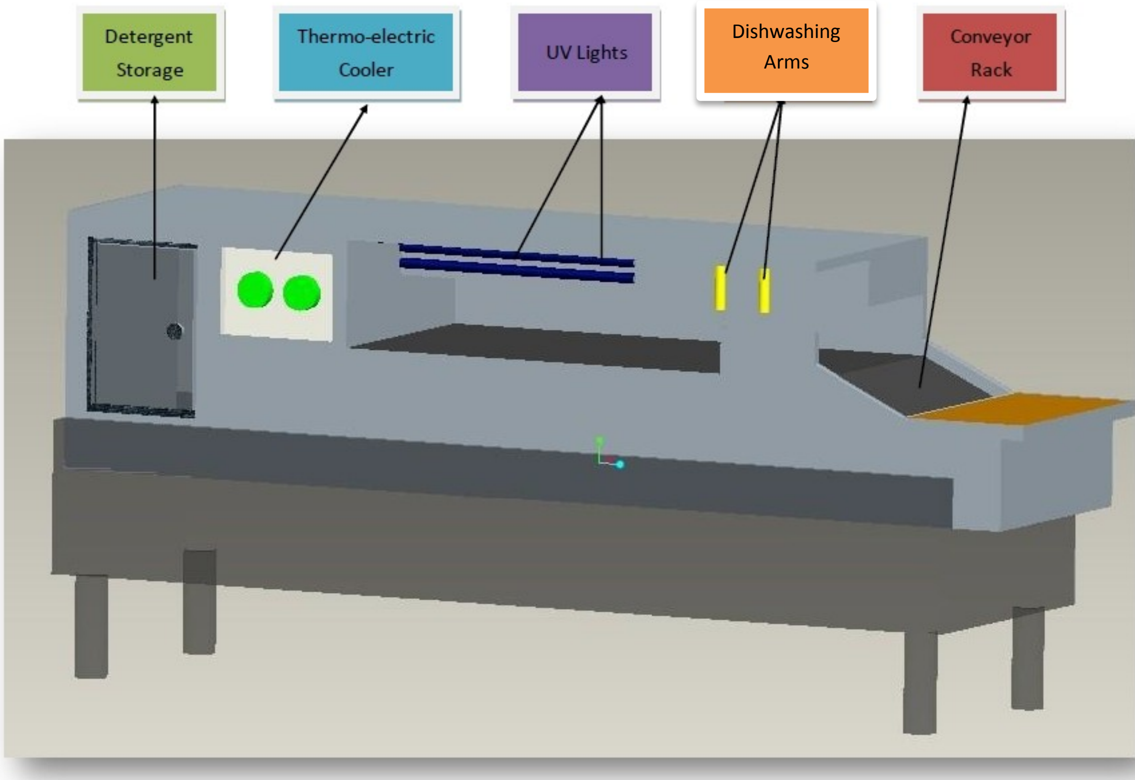

Figure 7. Schematic of final design

BUSINESS PLAN

Company Description

Our company will design and sell conveyor-type commercial dishwashers. We will contract out all of the fabrication to a manufacturer in the United States. We will provide a new brand of dishwasher that uses a fraction of the electricity of the best dishwashers currently on the market. We will be able to deliver our first product in three years, at a retail price similar to higher-end dishwashers on the market today. Our target customers are college and university administrators who are responsible for procuring cafeteria and kitchen equipment.

Market Analysis

In 2008, there were over 310,000 conveyor-type dishwashers installed in the U.S., with annual sales totaling 19,100 units [10]. As of 2009, there were 21 companies manufacturing commercial dishwashers [10]. Of those, the five largest were CMA Dishmachines, Ecolab, Hobart Corporation, Jackson, and Moyer Diebel Ltd [10]. In Navigant Consulting's report to the EPA, they assumed 1.9% annual growth in the commercial dishwasher market [10]. Obviously the state of the economy will affect the number of sales, but by marketing to colleges and universities, we can assume a fairly steady customer base. Our primary advantage over our competition is the fact that we are not constrained by existing infrastructure; we do not feel the need to use existing equipment or processes because none exist. However, this is one of our biggest disadvantages as well; we need to contract out all of our fabrication, resulting in higher expenses and reduced cost.

The average value of a high-end commercial dishwasher is around $36,000, and we plan to market ours at $40,000. We expect that our customers will be willing to pay the difference because of the use of more advanced technologies and the potential for savings through reduced utility costs. The input we have received from potential customers is that they are willing to purchase our product as long as the additional retail cost is offset by energy savings within 5 years. Because the industry is relatively small and specialized, it is more difficult for a new company to break in and gain market share due to the tendency of customers to select a product from a company that is well-respected and has brand name recognition. We are concerned about getting enough people to buy into the company to get it off the ground. Additionally, in the three years it takes for us to get everything up and running, it is possible that another company will come up with a similar, or better, product.

Product Description

Newer commercial dishwashers have shown consistent improvements in using less water and electricity than their predecessors. However, the fact remains that the water-heating and dish-drying processes are the largest sources of energy consumption in the dishwasher. Our product reduces energy consumption compared to the competition through two methods: using ultraviolet light to sterilize dishes after washing and employing thermoelectric coolers during the drying phase to reduce the amount of hot air needed to dry the dishes. Because sanitizing water must be heated above 120°F when using a chemical sanitizer, or above 165°F without the use of a sanitizer, employing UV light to sanitize the dishes reduces water and, more importantly, energy consumption [24]. By using thermoelectric coolers along the walls of the dishwasher, we can reduce the amount of moisture that condenses on the plates, lowering the heating requirement during the drying phase and hence the energy consumption. Not only do these technologies lower the amount of energy required to operate the dishwasher on a day-to-day basis, they are environmentally friendly as well. Our product will reduce electricity consumption by 19,100 kWh per year when compared to our most efficient competitor, eliminating approximately 10 tons of annual CO_2

emissions at a savings of $2,300 [40]. While our product is still in the concept phase, we can assure you that the dishwasher will clean just as many dishes to the same standard as any other dishwasher on the market, all at a cost savings to the customer. One of the dining facility managers at the University of Michigan has expressed interest in installing a new experimental dishwasher for the purposes of evaluating its performance, and has stated that they would be willing to spend anywhere from $10,000 to $15,000 more on a more efficient dishwasher that promised to recoup the price difference through lower utility bills within 5 years.

Marketing and Sales Strategy

Our first customers will be a half dozen hand-selected universities around the country whom we establish working relationships with during the development and prototyping of our product. We will offer our dishwasher to these institutions at a reduced price so that they can put the machines through the paces, so to speak. We will also conduct side-by-side tests of our machine with the best of our competitors to prove that our product performs just as well while using less energy. Then we will take these results and the positive reviews from our "test universities" to start building a reputation of excellence that we will use to expand our customer base once we go into full production and begin taking orders for our first year of sales.

We aim to launch our product by February 2015 in time for the North American Association of Food Equipment Manufacturers show in California, which is attended by a wide range of potential customers, including the universities whom we hope will be some of our first sales [41]. We also plan to advertise in the National Association of College and University Food Services' website and biannual magazine Campus Dining Today, which is read by the leading cafeterias in universities across the country [42]. We also hope to advertise through Google where our products would show up as paid advertisements whenever similar queries are posted to raise awareness about our product. We would also like to start involving independent sales representatives who deal with universities on a commission basis to market our product. For the one-on-one communication we would have to rely on the interactions between our sales representatives and the university procurement officers. This will give us an access to the very niche market that we are targeting. We will also work with existing distributors of kitchen equipment and set up our own website to facilitate sales.

Initially we would focus exclusively on selling high-capacity conveyor-type dishwashers to universities across the United States. If our business is successful, we will explore options for selling to non-educational institutions and expanding our product line to accommodate various sizes of kitchens. The potential to apply these same technologies to under-the-counter and door-type commercial dishwashers, with industry-wide annual sales of 20,000 units is very enticing [5]. A strategy that we could employ in the future is to lease out products rather than sell them. More than half of commercial dishwashers are rented rather than owned; leasing provides a higher profit margin for the retailer than selling, which would be advantageous for us [43]. This strategy necessitates having an efficient and extensive maintenance plan in place, requiring that we either employ additional staff or contract local service teams, creating additional costs. Most importantly, leasing would severely affect our cash flow as we would have to pay our contracted manufacturer straight away and absorb the temporary loss while the customer paid us a little of the price each month. Hence we can either wait till we are able to raise enough capital to engage in such a venture or apply for a bank loan. Taking out a loan would further reduce our profits because of the interest charged. However, because so many potential customers lease their machines instead of buying them, we would like to eventually expand our sales to include the option to lease.

Necessary Start-Up Funds

To estimate the cost of manufacturing our new dishwasher, we take our retail value of $40,000 and divide by 10 to estimate the cost to our contracted manufacturer of producing one unit. These costs include manufacture, testing, and transportation. We will assume that they will charge us 3 times cost for our initial, smaller, orders. Our manufacturing cost will thus be $12000 per unit [44]. Because we will contract out all of our production, we do not need to worry about covering the overhead cost of setting up a manufacturing plant. However, we will need to pay for essentials such as salaries, office space, professional design software licenses, domain name rights, miscellaneous office equipment, sales reps, advertising, and warehouse space once we start production. We estimate that this will cost us $1,000,000 per year. We will also have to pay to have our product tested for quality and safety control by the National Sanitation Foundation (NSF) or Underwriters Laboratories (UL) [45,46]. The EPA has authorized both the NSF and UL as third-party organizations capable of certifying commercial dishwashers as Energy Star-compliant [47]. We were unable to obtain quotes regarding the cost of these tests, but we expect that if we were to develop prototypes and then pursue certification, we would be able to determine which organization would provide the service at a lower cost. Because both companies are well-respected in the commercial kitchen appliance industry, we can pursue the less expensive option with no fear of negative repercussions amongst our future customers. However, for the purposes of this project, we will estimate that the tests will cost $500,000. With these estimates in mind and expected first-year sales of 100 units, we will need $3.5 million to operate our company before the first product is sold, with an additional $1.2 million to cover the manufacturing cost of dishwashers for the first year.

The current market supports around 20,000 dishwasher sales annually with a growth rate of 2%. We hope to gain a foothold in the industry our first year by selling 100 dishwashers, cornering a mere 0.5% of the market. We plan to escalate our annual sales by 100 units each year; our superior technology and energy savings give us confidence that we will be able to expand our customer base and capture 2.5% of the market by 2020. Our first-year profits, before taxes, will be $2.3 million. We will repay all of our debt and start turning a real profit during our second year. After 5 years, our total income will be $60 million before taxes, while our total expenses will be $26.5 million. If our sales track more towards our pessimistic estimate, we will still owe $4.1 million after the first year and will not break even until the fifth year. Once we are out of debt, the company will require the sale of 50 units every year to continue operations. Table 5 contains our range of predicted sales.

Table 5. Predicted dishwasher sales

Year	Pessimistic	Best Guess	Optimistic
1	20	100	200
2	50	200	500
3	100	300	1000
4	150	400	2000
5	200	500	3000

ADDITIONAL REFLECTIONS ON PROJECT OUTCOME

Consistency with Eco-Efficient Design

Sustainable design revolves around the "triple bottom line;" a new design must address economic, environmental, and social sustainability. Additionally, the design must be revolutionary in some way, changing the industry as a whole or influencing the way in which people behave. While sustainable design is the standard that we strive towards, we often have to settle for eco-efficiency. This is the case with our project. While we have improved the environmental impact of the top-of-the-line commercial dishwashers on the market today, the steps made are not revolutionary. We have not changed the way people view the need to wash dishes nor have we come up with an idea that will cause a paradigm shift in the dishwasher manufacturing industry. We believe that we can market our product at a price relatively close to the existing competition, but we did not tunnel through the cost barrier to achieve an exceptionally affordable solution. Finally, there is almost no social aspect to this design. While we believe that using less hot water and steam during the dishwashing process will make the working environment around the dishwasher more pleasant, it is not what we would consider to be radical social improvement.

