Siemens Food Sustainability at Penn State

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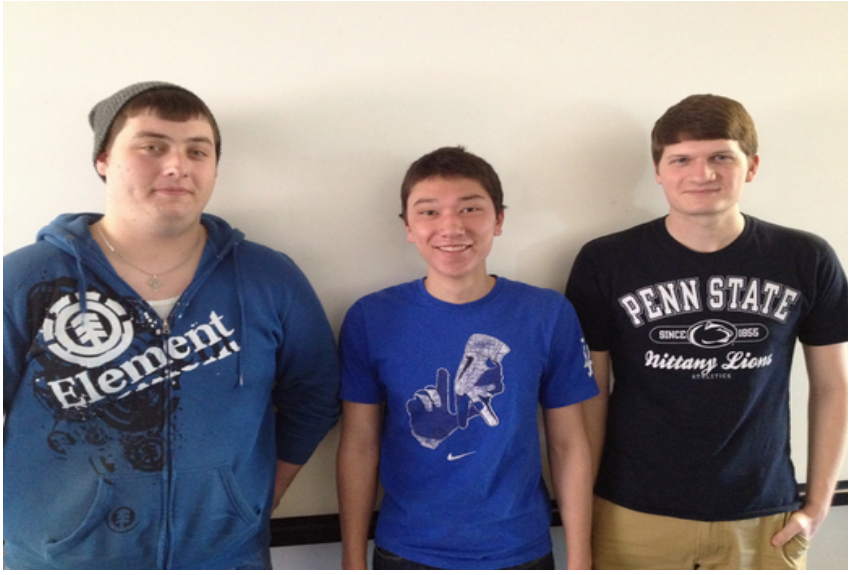
Introduction to Engineering Design 100.020
Instructor: Liz Kisenwether



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Team Name: Hooked on Ponics

Project Summary: The Penn State Main Campus needs to utilize more ecologically efficient means of localizing food sources for on-campus dining. Currently the campus spends approximately $1.7 million per year on vegetables and fish that can be grown using aquaponics (ie: lettuce, spinach, cucumbers, tomatoes, onions, and tilapia). Aquaponics is a system used to cultivate plants in nutrient enriched liquid – without soil – alongside fish, which are also later harvested.[1] With thanks to aquaponics.com and Green Towers, we have found that Penn State could save $2.1 million per year on the vegetables listed and tilapia by growing them here in a new aquaponics facility. PSU Aquaponics is a sustainable solution because it cuts down on food production and transportation costs, thus also reducing emissions that damage the Earth. The payback period for the costs to construct and start this plan is only about five and half years because of the savings on fish, crops, and transportation costs.

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Introduction

The problem we looked at and researched thoroughly at Penn State is the campus' less than perfect solutions to the dining commons' food sustainability. The team's definition for sustainability that was followed throughout the design process as a goal is creating systems to meet humanly needs that cause the least amount of damage to the Earth in an ethically balanced way. At first the team looked at ways to reduce the damage caused by both the campus' sources for food and water, but our instructor made us realize the water sources for this campus are already very efficient and improving them at all would just be a wasted effort. So this made us stick with just the food problem.

A few preliminary ideas were brainstormed to help reduce this sustainability issue, mainly the use of hydroponics to supply certain crops to the dining halls. Hydroponics is defined by dictionary.com as the cultivation of plants by placing the roots in liquid nutrient solutions rather than in soil.[1] This idea was thought of because a couple of the group members had already done research on this future of farming and already knew the great potentials from the system. The only problem with this was that the projected impact on the sustainability goal was slight since it was just a system for growing a few plants. Then something called aquaponics appeared in our early research which we saw as a much better potential for cultivating food locally. Rather than just growing crops like lettuce, spinach, tomatoes, cucumber, celery, and onions, which are all possible through both systems, aquaponics can grow certain fish, like tilapia, along with the plants. This was seen as a much better system to implement since buying fish at a large scale can sometimes be very expensive and growing them here instead would save most of this money.