If somehow this product were introduced to the market and became a sensational hit overnight, the potential downside to this triumph would be if everyone who owned a commercial dishwasher discarded their current model and bought ours, regardless of how old (or new) their functioning dishwasher was. This would cause an exceptionally high level of waste generation, equivalent to approximately 15 years' worth of dishwasher disposal. While this would not be exceptionally detrimental to the environment if most of the materials were recycled, it is still an unintended potentially negative impact of our design. We see no real threat of users operating this device in an unexpected fashion. Perhaps the operators would fail to properly load the dish racks to their full capacity or fail to properly maintain the machine, lowering its overall efficiency, but they would be just as likely to do this with other commercial dishwashers as well, so the relative improvement in environmental impact should be the same. Additionally, there are some safety concerns with our design such as exposure to hot water, UV lights, and moving parts, but there are safety features and emergency shutdowns in place and there are similar concerns with any commercial dishwasher.

Design Critique

If we were to do this project again, we would have chosen a different topic. Many of the problems we encountered over the course of the semester were caused by a lack of input from our potential customers. We would like to look into a product that is smaller, less expensive, and that has a larger market where it could be easily implemented. We believe that the biggest strength of our product is that it does in fact save energy over our baseline competitor, meaning that it is more efficient than any other commercial dishwasher on the market today. Our weaknesses mainly revolve around the difficulty that we foresee in entering the market. Because it is relatively small, we would have a tough time gaining market share. Our product is quite expensive, so we would need to gather a lot of initial capital. We need to contract out the actual manufacturing of our product meaning that our retail price will be higher and/or our profits will be lower. And we would need to develop an extensive maintenance service or contract that out, resulting in even lower profits. This problem is exacerbated by the fact that our machine is more complex and is more likely to need more frequent maintenance, whether it be replacing UV lights or dealing with a more serious problem. Finally, we would need to overcome regulatory barriers, since current legislation is written to require hot water or sanitizing solution to be applied after washing; UV lights are not a legal option at this point.

The biggest improvement we could make to our project would be to gather much more data, both in terms of needs-finding and concept validation. We feel that we sort of manufactured a need based on what we believed one of the major issues in the commercial kitchen to be. Hearing opinions from a wide range of people who actually work in the kitchens would be a much better way to start our design process. At a more specific level, we believe that we might run into problems attempting to properly enclose and protect the UV lights while still allowing relatively easy access to facilitate replacing the bulbs or performing routine maintenance.

Recommendations

There are several possibilities for future work and research that would improve the quality of this project. First, we only have data on the effect of thermoelectric coolers in household dishwashers. We assumed that they would be equally as effective when applied on the commercial scale, but actual testing should be conducted to determine their effectiveness. Second, the physical arrangement of the UV lights inside the dishwasher should be examined to maximize coverage of the dishes and optimize the number of bulbs and amount of energy used. Third, developing a more eco-friendly and economically viable wash water recovery system would be very beneficial, not just to this project, but to other applications as well. We believe there are two more potential extensions of this project. The first option would be to develop retrofit devices that could apply these technologies to existing dishwashers to improve their performance. While we understand that the customer would prefer an entirely new machine, these devices could be marketed to smaller business owners who cannot afford to tie up as much cash in equipment as, say, a large university. The second option is to an opportunity for expansion within the market once this product is a commercial success: applying these technologies to all four types of commercial dishwashers, rather than just focusing on conveyor-type machines. Both of these extensions would essentially require their own projects; they have different customer bases so new design ethnography programs would need to be carried out and more market analyses would have to be conducted.

Project Reflections

We believe that taking ME499 first would be very beneficial to success in this class. We had several concerns with our ability to absorb new information about sustainable design while attempting to apply these concepts to our design process. We found it more difficult to retain key concepts and ideas and did not feel that we really applied any of them successfully to our project. We acknowledge that it was repeatedly stressed to us that we should not be focusing solely on the environmental aspects of sustainable design and that it was essential to the success of a product for it to be commercially viable. However, we believe that our nonexistent experience with business plans and marketing strategies hindered our ability to focus on commercially viable opportunities and we feel that we focused too heavily on forcing environmental improvement. Finally, we would have liked to see a recap of all of the concepts we had covered over the course of the semester as we were preparing our presentation and final report. Perhaps we could have had one or two days of review instead of another lecture on LCA and its various manifestations? Or maybe because the business plan section was so hurried and superficial, could we have left it out altogether? We don't feel like we gained much by spit-balling sales numbers and knowing that they were inaccurate.

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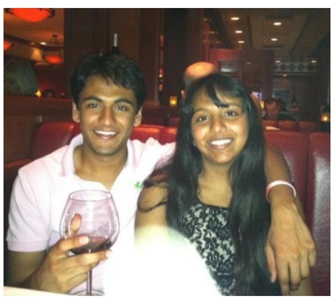
Appendix I - Team Introduction

Gaurav Gosain

I was born and raised in Delhi. I did my Bachelors of Engineering in Mechanical Engineering from Delhi College of Engineering (2007-2011). After that I joined Engineers India Limited which is a consultancy firm in OIL Sector in India. During my tenure I spent 1 year on site at Mangalore Refinery and Petrochemicals Limited; where I was responsible for construction activities related to mechanical works. I am currently specializing in design for my Masters (started this fall). I believe designing for sustainability is a dynamic process that evolves as time progresses. With the invention of new technologies and ever changing social practices; designing for sustainability becomes much more intricate and complex. I believe the key to finding successful solutions is strong will and thorough research. Collaborative endeavors are required at the global level for mitigating the biggest sustainability issues mankind faces. With this course and project I am taking the first step of thinking innovatively and learning to design for sustainability. I think with my love for details and technicality I can contribute in a good way to my team and also at the same time learn a lot from their experiences.

Masiha Khan



I was born and raised in Philadelphia, PA. I graduated from Villanova University last year with a Bachelor's in Mechanical Engineering. My senior year I conducted research in automatronics under Villanova's Mechanical Engineering Chairman Dr. C. Nataraj. I am a heavily service-oriented person; I was involved in Engineers Without Borders, Habitat for Humanity, and other service oriented programs. I firmly believe that what I do with my career should not only interest me and inspire me, but must also contribute the betterment of mankind. I am also very artistically inclined and I thrive in creative atmospheres. I had never considered going into sustainable design until I signed up for this class. Having started to dip my toes in the field, it seems to elegantly tie together the things I value most about engineering. I believe that my innovative spirit and strong focus are valuable assets as we try to wrap our heads around the complexity of this project.

Thomas Olsen

I was born and raised in Saint Paul, Minnesota. I attended the U.S. Coast Guard Academy and graduated in 2010 with a degree in Naval Architecture and Marine Engineering. I then served on a Coast Guard icebreaker home ported in Seattle, Washington for two years as Division Officer for the Electronics and Auxiliary Engineering divisions. I enrolled in classes at the University of Michigan in the summer of 2012 and expect to graduate in 2014 with two master's degrees, one in NA&ME and one in Mechanical Engineering. I have an underlying concern for mankind's future on this plant, and developed an interest in sustainability after taking courses in advanced energy solutions and hybrid electric vehicles. While I understand that universal sustainability is too big a task for any one person to accomplish, I believe that the more people who work on the problems from different angles, the more likely the end goal will be achieved. Within this team, I believe that I can contribute to the problem-solving process, motivate everyone to be proactive, and assist with report writing and proofreading.

Niket Prakash

I was born in the Eastern Indian city of Patna, and subsequently went to school in Kolkata, Delhi and Mumbai. I got my undergraduate degree in Mechanical Engineering from the University of Birmingham, U.K. During my undergrad, I was involved with several successful group projects ranging from technical ones designing a miniature 2-stroke engine and a gearing system to more general ones designing a cooling unit which covered the business aspects as well. In terms of sustainability, I have seen a tremendous change in India from the mid-90's to now with almost an inconceivable rise in prosperity. Having lived in the UK, I also realize that a massive gap that still exists in living standards. At the same time, I am also aware of the fact that if an unthinking implementation of existing technology takes place in developing areas it would be disastrous for our planet. There is a great need to develop new technologies to meet growing demands sustainably. The process and principles of sustainability provides the methods to achieve the desired improvement in living standards without compromising on environmental concerns. I tried to develop a Stirling Engine model at undergrad to convert heat to electricity to address some of these concerns. Through this course I hope to further my understanding of sustainability concepts and implement it in my future projects.

Hanyi Xie

I was born in Zhejiang, the southeastern coastal province in China. I earned my Bachelor's degree of Mechanical Engineering in University of Minnesota from 2009 to 2013. During my undergraduate college life, I did my Honor Thesis on an Air Energy Storage System, which is for sustainable energy storage. I also had an independent design project focusing on the advanced propulsion wheelchair system for the physically disabled. I enrolled the classes this fall in University of Michigan to pursue my Master's degree in Mechanical Engineering design approach. In my opinion, designers have the responsibility not only to make people's current life convenient, but leave resources as many as possible for next generations for their development. Sustainable design is such a subject that can burden our imagination to improve our life and change the world environmental friendly. Sustainability needs to be aware by more and more people. By taking this course, it is the first step I try in sustainable design area. I hope through the semester, I expect to broaden my horizon and gain skills and abilities for solving sustainable design problems.

Appendix II - Team Member Preparation Sheets

CATME Meeting Support **Team-Member Information for Gaurav Gosain**

Contact information *(e-mail, cell, Facebook, etc.)*.	gosain@umich.edu,734-272-2117
Preferred contact method and limitations *(ex., no calls after…)*.	Through email.
Availability for meetings *(days, times)*.	Monday (Any Time), Tuesday(after 5), Wed(after 4.30), Thursday(After 5), Friday(After 2) and Saturday(After 4).
Preferred meeting times and places.	Duderstadt Library
Preferred work styles relating to teamwork.	Collaborative and Progression after Mutual Agreement.
Strengths related to teamwork.	Good Coordination and Responsible.
Strengths related to the team's task.	Good Technical and Analytical skills.
Weaknesses related to teamwork.	Sometimes Introvert.
Weaknesses related to the team's task.	Not fully aware of American Culture.
Personal Background *(whatever you want to share, such as major, interests, personality characteristics)*.	Major in design. I like methodical and analytical approach to any problem.
List anything else that you want your teammates to know.	

CATME Meeting Support **Team-Member Information for Masiha Khan**

Contact information *(e-mail, cell, Facebook, etc.)*.	masihak@villanova.edu
Preferred contact method and limitations *(ex., no calls after…)*.	email
Availability for meetings *(days, times)*.	Tuesday nights, Sundays, Tuesday/Thursday before class
Preferred meeting times and places.	Central, North
Preferred work styles relating to teamwork.	Frequent Updates, Individual tasks
Strengths related to teamwork.	Leadership, quality work, task driven
Strengths related to the team's task.	Mathematical, Logic, Design
Weaknesses related to teamwork.	I can be stubborn
Weaknesses related to the team's task.	Sometimes I need to be brought back to the big picture
Personal Background *(whatever you want to share, such as major, interests, personality characteristics)*.	Mech Eng
List anything else that you want your teammates to know.	

CATME Meeting Support **Team-Member Information for Thomas Olsen**

Contact information *(e-mail, cell, Facebook, etc.)*.	Email: tolsen234@gmail.com; teolsen@umich.edu Phone: (206) 755-5926
Preferred contact method and limitations *(ex., no calls after…)*.	Preferred: Gmail No calls on weekends or after 5pm on weekdays
Availability for meetings *(days, times)*.	Monday/Wednesday after 10am Tuesday/Thursday 12:30-3pm Friday all day
Preferred meeting times and places.	North Campus Monday or Wednesday
Preferred work styles relating to teamwork.	Set and follow a schedule, equal work sharing
Strengths related to teamwork.	Efficient worker, good at frequent communication
Strengths related to the team's task.	Good at planning, analyzing, and report-writing
Weaknesses related to teamwork.	Sometimes unwilling to let others do their fair share of the work
Weaknesses related to the team's task.	Not great at interviews
Personal Background *(whatever you want to share, such as major, interests, personality characteristics)*.	U.S. Coast Guard officer Naval Architecture & Marine Engineering / Mechanical Engineering graduate student, 2nd year
List anything else that you want your teammates to know.	

CATME Meeting Support **Team-Member Information for Niket Prakash**

Contact information *(e-mail, cell, Facebook, etc.)*.	E-mail : niketpr@umich.edu Cell : 734-353-8956 Whatsapp : +447587187459
Preferred contact method and limitations *(ex., no calls after…)*.	Email or whatsapp are always welcome, also would prefer to be informed about emergencies via phone calls at any time of day (or night) rather than not being disturbed at all.
Availability for meetings *(days, times)*.	All lecture days from 2 pm. All other working days after 5pm. Willing to work on weekends if meetings are planned from before.
Preferred meeting times and places.	During available hours in the North Campus
Preferred work styles relating to teamwork.	Set our goals for each meeting for every member to work on individually. Work in group to amalgamate information and debate direction of next task. Adhere to directions set by the group.
Strengths related to teamwork.	I have been a part of several successful group projects at undergrad involving technical and general topics with group members from diverse ethnic and national backgrounds. Having lived in foreign cultures for a while I can interact with a diverse group.
Strengths related to the team's task.	I have a strong academic record and solid technical knowledge in core mechanical engineering subjects.
Weaknesses related to teamwork.	My persistent (and sometimes needless?) questioning can be irritating for other group members, but I like to work with everything defined for myself.
Weaknesses related to the team's task.	I am unable to work properly if deadlines for every deliverable is not pre-determined. I like working to a schedule and completing everything JUST before it.
Personal Background *(whatever you want to share, such as major, interests, personality characteristics)*.	My major is in ME and I have an undergraduate degree in that as well. My undergrad involved several design courses and I am well versed with them. I read a lot of publications on current affairs and am generally well informed about the world. I am soft-spoken and generally polite but irritatingly persistent.
List anything else that you want your teammates to know.	Ann Arbor is the fifth city in the third country that I am living in so I have had a nomadic existence.

CATME Meeting Support **Team-Member Information for Hanyi Xie**

Contact information *(e-mail, cell, Facebook, etc.)*.	612-701-9972 xiehy@umich.edu
Preferred contact method and limitations *(ex., no calls after…)*.	Email would be the most efficient way
Availability for meetings *(days, times)*.	Monday: 11:00-14:30 Wednesday: 11:00-14:30 Friday: After 13:00
Preferred meeting times and places.	Monday and Wednesday afternoon North campus
Preferred work styles relating to teamwork.	Discuss the ideas together Split for individual tasks Take advantage of every group member's strengths
Strengths related to teamwork.	Patient, easy to communicate
Strengths related to the team's task.	CAD model Construction Calculation Data Processing
Weaknesses related to teamwork.	
Weaknesses related to the team's task.	Written English
Personal Background *(whatever you want to share, such as major, interests, personality characteristics)*.	Mechanical Engineering major in Design Approach
List anything else that you want your teammates to know.	

Appendix III - Team Charter

CATME Meeting Support

Team Charter for Team 1

Team Member Names	Contact Information (e-mail, cell, Facebook, etc.)	Preferred Contact Method / Limitations (ex. no calls after…)
Gaurav Gosain	gosain@umich.edu (734) 272-2117	Preferred: email
Masiha Khan	masihak@villanova.edu	Preferred: email
Thomas Olsen	tolsen234@gmail.com (206) 755-5926	Preferred: email
Niket Prakash	E-mail : niketpr@umich.edu Cell : 734-353-8956 Whatsapp : +447587187459	Preferred: email or whatsapp
Hanyi Xie	xiehy@umich.edu (612) 701-9972	Preferred: email

Team Member Names	Strengths related to teamwork and the team's assigned task.	Weaknesses related to teamwork and the team's assigned task.
Gaurav Gosain	Coordination, responsibility, and technical/analytical skills	Sometimes introverted, not fully aware of American culture
Masiha Khan	Leadership, quality of work, math, logic, and design	Sometimes stubborn, can lose sight of the big picture
Thomas Olsen	Efficiency, communication, planning, analyzing, and report-writing	Sometimes unwilling to delegate work, interviews
Niket Prakash	Past participant in successful design projects, good at working with a diverse group, good academic record	Persistent questioning can be irritating to others, tends to complete work just before deadlines.
Hanyi Xie	Patience, communication, CAD model construction, calculations and data processing	Written English

1. What are your team's goals for the collaboration?

These should relate to the team's performance on the project as well as the processes that the team will follow to complete the project. What are your team's expectations regarding the quality and timeliness of the team's work?

We all agree that we want to receive an A on this project and are willing to put in the effort to do so. We will complete all assignments at least 24 hours prior to deadline to allow sufficient time for final editing. We want to develop as our final product something that could actually succeed in the commercial marketplace.

2. Who is responsible for each activity? What roles will each member have?

Don't forget to include logistical tasks, such as arranging meetings, preparing agendas and meeting minutes, and team process roles, such as questioning (devil's advocate), ensuring that everyone's opinion is heard, etc.

Thomas will take the lead in arranging the timeline for completion of different parts of each assignment. Each member has agreed to play devil's advocate from time to time and ensure that they are voicing their opinions during group meetings. When work is being divided amongst the group, tasks will be assigned based on aptitude and the potential to take advantage of personal connections or networking opportunities.

3. What is your timetable for activities?

(Due dates, meetings, milestones, deliverables from individuals, if appropriate)

We will follow the syllabus when setting deadlines. We will meet every lecture period, with the possibility of extra meetings as needed. Individual tasks will be completed as planned in the timelines for each assignment.

4. What are your team's expectations regarding meeting attendance (being on time, leaving early, missing meetings, etc.)?

Team members are expected to arrive on time and stay until all tasks are done, with reasonable exceptions. It is expected that individuals will not schedule other meetings, etc. for immediately before or after our planned meetings.

5. What constitutes an acceptable excuse for missing a meeting or a deadline? What types of excuses will not be considered acceptable?

No excuses are acceptable for missing an assignment deadline, unless prior approval has been given by the instructor. Illnesses, other academics, and emergencies are acceptable excuses for missing meetings.

6. What process will team members follow if they have an emergency and cannot attend a team meeting or complete their individual work promised to the team (deliverable)?

If an emergency arises, email all group members as soon as possible. If an individual is struggling to complete their work, inform others earlier rather than later so that the workload can be redistributed.

7. What are your team's expectations regarding the quality of team members' preparation for team meetings and the quality of the deliverables that members bring to the team?

Everyone is expected to complete graduate student-level work. If everyone is assigned a task for a given meeting, everyone is expected to complete it – don't rely on everyone else to do the work.

8. What are your team's expectations regarding team members' ideas, interactions with the team, cooperation, attitudes, and anything else regarding team-member contributions?

If you have an idea, don't be afraid to speak up. Ask questions if you don't understand something or feel like something is not being properly addressed.

9. What methods will be used to keep the team on track?

How will your team ensure that members contribute as expected to the team and that the team performs as expected? How will your team reward members who do well and manage members whose performance is below expectations?

Goals and expectations will be clearly defined. Everyone is mature enough to monitor their own work. Team members can expect fair evaluations by peers in post-assignment reflections.

Appendix IV – Design Ethnography Details

Gaurav's Observations

Preliminary Observations on Bursley Diner:

I had the opportunity to interview a few people although I did not have the chance to interview the cooks (I am trying to get some answers from one of my friends who is a student cook) and the manager. I observed the dish room but I could not observe the kitchen because they just do not allow anyone to stand there. So, I guess I will try and have more observations on Monday.

Here are the general observations:

(a) Architecture points:

- From the construction it is clear that they have quite a lot of natural lighting.
- The food items are divided into several parts:
  1) Sweets: These include cookies and cakes. The only appliance they use here is the oven for baking the cookies.
  2) Deli: Sandwiches and Subs: The main counter has meat and other vegetable items. The meat is to be cooled and so a range of temperature is to be maintained.
  3) Salad Bar: There are a total of 3 Salad stations. All 3 have black plastic trays which need to be cooled from a cold water current under the trays. Separate stations use separate machines to do so.
  4) Milk Station or Beverages: There are two counters where you can get milk. Milk flavors are Chocolate, Skim and Full. For people who are lactose intolerant they have a different smaller fridge outside the milk bank which contains almond and soy milk etc. Milk is brought in I suppose 5 Gallon bags which are placed in containers connected to sockets on the wall inside the milk bank. The temperature on the Milk bank room is maintained between 30-40F. Other products stores are Yogurt, Fresh Cut Fruits, Ice Cream Bags; Juices. There are in total 3 juice machines.

     The milk banks are used for different purposes. One is used for primarily storing milk. The other one is used for storing Juice Boxes.
  5) Pizza n Pasta: Here is where we have pizza and pasta. This counter has a lot of appliances mainly for preparing pizza bread and cooking the pizza.
  6) Main Dish: Main dishes are served over two counters separated because of Veg n Non Veg. They have to keep the dishes hot so it is done by heating the trays by a current of warm water under the trays, opposite to what is there in Salad bar.
  7) Grill: Now here is where I was stumbled quite a lot. The Grill is on continuously and the machine is a complex one. It heats the upper surface of the grill but at the same time the meat (hams) and chicken pieces are cooled in sliding containers below the grill. The oil is heated continuously for making fries and stuff.

- Dishwashing Room:
  1) The dishwashing room has a huge dishwashing machine which exhausts hot air through a duct. (I could not find out where it goes but it looked like it went to the roof.)
  2) For washing the dishes, first the dishes are cleaned and the food left on the plates is scraped off using water jets and sprays. The waste food goes through an in-sinkerator and then to the waste disposal. I don't yet know whether it is composted or not.
  3) Then the dishes are passed through the dish machine. After which they are collected and stacked.
  4) Silverware is cleaned through preparing a solution first in a container. The first process involves cleaning through jets. Then placing the silverware in a solution. After which they are removed and passed through the dishwashing machine.
  5) The temperature of the dishwashing room is above the comfortable level. Humidity is also quite high. To reduce the heat there a no. of blowers and fans in the dish room which help circulating the air.

- Food Prep and Kitchen:
  1) Meat is already cut and is stored in refrigerated rooms along with other food items.
  2) Fruit and some of the vegetables are prepared here. Spinach is specifically brought in plastic bags already cleaned and washed.
  3) A lot of prepared items are stored in heaters. They have 6-8 heaters all around the kitchen.
  4) For handling meat the aluminum pots and pans are used. There is a different dish washing room specifically for cleaning aluminum pans.
  5) A separate cooler is there just for storing ice.