After the team established that aquaponics would be the solution to the goal of food sustainability, the next part was finding out the numbers. In the beginning all of the numbers we needed to find were for the current conditions of purchasing for the crops and fish that could be replaced by aquaponics. What should have been one of the easier parts of the research turned out to be one of the more difficult in cost gathering. The school's director of food and housing and the director of purchasing were both contacted but the numbers we needed on the current conditions could not be disclosed. So this made us resort to surveys and rough estimations from the survey numbers to gather current costing conditions.

Concept Development

The next step in this project was to distinguish between the most and least important aspects needed to look through in the final design for the aquaponics system. A tool used to determine the most important criteria for the design is called an Analytical Hierarchy Matrix (AHP). An AHP Matrix was performed on five criteria we believed most relevant for the design and has been presented in **Chart 1**.

Chart 1: AHP Matrix for Preliminary Design

	Efficiency	Cost	Versatility	Productivity	Aesthetics	Totals	Weight
Efficiency	1	1	2	0.5	3	7.5	22%
Cost	1	1	2	0.5	4	8.5	25%
Versatility	0.5	0.5	1	0.5	2	4.5	13%
Productivity	2	2	2	1	4	0.33	33%
Aesthetics	0.33	0.25	0.5	0.25	1	2.33	7%
					Total	33.83	

From this matrix it could be decided that the most important aspects that needed the most attention when planning are the productivity and cost of the design, therefore these were what would be looked at most in our research and planning.

Due to the variety of aquaponic designs and ways they have been implemented around the world, there were many initial design solutions that the team thought about, all with their own pros and cons. Brainstormed ideas for the aquaponics building design included a tower of floors that would reduce the land taken up by the building. This idea was quickly changed since Penn State has a good amount of available land. Another design was to just have one floor of aquaponics with a much larger base area. This idea was also then dismissed because of two small factors that worked against the two major design criteria from the AHP matrix, costing and productivity. Through research on construction cost, it was found that building up costs less than building more along the ground, ie: one floor would cost more than two floors of equivalent cubic volume.

The final design was just a small twist from both of the designs. After looking at the numbers – the current crop volume purchased and potential crop volume from an aquaponics system – ten floors, a medium to large floor value from the first two ideas was a sufficient floor

level. At ten levels, the planned square footage of each floor of the plant (about 56,000 sq. ft. each) would be sufficient for producing goods for the dining commons. The reason for ten floors at an area of this is that the amount of fish that could be grown would supply about two thirds of the need for the dining halls and would almost perfectly match the need for the vegetables.

Image 1: Potential Site for Aquaponics Plant [2]

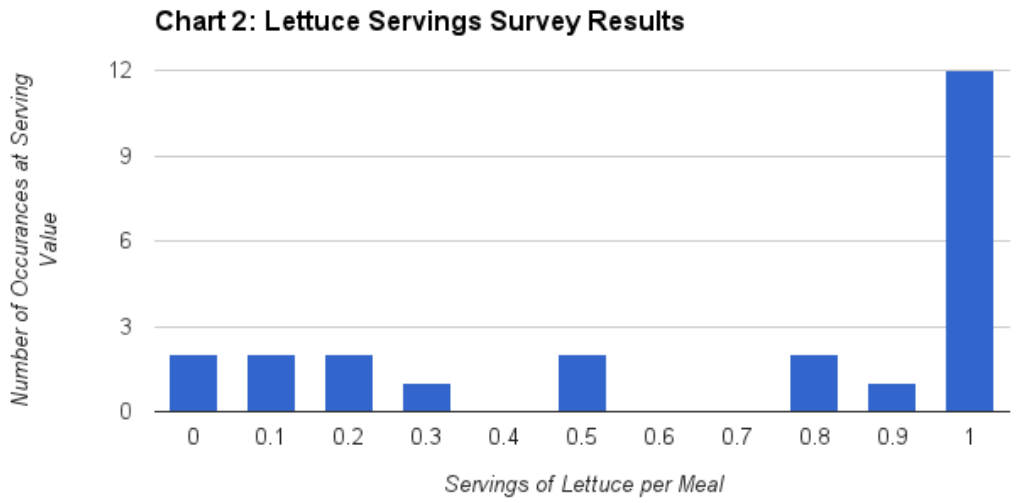
No matter the square footage of the final design or other aspects affecting nearby areas, the location for this potential project was selected on the east side of campus. Along Porter Rd. next to the intersection with College Ave. and near the Swine Research Center, there is a large area of available land owned by Penn State where an aquaponics plant could be built. This area is great because the closer the campus it is, the lower the costs of transporting the goods and the easier it is for students to run the plant, which became a part of the plan in order to reduce costs to run the plant. A satellite image of the potential building site has been provided by Google Maps in **Image 1** above.