Key Observations:

1) Bursley has plastic trays which students pick up as soon as they enter the hall. The students then go after every counter where there are separate ceramic plates having food at different counters. Trays are means for carrying more food and stuff; so that they don't have to go back again to the counters.
2) Tissue papers are placed on the tables. It says on the tissue papers that these are bio degradable.
3) Trash Bins are placed at one side of the hall. People throw the tissue papers and straws and other primarily plastic waste in the dustbins. There is no classification for recyclable waste.
4) The trays carrying the leftover food are kept on conveyor belt. The belt isn't operated continuously. On an average for 7-8 times/Hour when the belt is fully stacked with trays.
5) There is lot of food that is being wasted here. On average I found 3/5 trays to carry some food.
6) Scraping off the food takes a lot of water. The dishes before going into the dishwasher are nearly clean. The dishwasher is primarily sanitizing them.
7) Sources which are water intensive in the dish room:

- Water circuit running under the conveyor belt. This is where glasses and cups are placed for initial cleaning.
- The water jets used for scraping food.
- The dishwasher

8) Sources which are electricity intensive:
   - The dishwashing machine.
   - The fans and blowers in the dish room.
   - Conveyor belts.
9) The conveyor belts are split into 2 parts and so as a dish room worker pointed out that if we remove the trays completely then the plates won't be able to move on to the next belt. It is because of the length of the tray that it passes over to the other belt. If we decide to remove the trays then we have to replace the belts.
10) Most of the time the dishwasher is cleaning the trays only. Plates are stacked along with the glasses and cups. The cycle for cleaning is around 7-8/hrs.

Interviews Q&A:

Students

1. What year of school are you in?
   Fernando-Undergrad - Sophomore, mechanical.
2. Are you on a meal plan? Which one?
   Meal Plan is the Block one. Usually eats 3 times a day.
3. What kinds of food do you typically eat?
   Non-Veg Grill, Fruits and Salad.
4. Do you have any dietary restrictions? (Vegetarian, lactose intolerant, food allergies, etc.)
   Nope.
5. Are you satisfied with your food options/variety?
   No. Bursley has a lot of options for veg food but not so much options in veg.
6. Do you think the food is fresh enough? Does it sit out too long?
   The food is usually fresh. If you are early in the opening it is very good but if you are late in the shift then sometimes the food may be not fresh enough especially on the grill.
7. Are the dishes and utensils clean?
   Yes the dishes are clean. The silverware sometimes is not that clean.
8. Do you feel like you have to wait a long time to get food?
   No, the food is usually readily available. Even if there are queues they are not that long.
9. How often do you eat all the food on your plate?
   Most of the times food is left. Reason being that I can only check-in once and due to that sometimes if I am hungry I tend to take more food so that I can eat as much as I can. This ensures that I won't go hungry for another 4-5hrs.
10. Would you like the opportunity to take leftovers home?
    Yes definitely. I think that is the biggest disadvantage of bursley. Sometimes when I am late for class I want to have the food on the way I can't do it.

11. Do you recycle/compost waste when you are done eating? Is it easy/convenient?

No, we can't take our food with us, so if I am not able to eat everything I have to throw it away. We just have to put our plates on the belt that's it. I usually throw my tissues and straws in the trash bins but sometimes I forget.
If bursley had different dump for food and plastic etc. I think I could dump my food differently, it can be done but with such huge crowd I think it could be tough.

12. Rate the cafeteria 1 (worst) through 5 (best) in the following categories. Please explain.
    a. Food quality-3
    b. Food variety-4
    c. Food presentation-4
    d. Cleanliness-4
    e. Convenience-2
    Reason for the low rating is that bursley is not open 24hrs. Sometimes at night when I am studying and I am hungry I can't come here. They just have limited shifts for breakfast, lunch and dinner. Other colleges have 24hr cafeteria. If they are bothered about waste then they could have orders placed or may be charge extra money for it but there must be a system for night.
13. What is your most favorite part of eating in the cafeteria? Your least favorite?
    Eating with friends. If there were no friends while I eat I might just have my food and go in 10min but I usually stay for more than half hour just so I can talk n catch up with my friends.
    Least favorite part is when I can't go to bursley since it is closed.

Line Servers

1. What year of school are you in? (if applicable)
   AMU student undergrad.
2. How long have you worked here?
   More than a year.
3. What is your job in the cafeteria?
   Many jobs sometimes I work at Deli sometimes I serve.
4. Do you stay in the same position or rotate occasionally?
   No I rotate often.
5. What kind of hours do you work?
   4-5 hr shifts 4-5 days a week.
6. Are you instructed on portion sizes? Do you follow those guidelines?
   Yes we are instructed on portion sizes. We have to follow it unless the student specifically asks for more.
7. Do students ask for more food? Do you give it to them?
   Yes but very rarely. Yes I give the food but if I think that they are asking for too much then I consult my supervisor.
8. Do you have any input on when fresh food is brought out from the kitchen?
   Usually at the deli we have to check the temperatures of the meat at regular intervals. Other food like curry and rice n stuff is already prepared and we have to collect the same from one of the heaters in the kitchen. We just have an idea when to bring out the food.
9. Is there any extra prep/removing packaging when the food is brought out?
   No it is usually just covered with plastic film. So not much prep is required. On the grill and pizza we have to cook food.

10. Do you throw anything away?
    Yes sometimes when some of the food is left on the blackware at the end of the night shift. But usually we try to save as much as we can and if some of it is left we try to put it and mix which the new stock.
11. Do you see any big sources of waste in your job?
    No not much, we try to utilize as much as we can.
12. What is the best part of your day? The worst?
    The best part of the job is the interaction with the fellow colleagues. The worst part is to stand at one place for hours. It gets tiring sometimes.

Dish Washers

1. What year of school are you in? (if applicable)
   P.H Roe Sophomore.
2. How long have you worked here?
   4-5 months.
3. What is your job in the cafeteria?
   Mostly in the dish room although I have worked in other shifts like serving etc.
4. Do you stay in the same position or rotate occasionally?
   Yes I rotate.
5. What kind of hours do you work?
   3-4hrs 3-4 days in a week.
6. What tools/appliances do you use?
   We usually have brushes and water jets. The glasses and plates are stacked in plastic containers which makes it easier to load it on to the dishwasher. Silverware needs to sorted as per whether they are spoons, knives and forks and placed in different cups.
7. Does the work environment make you physically uncomfortable?
   Sometimes in the summer it gets really hot and humid but in winters and like now it is okay. The humidity makes you sweat a lot but it is not that uncomfortable.
8. Do you feel like there are any safety concerns? (Scalding, getting cut on knives, etc.)
   Only with the floor being wet. Other than that I don't think there is any.
9. Do you ever break dishes? If yes, what happens to them?
   Yes everyone does. Usually in a day 30 plates are chipped or broken. The glasses are plastic so around 2-3 glasses break every day.
10. Do you have to throw anything away?
    Yes the broken plates and glasses. Other than that I think since we have to keep our hand hygienic we have to change a lot of plastic gloves. I usually change them after every activity and every half hour.
11. Do you see any big sources of waste in your job?
    The biggest wastage is food. Almost every tray we get has some leftover food on it. Then to clean it we have to use the jets so that the plates and trays don't have any food stuck to them. Sometimes, more than half of the food is not eaten and foods like whole pizza slice and fruits are left.
12. What is the best part of your day? The worst?
    Best part is the working with friends. They usually play music in the dish rooms it's good to work there. The worst part can be cleaning and the humidity.

Masiha's Observations

Friday Oct 4 2013

West Quad: Mojo

Specs:

- 2 floors
- Upstairs: Market, Seating ~ 50
- Downstairs: Dining Hall, Seating ~ 250

Stations:

- Pizza Station
    - Large Fire Oven: fits about 4 pizzas at once
    - 4 different types of pizza presented as whole pies
        - Heating lamps
        - Plates stored underneath
        - Self-Serve
    - 2 workers
- Burger Station
    - 1 Grill
    - Burgers and Dogs served individually in plastic baskets
    - 2 workers
    - Heating Lamps
- World Palate-World Cuisine
    - 10/4/13- Dumplings, noodles, and veggies
    - Served as meal on a plate
    - Plates put out under heat lamps
    - 5-6 workers
    - More rounded meal
        - approximately 1 serving of meat, carb, and veggies or vegetarian option
- Homestyles
    - 10/4/13- Roast beef au jus, Brussels sprouts, and mushroom risotto
    - 3-4 workers
    - 2 grills
    - Homestyle food
    - More rounded meal
        - Approximately 1 serving of meat, carb, and veggies or vegetarian option
- Salad Bar
    - 3 Sections
        - Salad Station and Fruit
        - Bagels, Bread,
        - 2 running conveyor style toasters

  - Entirely self-serve
- Dessert
  - 10/4/13: Chocolate raspberry cake, cookies, cut fruit
  - 1 large fridge
  - 2 confectionary ovens
  - 1 worker
  - Fro-yo station
    - Cone dispenser, 2 fro yo machines
    - Self-serve
- Drinks
  - 3 stations
  - Dispensers: 28 soda, 16 Juice, 6 milk
  - Blue Plastic 12 oz cups
  - Coffee Station
    - Tea
    - 2 hot water dispensers
    - 1 coffee machine
    - Cappuccino machine
    - 1 cream dispenser
- Silverware
  - Metal
  - Containers dispersed around cafeteria

Eating Patterns:

- Boys
  - Avg 3-5 plates
    - 2 platters, 2 small plates
    - 3-5 utensils
    - 1-2 drinks
    - Get more food: around 3-4 times
- Girls
  - Avg 2-4 plates
    - 1 platter, 2 small plates
    - 3-4 utensils
    - 1-2 drinks
    - Get more food: around3-4 times
- Time
  - 5:40 pm- 50% Occupancy
  - 6:10 – 70%
  - 6:30 – 80%
  - 7:00 – 70%
  - 8:00 – 40%

Energy:

- Very well lit, about 500 lights not including heating lamps
    - All seem to be energy efficient soft white light bulbs
- Windows along one wall
- Upper level is a balcony surrounding a large open area in the middle
- Open and serves dinner until midnight

Cleaning:

- 70% of dishes returned have little to no food on them
    - No trash cans near the plate return area
    - Trash, remaining food, and utensils returned on the plates
- Return plates on a conveyor system that takes the plates behind a wall

Niket's Observations

I managed to interview two people who work at Bursley and get a sense of what goes on. This is a rough draft and I will distill it after our meeting tomorrow.

So the first person I interviewed works mostly as a line server and has the closing shift. In terms of serving sizes she said a pizza is cut into 8 pieces and everyone gets a slice, pasta is similarly rationed with just 2 scoops and so on for the main dish. For the main dish these guys place everything on the plate and leave it on an electric heater for students to collect. According to her people rarely ask for more and do it only if they are allergic to something and can't eat it.

When the dishes come from the kitchen, meat is served in different pan sizes and they get about 50 dishes in one pan (depending on the meat). They consume about 20-25 pizzas in an hour. Everything is prepared from before and is kept on the warmer with average times being about 2 hours. The dishes are covered in cling film in prevent spillage while moving it from the kitchen to the serving area. There are warmers everywhere with hot plates for ceramics and boiling water for metal. The water is boiled through an electric heater beneath them. Each dish has its own serving spoon, individual tongs. They use ceramic plates, metal cutlery, plastic glasses and tissues. All servers wear gloves, net & cap and an apron.

A lot of frozen stuff is used especially in vegetables which is steamed in the kitchen before being sent out. Most of the food stuff have dates underneath it indicating the use by date. Cheese and milk are kept for some time. Milk is served through pipes connected to plastic bags where it is stored.

She was surprised at the wastage of food and said that when the shift changes everything from before is thrown away (freshly cooked only). Workers do not get anything unlike Ugos and other such places. The pizza bases are prepared in house and is thrown away after 2 days. She said that they do have a monitoring system and a call is taken every 15 minutes to check student traffic and also judge from one meal to the next, (e.g. Lunch to dinner). She felt that the food wastage was down since the term started and the halls were running at full capacity. She said that a lot of food is thrown and since food is served on the plate from before there isn't a chance for students to reduce the serving size and so no one asks for less. Cookies are apparently kept for the whole day and only cake or pie is thrown away at the end of a meal.

In terms of consumption, she felt it depends a lot on the kind of food being served with certain varieties of meat being more popular and seafood being less so. It was all about the preparation according to her.

Some of the good points that she mentioned were how everything was listed from calories to allergy advice to serving sizes ensuring students make an informed decision. For food stuff like milk and cereal there is a lot of choice with several options even for drinks.

The bit that she hates is when she had to clean up. The cheese sticks to the counter and requires detergent and rags to clean up and also changing the water in the boilers. She also has to prepare for the next day by getting everything ready.

At the end of the interview she repeated her pet peeve of not being able to carry food home. Even students are restricted from doing so and hence can't eat once the place is closed. She recalled that one time she threw away 120 pancakes and 200 waffles. The disposal is in plastic bin bags.

The next worker I interviewed had worked for about 5 weeks before he quit. He had worked in the dish room, as a server and a dining room assistant.
The dish room is where dishes are cleaned by first removing the left-over food and cleaning the utensil with a jet spray that has pre-mixed detergents. This is then sent through a heated chamber to sterilize them. They are then collected and stacked away. He said that the room didn't have ACs so it was difficult to work and they had to do a 3 hour shift which was exhausting. They had gloves, cap and an apron. He also said that the cooking utensils were sent around twice to thoroughly clean them.

The food was thrown away in plastic bin bags probably into a dump. My interviewee was impressed with the design, and scheduling that ensured proper allocation of work.

While working as a dining room assistant he had to clean soiled tables, place tissues, vacuum, broom and mop with either detergent (red bucket) or water (green bucket). There was no place to throw food away and the students left their left-over food on the plate itself.

He thought the staff wasn't allowed to eat as they would waste time eating and it was an understandable managerial decision.

As a line server he was supposed to ensure that the food looked appealing when serve do the plate. He also said that students carried their trays around and picked up plates on them. Otherwise his observations were the same as the previous girl.

He had also worked as a food runner where he collected filled dishes from the kitchen and brought them to the serving area. He had no interaction with the staff to inform them about the consumption patterns on the day. Each dish had about 7-8 pans prepared from before and placed on a heater hardly any cooking took place during a meal according to him. Veggie patties, pizzas etc. were prepared on demand.

The disposal of cling films, plastic gloves and caps were in the same bin as food. Garbage bags were deposited in huge containers that were driven away in a truck.

Hygiene wise he was satisfied and didn't see a problem in operations.

The third person I interviewed had worked for a week as a server on different serving stations.

At the fruit station he just ensured that the fruits were fresh, the trays well stocked and the area clean.

Sandwich statin was more fun as he had some interaction and prepared sandwiches according to the demands of the students

Otherwise he reiterated all of the previous points on wastage of food and moaned about working the closing shift which involved a lot of work.

Hanyi's Observations

Students

1. What year of school are you in?
Third year in U of M
2. Are you on a meal plan? Which one?
I used to have the 14 meals/week meal plan, but now I cook by myself
3. What kinds of food do you typically eat?
Pork, beef, egg, rice, vegetables, and fruits
4. Do you have any dietary restrictions? (Vegetarian, lactose intolerant, food allergies, etc.)
Nope
5. Are you satisfied with your food options/variety?
Not really. As for the very beginning, I felt like the food in dining is various, but after eating for one or two months, we noticed that the categories of food are always those ones
6. Do you think the food is fresh enough? Does it sit out too long?
Sometimes the vegetables and fruits are fresh, but sometimes are not. I think it is simple to tell whether they are fresh or not
I do not think they are sit too long, but maybe 1 or 2 days
7. Are the dishes and utensils clean?
Parts of the dishes are not so clean; you can see the oil on them
8. Do you feel like you have to wait a long time to get food?
Not too much time, but normally the waiting time is acceptable
9. How often do you eat all the food on your plate?
Most of time
Because I think giving back the dishes with too many foods left is not good
10. Would you like the opportunity to take leftovers home?
No, I do not want to.
11. Do you recycle/compost waste when you are done eating? Is it easy/convenient?
No, we just put all things including dishes and foods left back to the cleaning staff
12. Rate the cafeteria 1 (worst) through 5 (best) in the following categories. Please explain.
   a. Food quality ④
   b. Food variety ③
   c. Food presentation ④
   d. Cleanliness ④
   e. Convenience ④
13. What is your most favorite part of eating in the cafeteria? Your least favorite?
   Favorite part is Very convenient especially during the midterm week or busy time.

Cooks

1. What year of school are you in? (if applicable)
The fifth year
2. How long have you worked here?
2 years (but not continuous, and it is a part time)
3. What is your job in the kitchen?
Cooking the noodles, making pizzas
4. Do you stay in the same position or rotate occasionally?
Rotate

5. What kind of hours do you work?
5h/week
6. How much food prep vs. cooking do you have to do?
Provide the amount for lunch time or dinner time
7. How much food do you throw away?
Very little
8. Do you deal with packaged food? If yes, what kind of packaging?
The frozen raw shrimp or some other frozen foods
9. Do you reuse prep bowl, etc. or do you have to wash them repeatedly?
No. As the bowls will be prepared by other staff and at the place I cook, there is not water resource I can directly use
10. Do you interact with people going through the food line?
Yes, as far as I finishing cook, I need to deliver the foods to students' plates
11. Do you see any big source of waste in your job?
Not really
12. What is the best part of your day? The worst?
I like people come back and ask more foods I cooked
The worst is that the food is left and no one wants to eat it

Dish Washers

1. What year of school are you in? (if applicable)
The fourth year
2. How long have you worked here?
Just have some periods of part time
3. What is your job in the cafeteria?
Recycle the dishes and put them into the washing machine
4. Do you stay in the same position or rotate occasionally?
Rotate
5. What kind of hours do you work?
4hour/week
6. What tools/appliances do you use?
Hands with gloves
7. Does the work environment make you physically uncomfortable?
Not very comfortable, as the machine has noise and the room temperature is relatively high
8. Do you feel like there are any safety concerns? (Scalding, getting cut on knives, etc.)
Yes, the machine is running in a relatively moist environment and also the dish washing process needs to be touched with water, so probably people should pay more attention to the electricity
9. Do you ever break dishes? If yes, what happens to them?
No, the dishes are plastic and they are not fragile
10. Do you have to throw anything away?
We need to put the left food in dishes to a big plastic bag
11. Do you see any big sources of waste in your job?
Yes, water, foods, and energy
12. What is the best part of your day? The worst?
The best is to see all the dishes are cleaned, the worst is all the dirty dishes are full filled the window

Interview with Director of Dining

Q) How long have you been working here?
I have been working for past 33 years at UMich, prior to that I was at Purdue for 5 years.

Q) How are the menus decided at dining halls?
The menus are created based on feedback received by the students. We also observe the food that is being left uneaten – so we have an idea of what the students like or dislike. The executive chef at each dining hall also keeps the variety.

Q) How do you determine the quantity of food?
We have an in-house software which is based on the past data of food consumption. The data is analyzed based on the supply of food articles; the weekly consumption etc. So we get an idea on the amount we are cooking and procuring.
It also depends on type of food e.g. chicken nuggets. Students really like it so we take a margin on it.

Q) How do you determine the food sources to choose from?
We always try to get as much local food as possible. Recently, we introduced sustainable sea food. The only problem with it is that sometimes it is tough to procure sustainable food- due to the lack of supply which results in higher prices. So, we need to keep an eye on how much are we spending.

Q) How do determine the prices?
Prices are again evaluated through past data. The prices are revised every year.

Q) What kind of feedback system you have?
We have suggestion cards, surveys and active live feedback. But what I mostly do is I go out and sit with students-talk to them; ask them if they like the food or not. I believe if people are paying for their food they have the right to ask questions.

Q) What are biggest sources of problems in dining halls?
The major problems are – limited resources, limited facilities and labor. In month of September labor is the biggest concern for us.

Q) What are your concerns when you look for a dishwasher?
My major concerns are:
Capacity: We estimate the requirement of dishes based on the number of students eating. Suppose our requirement is of 2000 dishes/hr. If on a day in a month we require 5000 dishes/hr. I would not buy the machine with 5000 capacity. I would do something to operate the machine with 2000 capacity to improve its throughput. Good throughput is our major requirement with flexible capacity.
Manufacturer's Reputation: MEIKO and HOBART are the manufacturers with good reputation. The past track record of a model by a manufacturer is also evaluated.
Resource Consumption: The water and electricity consumption is taken into account and average monthly resource cost is evaluated and compared with other models.
Noise: Noise is also a major concern. If the equipment is too noisy it makes it difficult for it to operate without ear plugs but that is really tough. So we also choose a machine which is quieter to operate.
Working Conditions: Conditions should be comfortable to work in. Humidity and heat should be limited to minimum.

Q) Maintenance issues related to Dishwashers?
We usually have an assessment done of the machine every month. Since dishwashers are operated daily and that to around 10hrs/day. The assessment is done by third party companies suggested by the manufacturers. Service maintenance is usually required every months or so.

Q) What is usually the lifetime of dishwasher?
15-22years.When it requires frequent maintenance we usually have a full assessment done. This provides valuable insight whether the machine needs to be changed or not.

Q) What is the procurement process for Dishwashers?
We have a bidding process. But as I mentioned earlier all factors are taken into account. We usually build up a base specifications developed by engineers, traders, plumbers and electricians and our past records. The equipment that best suits our needs is selected.

Interview with design rep from Hobart

Q) How often do you come out with new commercial dishwasher models?

Flight type: 1996-FT900, 2008-FT900BD, 2013-FT950

Q) What causes a new model to be produced? Annual turnover? New technology? New aesthetics?

Mostly develop add-ons that reduce water consumption; from the 96' model that used 325lbs water/hr and add on was put out in '01 that reduced it to 150 lbs/hr, and now there is an add on that reduces water consumption to 124 lbs/hr. The 2008 model uses only 90lbs/hr and the 2013 model uses only 74 lbs/hr. However, the more advanced models have a bigger footprint.

Q) What are your primary goals/concerns when designing a new dishwasher?

Driving factor is finding balance between water usage, energy usage, and output quality. The difficulty is finding the proper balance while still reaching quality standards.

Q) How much has commercial dishwasher design changed in the past 10 years?

As there is a greater focus on reducing usage costs, newer models have immensely reduced water and energy consumption involving new technologies such as booster heaters that allow the hot water source to be turned off during cleaning because excess heat is recycled to heat a cold water source.

Q) Do you try to design all your models to meet Energy Star requirements? Why/why not?

Yes. Dishwashers are designed and produced and tested by numerous outside agencies that determine if the machine reaches regulations.

Q) Does your company provide maintenance services yourself? Or is it contracted out?

Yes. All service is conducted through the Hobart service team.

Q) What are the design areas/requirements you think are most important?

Water usage, Energy usage, output quality

Specification feedback from dishwashing staff

- **Please read through the attached Excel File and add comments and make preference rank to each item.**
- **PS: DW stands for options related to Dishwasher**

Requirement	Rank	Comments
Limit heat/humidity in workspace	★★★	In fall semester and spring semester, it is Ok. While I have worked in summer in Centennial Hall for dish washing staff and the experience is very bad.
Limit noise	★	We are pretty busy during the meal time and we pay less attention to the noise. I guess if it is in an acceptable range, we may not care much since students who are eating also make a lot of noise.
Prevent steam/hot water from scalding user	★★★	Safety should always be the most important thing
Prevent wet floors, other slip/trip hazards	★★	People are always trying to avoid this one; the fact is water exists everywhere, and we even do not know where it comes from. Trying to prevent the leak of steam during machine operation is necessary. Sometimes people may trip over due to the wet floor
Prevent user exposure to harmful chemicals	★★	The solution for washing and sanitizing is provided by UDS (University Dining Service), the only thing we want to pay attention is the amount
Ensure electrical/natural gas safety	★★★	Safety should always be the most important thing
Utilize common kitchen power source (Plug into regular outlet?)	★	I think any power which can guarantee the machine work should be OK
All moving parts enclosed/inaccessible during machine operation	★★★	Yes, it not only prevent people from cutting fingers, but also make sure no things fly into the machine to get it stuck
Emergency shutdown feature	★★★	I like this set up for two options to stop the machine, very useful
Removal and proper disposal of waste from tableware (compost/recycling/trash)	★★	This is a part of our job. We collect the dishes and move the waste and put the dishes (without any solid on that) into dishwasher
Wash & sanitize dishes to meet regulations	★	Actually, we have never care the regulation, or we default the dishes washed by the machine meets the regulations
Dry & cool dishes	★★★	This one is very sweet. If your design can make Dishes cool to <133 deg F within 3 seconds of leaving machine, it would be good for us to get rid of scald
Adequate throughput to meet demand	★	Actually, I do not know how to adjust the number. Sometimes, students come together and the service line asks us for more dishes. Sometimes, even we carry the dishes to the hall, few students there. The problem is we cannot control the relationship between demand and time since they are random.
Prevent damage to tableware	★	According to my experience, the lost of dishes due to students take them out of dining hall and do not bring them back is much worse than the damage itself
Not take up excessive space	★	Yes, the less space is a better choice. But compared to the other options, I would vote this one less important
Materials	★	Probably, the design worker pay more attention to this one, neither for us
Adequate lifespan and durability	★★	If you are asking my personal aspect, I would say I do not know since my working time is much less than the machine's life time. But for the UDS, I think it is important, they do not want to change the machine frequently as it will influence the operation of dining service and waste a lot of time and money
Cost no more than ballpark for existing options	★★★	The same reason as above. The UDS has its own budgets for purchasing the dishwashers. The more advanced machines may cost more money. They do not want to have any problems of overspend

- **There are two of this blank table I sent out, one of my friend is working with the dishwasher things, the other is cleaning the tables and collecting the tableware. I combined their comments together into one form so that it is easy to read. For the contradiction rank of items, I asked them to convince each other to get the final thoughts, which I put in this table.**

Product validation interview with Bursley Hall Dining Facility Manager

Q) How important is brand name and companies reputation when selecting a kitchen appliance (dishwasher)?

A) It is important. We always look for companies with good proven record. But as far as new companies are concerned if they are willing to provide their equipment as pilot equipment for testing then it is fine. We also travel to food and trade shows where a lot of equipment is showcased so if we like any equipment we ask for the detailed features.

Q) What would entice you to buy a dish washer from a new company?

A) Definitely not less cost. The company should be certified from NSF and energy star. Plus we also vouch for companies that are making more sustainable products from design point of view. Consumer records also can help if the company could generate those.

Q) What is longest payback time you can accept? Suppose our product costs 10k more?

A) 10k – 15k is insignificant. Most of the time, if the equipment is eco-friendly and can recover its cost in even 4 -5 years it is totally fine. The other factor is reliability. If there is a major breakdown you know it costs around $2000 just on the paperwork! We have to send out orders for new parts and stuff and losses are also incurred due to stoppage of work.

Another interesting factor is that when new buildings are constructed, big equipment such as the dishwashers are a part of the whole multi- million dollar project. This is because the construction of the kitchen is mainly dominated by the dishwasher because of its size. Also we want to minimize the distance the plates need to travel in total. So again 10k-15k does not make a huge difference here.

Q) Views about add-on?

A) We believe add-ons are not that efficient in functionality. I would personally prefer a product that has in built features for efficiency and sustainability.

Q) Views about design?

A) Thermoelectric coolers are innovative and I would definitely look forward to it. I am not that much worried about how dry it would get the dishes. The dishes that we take out of the machine are usually very wet. But if it does the job while consuming less energy it is welcome. You need to make sure UV lights are sealed properly. In case any PPEs are required that should be a part of the specifications.

Energy savings are very good. Water recycling unit should be placed properly and the cartridges should be easily to replace. Wash water has a lot of junk in it so the refining has to be good.

Given the cost savings I would definitely pay more by about 10-15k. It is going to pay itself back in less than 3 years, so it is a good prospect.

Product validation feedback from dishwashing staff

➢ *Rank the features*

	L.Sun (General)	T.Xu (Dishwashing staff)
Waste heat recovery system	★★★★★	★★★★★★
Water recycle unit	★★★★★★	★★★★★
Compressed air for food removal	★★	★★★
UV sanitization	★★★	★★
Thermoelectric coolers	★★★★	★★★★
Declined convey belt	★	★

It seems like the features are divided into three classes, the *Waste heat recovery system* and *Water recycle unit* are the most important ones, then are the *UV sanitization* and *Thermoelectric coolers*. The *compressed air for food removal* and *declined convey belt* are the least significant ones.

➢ *Summary of safety concerns:*

For the water recycle unit: if the recycled water will be used to deal with foods, the quality of water should be strictly controlled according to related principles/standards.

For the compressed air system: the pressure limit for the dishwasher needs to be re-estimated, since the compressed air requires the material to withstand the high pressure, also need to take the material of dishes into consideration.

UV sanitization: is there any standard you should refer to for how large the light intensity is enough to perfectly obtain the sanitization process. How to control and periodically measure the standard?

Declined convey belt: there is, more or less, relatively high humidity around the dishes. Declined convey belt will make the dishes or food remain slide down. Is there any measurement to avoid such case?

➢ *Other recommended features:*

Some ideas they gave me are pretty similar to what we have done before for the brainstorming process.

Additional product validation feedback from dishwashing staff

They were not happy to change the sanitizing solution.
They were curious about the total time reduction and felt that if it was only a few minutes it wouldn't make a difference to them.
The new belt with the inclined slope would increase the effort required to place the rack on the conveyor belt.
Also they weren't too sure about changing the rack shape which might make placing plates difficult.
Finally they were happy about the drying feature as it would reduce their wiping time.

Appendix V – Requirement-to-Specification Mapping

Requirement	Specification
Limit heat/humidity in workspace	Limit heat index in space to less than 91 deg F
Limit noise in workspace	Limit noise production to 75 dB while machine is in operation
Prevent steam/hot water from scalding user	Enclose water while machine is in operation
	Enclose steam while machine is in operation
	Vent steam before user can open machine
	Machine must be thermally insulated to limit surface temperature to 140 deg F
Prevent wet floors, other slip/trip hazards	Enclose water while machine is in operation
	Provide overflow drain piping to prevent water overflow
	Vent steam before user can open machine
	Utility lines cannot be horizontal on the floor and exposed
	Utility lines must be insulated with non-absorbent material
All moving parts enclosed/inaccessible during machine operation	Enclose moving parts while machine is in operation
Prevent user exposure to harmful chemicals	Do not use chemicals requiring protective clothing (OSHA standards) in the dishwashing process
Ensure electrical safety	Electrical units close to sinks have to be watertight and washable
Ensure natural gas safety	If natural gas heating is used, comply with all safety regulations
Emergency shutdown feature	Provide mechanical and electrical emergency stops
	Provide emergency stop feature if machine is opened during operation or maintenance is being conducted
Adequate throughput to meet demand	Maximum cleaning capacity of at least 625 disher per hour
Adequate lifespan and durability	Withstand 1,000,000 cycles with only minor replacements or repairs (Dishwasher only)
Utilize common kitchen power source	If machine requires electricity, must be adaptable to 208V, 240V, or 480V power
Not take up excessive space	Maximum dimensions of 3.5 x 2.0 x 2.5m or maximum volume of 17 cubic meters
Cost no more than the ballpark for existing options	Retail cost of $40,000 or less
	Product pays back capital cost with energy savings in <5 years
Removal and proper disposal of waste from tableware	Solid waste must be removed and disposed of prior to entering dishwashing stage
Wash and sanitize dishes to meet regulations	Water temps between 150-165 deg F while washing
	Water temps above 120 deg F while washing (with sanitizing solution)
	Water temps between 165-180 deg F while sanitizing (no sanitizing solution)
	Chemical sanitizer must contain chlorine, iodine, or quaternary ammonium
	Must use less than 0.005 gallons of water to clean each plate
	Must consume less than 100 kWh/day
	Ensure materials used can withstand 165 deg F w/ sanitizing solution or 180 deg F w/out sanitizing solution
	Ensure materials used can withstand operating pressures
	Drain line cannot be connected directly to sewer line (Dishwasher only)
	A visual or audible sanitizing agent flow indicator must be installed in a conspicuous location (Dishwasher only)
	Detergent and sanitizing solution tank caps must be easily accessible (Dishwasher only)
Dry and cool dishes	Dishes must cool to 133 deg F within 3 seconds of leaving machine (Dishwasher only)

Appendix VI – Failure Mode and Effects Analysis for Safety Requirements

Description	Probability	Severity	Detection	Risk Level
(Enclose steam while machine is in operation) Steam Burn	B	IV	2	Moderate
Enclose moving parts while machine is in operation (Injury due to moving parts)	C	IV	2	High
Machine must be thermally insulated to limit surface temperature to 140 deg F (Heat Injury)	D	IV	5	Unacceptable
Utility lines cannot be horizontal on the floor and exposed (Electrocution)	B	VI	5	Unacceptable
Do not use chemicals requiring protective clothing (OSHA standards) in the dishwashing process (Burns)	D	VI	5	Unacceptable
If natural gas heating is used, comply with all safety regulations (Gas Leak)	B	VI	5	Unacceptable
Solid waste must be removed and disposed of prior to entering dishwashing stage (Stops Machine Operation)	C	III	5	High
Chemical sanitizer must contain chlorine, iodine, or quaternary ammonium (Hazardous chemicals on utensils)	C	VI	5	Unacceptable
Ensure materials used can withstand operating pressures (Utensils Break)	C	IV	1	Moderate

Probability (P)

Meaning	Rating
Extremely Unlikely (Virtually impossible or No known occurrences on similar products or processes, with many running hours)	A
Remote (relatively few failures)	B
Occasional (occasional failures)	C
Reasonably Possible (repeated failures)	D
Frequent (failure is almost inevitable)	E

Detection (D)

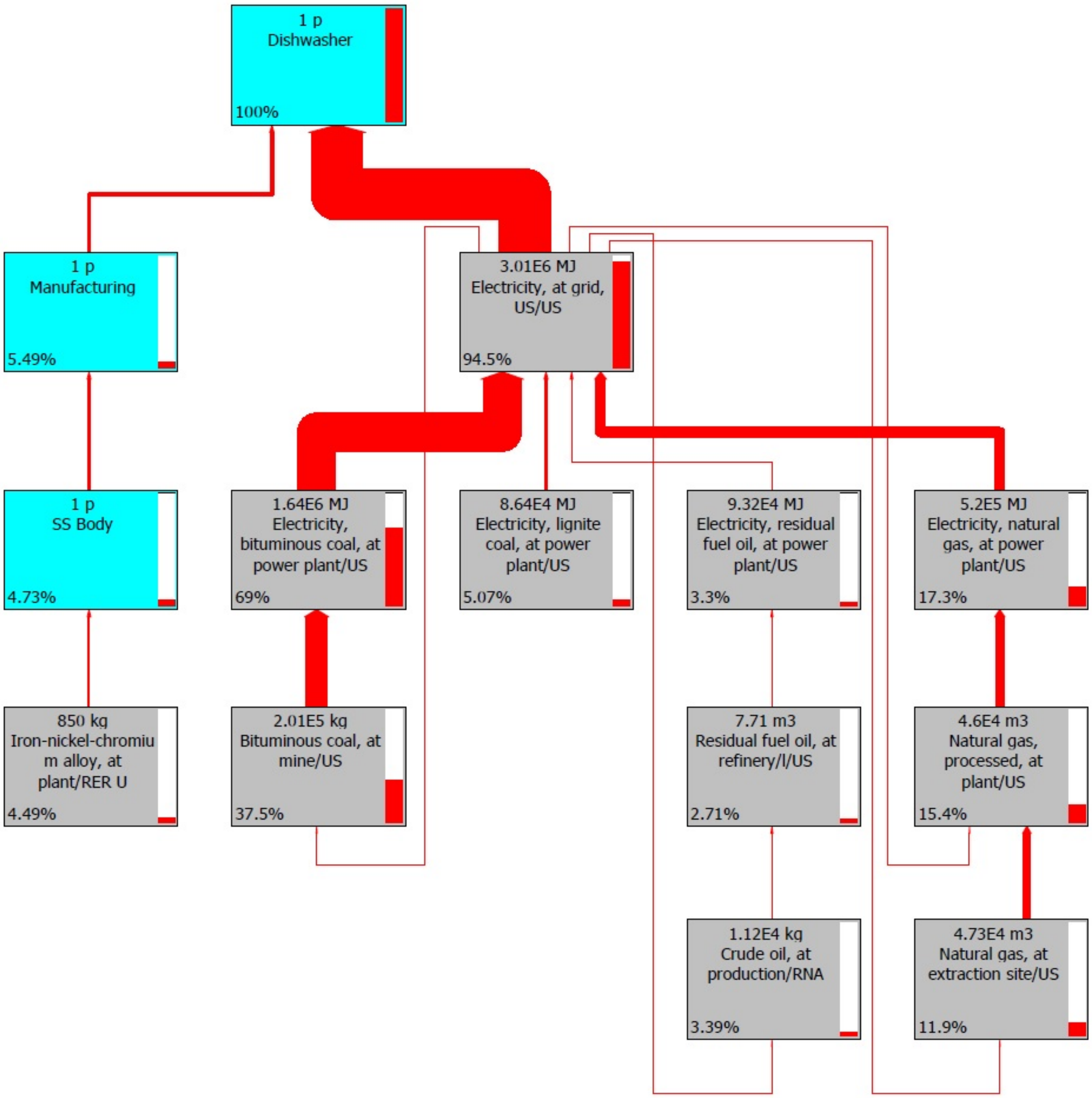
Meaning	Rating
Certain - fault will be caught on test	1
Almost certain	2
High	3
Moderate	4
Low	5
Fault is undetected by operators	6

Severity (S)

Meaning	Rating
No relevant effect on reliability or safety	I
Very minor, no damage, no injuries, only results in a maintenance action (only noticed by discriminating customers)	II
Minor, low damage, light injuries (affects very little of the system, noticed by average customer)	III
Moderate, moderate damage, injuries possible (most customers are annoyed, mostly financial damage)	IV
Critical (causes a loss of primary function; Loss of all safety Margins, 1 failure away from a catastrophe, severe damage, severe injuries, max 1 possible death)	V
Catastrophic (product becomes inoperative; the failure may result complete unsafe operation and possible multiple deaths)	VI

Probability / Severity -->		II	III	IV	V	VI
A		Low	Low	Low	Moderate	High
B		Low	Low	Moderate	High	Unacceptable
C		Low	Moderate	Moderate	High	Unacceptable
D		Moderate	Moderate	High	Unacceptable	Unacceptable
E		Moderate	High	Unacceptable	Unacceptable	Unacceptable

Appendix VII – Eco-Indicator 99 network for Meiko K-400



Appendix VIII – Concept Generation Brainstorming

Dishwashers

Using steam for power: (electricity)
- steam turbine
- waste heat scavengers

Using steam for heat: (electricity & water)
- heating food on serving line
- heating water tank/incoming water
- heating steam cooker/food cabinets

Reusing wash water: (water)
- pre-heating clean wash water
- re-using rinse water (pre-wash)
- running waste water through some sort of filter and using it for irrigation purposes

Alternative heating of water: (electricity)
- solar power
- natural gas
- biogas/biodiesel from composted food

Dish drying: (electricity)
- adsorption
- centrifuge
- air drying on conveyor belt (with hangers?)

Different detergents: (electricity)
- better performance in cold water

Sanitizing: (electricity/water)
- UV light
- radiation
- alcohol bath
- lower temp sanitizing

General

Food-phobic tableware:
- applied coating
- peeling layers/shedding
- exuding coating (enzyme?)

Compostable tableware

Disposable tableware

Food waste removal:
- compressed air
- manual scraping
- centrifuge
- bacteria
- dogs licking the plates clean
- burn it off

Locate kitchen underneath cafeteria - use radiant (& rising) heat:
- heat food on serving line
- heat space during the winter

Removal of tableware from the system:

- serve liquefied food in disposable bags
- distribute nourishing IVs
- have diners eat out of serving trays

Use a green roof to maintain temperature

Appendix IX – Description and Scoring of Generated Concepts

Design Concept ==>	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	A+F+K	A+G+J	B+I+M
The (additional) capital cost of the product is paid back through energy savings in less than 5 years	4	3	2	3	1	5	1	1	4	3	4	1	5	3	2	4	3	3	5	2	4
Water consumption is reduced to 0.005 gallons per plate.	1	4	4	1	4	2	1	3	2	1	2	2	1	1	1	1	1	1	2	1	4
Energy consumption does not exceed 100 kWh per day.	2	3	1	3	1	2	1	1	3	2	2	2	3	3	1	1	3	3	2	2	5
Steam is enclosed during operation and properly vented before the user can open the machine.	5	3	3	3	3	3	5	3	3	5	2	4	4	5	4	5	3	3	5	5	4
The exterior surface of the machine does not exceed 140 deg F.	3	3	3	3	3	3	3	3	3	4	3	3	4	5	4	5	3	3	3	4	4
Dishes are cooled to below 133 deg F within 5 seconds of leaving the machine.	1	1	1	1	1	1	5	1	1	1	1	1	3	4	2	5	1	1	1	5	3
The maximum cleaning capacity of the system is at least 625 dishes per hour.	3	3	3	3	3	3	4	3	3	2	4	4	4	2	3	5	3	3	4	3	4
Total score ===>	84	93	72	75	63	93	64	57	90	77	82	61	106	95	63	98	75	75	100	81	127

Dishwasher Accessories

A: Waste heat recovery system- This add- on recovers the heat by regulating the exhaust steam through a heat exchanger to heat the incoming water. Instead of shell and tube direct mixing of rinse water and steam could be implemented. Advantage: Saves the energy required to heat the water. Disadvantage: Regulation of steam is possible only when the dishwasher is operating.

B: Water recycling unit: This accessory placed before the drain of the dishwasher can act as filter using reverse osmosis to filter the waste water. The recovered water could then be supplied to the incoming rinse water tank. Advantage: Reduces water wastage significantly since the water drained has minimal solid particle impurities and much of the water can be recovered. Disadvantage: Additional tank and pumping arrangement may be required. If filtering is done mechanically, then maintenance is increased.

C: Install a filtration system underneath the sink when scraping off food to recycle the water. Can be a very simple filtration process using a semipermeable membrane or something of that sort.

D: Direct heating using solar panels installed on top of the roof. Only hardware addition is the glass and reflectors. Should reduce electricity consumption by quite a bit.

E: Use compressed air to scrape off food. Reduces water consumption but increases energy consumption significantly through the process of preparing compressed air. Way more efficient than water cleaning as the pressure is significant.

F: Design a better dish rack that exposes more surface area to the water jets inside the machine.

G: Add another compartment at the end of the washer to house a high-powered fan or compressed air to dry tableware. Can compare energy consumption patterns. This gives a much cleaner and drier surface however it might be less efficient in terms of number of plates dried per hour and would require more effort.

H: Let the water piped out from dishwasher be used by toilets. Of course, the water coming out of dishwasher should be filtered or handled with adding disinfectant before being transferred to the toilets.

I: Install ultraviolet lights in a compartment after the wash cycle. This can be used to sterilize the tableware without the use of very hot water and/or chemical sanitizers.

New Dishwashers

J: 3 separate compartment dishwasher- 1st compartment is used for loading the racks and plates, 2nd is used to actually wash and sanitize the dishes, this compartment shall have closing doors on each side ensuring that heat and steam do not escape the chamber. Heat is then used to pre-heat incoming wash water. Doors to be opened only for rack in-out flow. 3rd compartment used for drying.

K: Inclined Conveyor Dishwasher: The conveyor of the dishwasher is heavily loaded with dishes and racks. Additional back pressure imposed due to water jets further increases the power requirement to move the belt. Contrary if an inclined conveyor is used, this reduces the power requirement of the conveyor. The water jets can be directed in the direction of motion of the conveyor with plates facing the jet. Ideally the conveyor could be vertical.

L: Automatic dish distribution system: The door for dishwasher machine is not necessary as big as the normal one. A suitable size of entrance is provided to let the dishes come into and out of the dishwasher. Since dishes are put on the conveyer, it carries the dishes into the dishwasher, then the machine will automatically sorts the dishes to maximize capacity and then adjusts wash cycle to match number of dishes. Disadvantage: advanced technology is needed to accurately calculate the positions for each dishes.

M: New dish drying system: Use a separate compartment for the drying cycle and use thermoelectric coolers to dry dishes instead of relying purely on heaters.

N: New dish drying system: Use an absorbent reforming sponge that is passed over the dishes.

O: High-pressure cold water mist system: Water mist has large surface area and will absorb heat very effectively. Heat/steam is vented from dishwasher after sanitizing/drying stage into separate water mist compartment. Mist is activated, absorbs heat, and is used to supply water to wash tank.

Non-Dishwasher Solutions

P: Use of Biodegradable Plates: Plates could be made up of organic materials which are biodegradable. This eliminates the need for washing the dishes.

Q: Redo the piping of the cafeteria to ensure more efficient heat distribution. Use waste heat from kitchen appliances to keep food warm as it is waiting to be served. A lot of waste heat can thus be recycled from the kitchen to the serving area.

R: Reroute heat exhaust vents from kitchen appliances to allow it to heat the dining area during cold months and vent to the outside during warm months.

Appendix X – Alpha Design Energy Savings Calculations

<table>
<tr><th colspan="2">ENERGY SAVINGS</th></tr>
<tr><td>UV Light [36,48,49,50,51]</td><td>Sanitizing Baseline</td></tr>
<tr><td>254 nm wavelength used by germicidal lamps. For more effectiveness need to circulate air or water continuously.
Key points:
• There should be no obstacle in line of sight.
• Sterilizing and Disinfecting are different usually disinfecting can be achieved up to 99.9999% (this is called 4th log reduction).
Disadvantages:
• Light and repair phenomenon where DNA of bacteria repairs itself after being damaged.
• UV lamps need to be replaced annually. In addition dust film over UV lamps reduce effectiveness and so regular cleaning is required.

UV Dosage Calculation:
• For a 4log reduction in water 200mJ/cm2 of exposure is required.
• Assuming it would take twice the amount of radiation to sterilize plates.

UV dosage for plates: 400mJ/cm2.
An average plate can be considered to be a disc of 10cm.
Total exposure area = 2*∏*(10)^2 = 628.31 cm2.
Total power requirement = 400*628.31= 0.251 J

Assuming a total of 0.25% efficiency we have total power = 1J/plate

7000 plates = 7kJ /hr.
If dishwasher is operated for 10hrs everyday total power required = 70kJ= 0.0196 kWh

Taking an overall factor of 5 considering dust on lamps and other unknown environmental inefficiencies.
Total power = 0.1 kWh</td><td>Requires sanitizing solution and motors for pumping rinse water = 0.55kW.
Heater for rinse water tank = 20kW.
Total power assuming heater is operated 10% of the total time the dishwasher operates for heating the water required for sanitizing. (This is based on the fact that water may not loose heat rest of the time.)

Total power = 0.55*10 + 0.1*20*10= 25.5kWh</td></tr>
<tr><td colspan="2">Total Electricity Savings = 25.5 – 0.1 = 25.4kWh/day = 9271kWh/year</td></tr>
</table>

<table>
<tr><td>Thermoelectric Coolers [37,52,53,54,55,56]</td><td>Blower Drying Baseline</td></tr>
<tr><td>Results in condensation drying instead of evaporative drying in the dishwasher.
Works on the principle of Peltier effect.

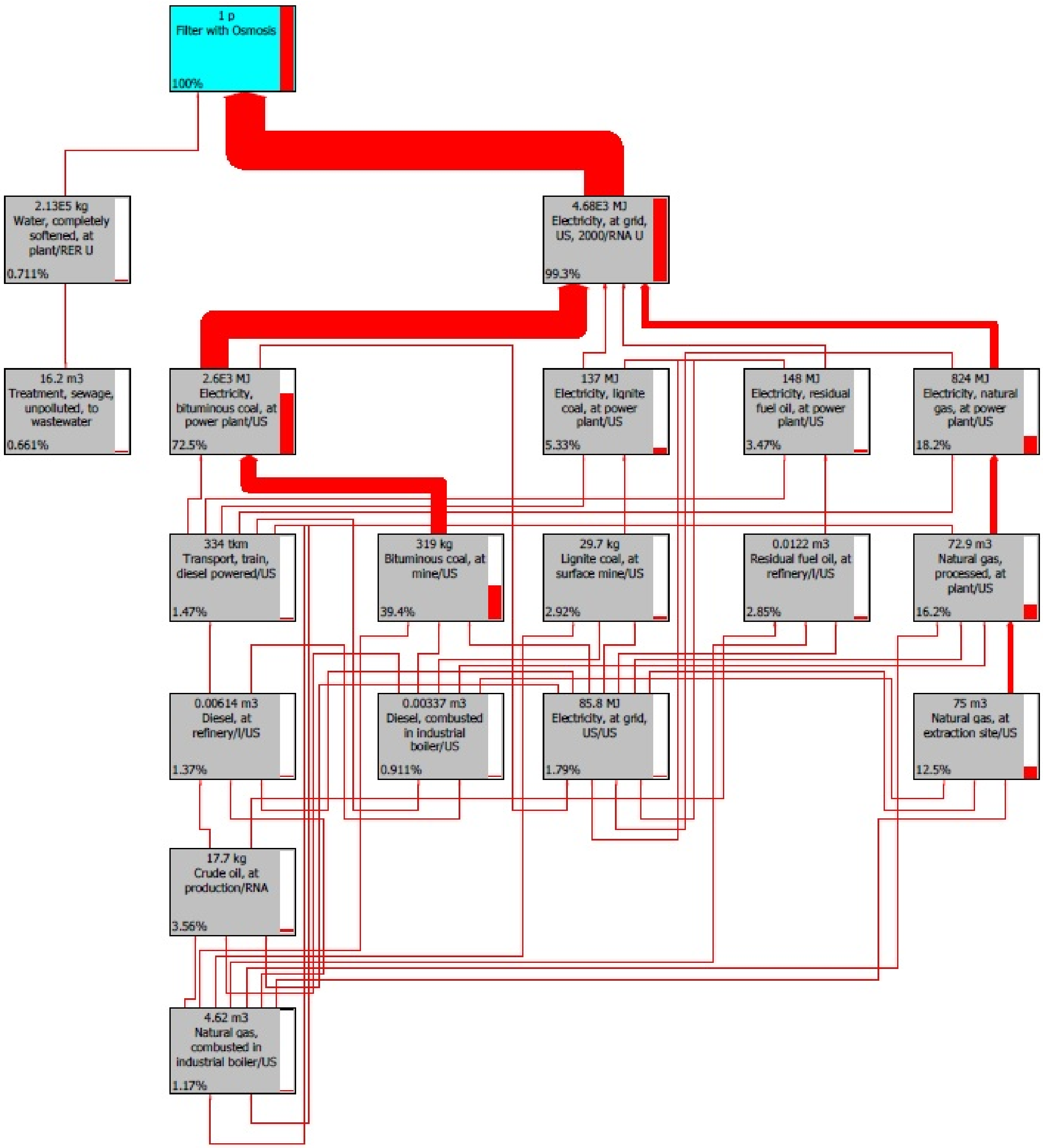
Power Calculations:
Suppose that drying takes 90s. The thickness of the steel plate to be cooled inside the drying section to be 2.5 mm = 0.0025m.
A cooling of 1/5 of the area of the drying section side wall is assumed to cause sufficient condensation on the wall to improve drying.
Total area = 0.5x0.5 = 0.25m2.
Area to be cooled = 0.25/5 = 0.05 m2.
Density Steel = 8010 kg/m3.
Specific Heat = 460 J/Kg C
Temperature Delta = 40
Q = (0.0025 x 0.05 x 8010 x 460 x 40)/90 = 204W
Q is the total amount of heat to be removed.
Efficiency of TEC = 30%
Total Power required = 650W = 0.65kW.</td><td>Blower motor = 0.37kW
Heating Element = 3kW.

Total power = 3.7kW.</td></tr>
<tr><td colspan="2">Total Electricity Savings: 33.7 – 6.5 = 27.2kWh. 27.2*365 = 9928kWh/year.</td></tr>
<tr><td colspan="2" align="center">WATER SAVINGS [38]</td></tr>
<tr><td colspan="2">Suppose that the reverse osmosis system operates on 60psi pressure with 5:1 ratio.
Total flow rate calculation:
Total gallons per hour at full capacity = 0.28 x 306 = 85.68 gallons/hr = 0.3243m3/hr.
Q = total flow rate = 0.3243/3600 = 0.00009 m3/s.
Pressure = 60 psi = 60 x 0.0689 = 4.134bar
Assuming the pump has 50% efficiency:
Power = PQ/(1000*efficiency) = 0.0744kW. It would require 0.37kW motor.
Total additional power required = 0.37x10x365 = 1350kWh/year</td></tr>
<tr><td colspan="2">Total Water Savings = 85.68/6 = 14.28 Gallons/hr => 14.28x10x365 = 52122 Gallons/year</td></tr>
<tr><td colspan="2" align="center">TOTAL SAVINGS</td></tr>
<tr><td colspan="2">From Power: (9217+9928 - 1350)*0.12 = $2125.4/year
From Water: (52122/7400) * 36.53 = $257.299/year.</td></tr>
</table>

Appendix XI – Environmental Impact Assessment of Reverse Osmosis and Filtration Systems

SimaPro 7.3 Educational | Network | Date: 12/12/2013 Time: 2:00:51 PM
Project: Filter Osmosis

Product:	Filter with Osmosis
Project:	Filter Osmosis
Category:	Assembly\Others
Method:	Eco-indicator 99 (E) V2.08 / Europe EI 99 E/E
Selected weight:	Single score, (Pt)
Node weight:	Including inputs
Exclude long-term emissions:	No
Node cut-off:	0.63%

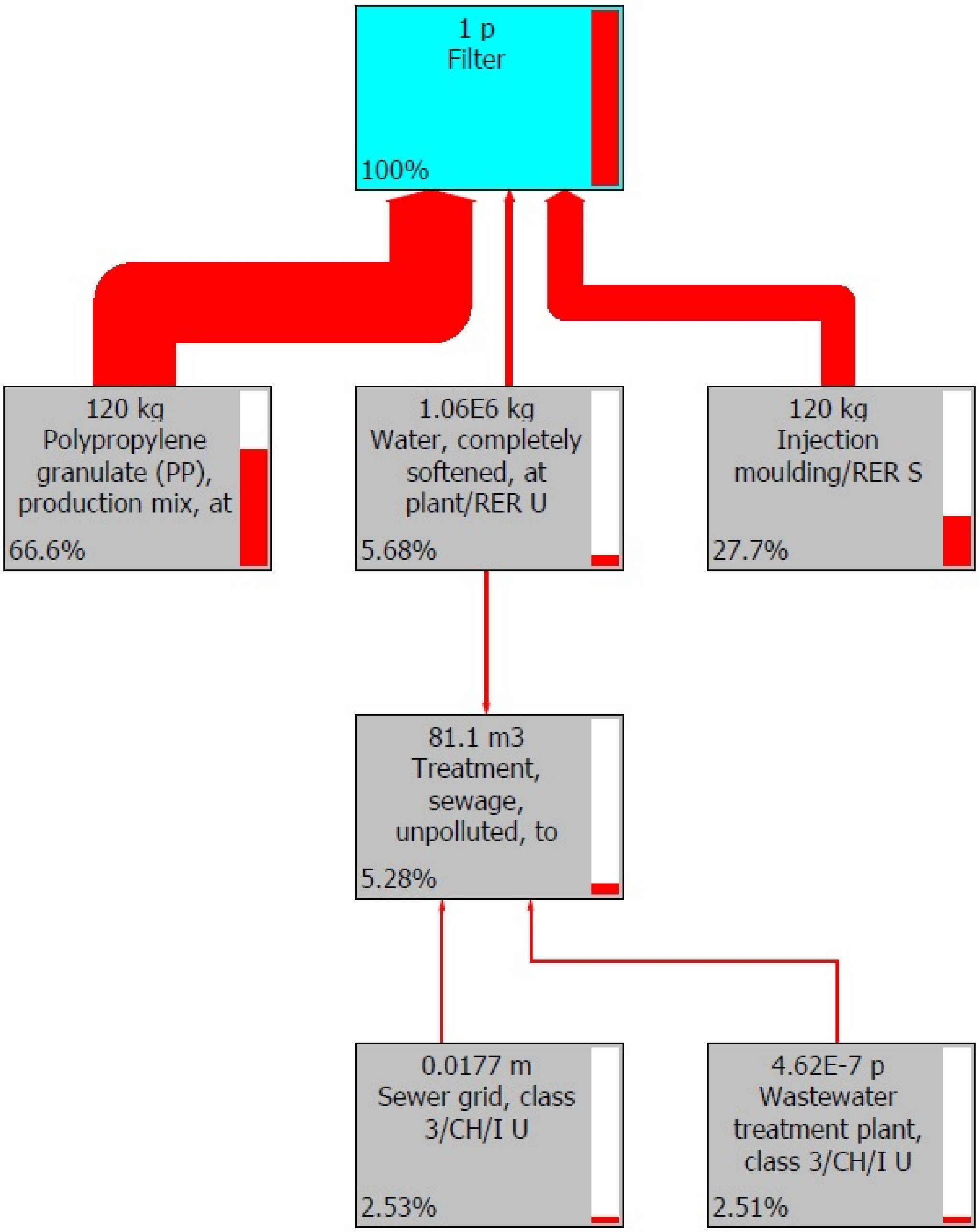


SimaPro 7.3 Educational
Project: Filtration

Network

Date: 12/12/2013 Time: 1:51:28 PM

Product:	Filter
Project:	Filtration
Category:	Assembly\Others
Method:	Eco-indicator 99 (E) V2.08 / Europe EI 99 E/E
Selected weight:	Single score, (Pt)
Node weight:	Including inputs
Exclude long-term emissions:	No
Node cut-off:	2.3%



Appendix XII – Final Design Energy Savings Calculations

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Total Savings: 33.7 – 6.5 = 27.2kWh. 27.2*365 = 9928kWh/year.	
TOTAL SAVINGS	
(9217+9928)*0.12 = $2297.4/year	