Detailed Concept Development

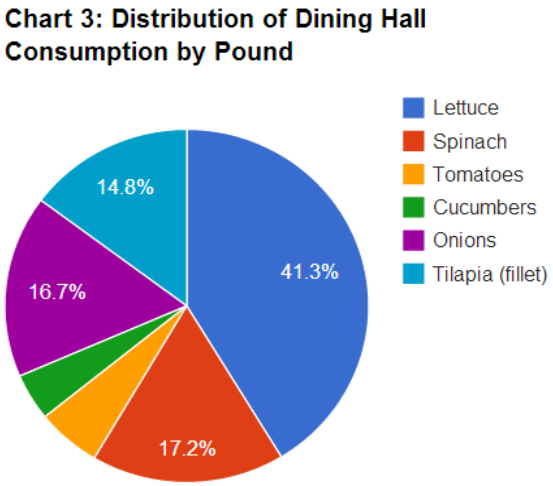
The first step in designing an efficient and self-sufficient aquaponics system was to determine all of the costs and quantitative benefits from the Penn State Main Campus switching to aquaponics as its main source of lettuce, spinach, tilapia, etc. To start this we researched what the current pricing conditions for these vegetables and fish were at Penn State. From the PSU Director of Purchasing, John Mondock, we learned that the school does already try their best to purchase food as locally as possible while still being fiscally responsible since local foods are usually less available and more expensive. Mr. Mondock, however, was unable to provide us with actual numbers for costing.[4] This forced us to find other means of approximating the current spending on these goods.

The method we chose to gather numbers was then by holding a quick survey of our classroom asking our classmates how much lettuce they ate at the dining commons per meal. We asked them approximately what value they would give to the number of servings of lettuce per

meal they ate for lunch and dinner at the dining commons (one being one serving every meal and 0.5 being every other meal). The results of this survey resulted in an average of 0.65 servings of lettuce per meal (one serving being defined as about 72 g of lettuce).[5] A distribution chart of this survey's results has been provided in **Chart 2.**



From these numbers we were able to approximate the number of servings of lettuce served to Penn State by multiplying this value by the average number of meals provided by the campus per year – about 87,000 meals per week or 4.5 million meals per year. This resulted in about 400,000 pounds of lettuce per year. From this survey, the numbers for lettuce, and observations in the dining halls, numbers for how many pounds of each other vegetable were derived and are presented in **Appendix 1**. Finding the values for fish was a little different though. A ratio of meals with fish was found from the menus provided online then this ratio was used to determine approximately how many pounds of fish (filleted) were purchased by the school each year.[6] A pie chart (**Chart 3** above**)** has been created to help visualize the distribution of each good by pound. By using wholesale unit costs from foodcoop.com we were then able to estimate what the school spends annually on all these goods, these values have also been presented in **Appendix 1**.[7]



Once all of the current inputs for these certain goods were found, the next step was to find the most efficient number of C1200-Z units to use. Our final design is based off of the C1200-Z system from the aquaponics.com website. Instead of the school building their own system design, a C1200-Z system can be purchased online for a ninety-eight thousand dollar base price. Time and money would be saved by purchasing an already proven system. Our team members decided that forty units would be necessary, provided that a variety of crops besides lettuce would be grown. We agreed that growing onions, cucumbers, spinach, and tomatoes with the lettuce would be more beneficial. **Chart 4** below provides specific sizing and production numbers for the C1200-Z.

Commercial-1200	C1200	C1200-Z
Annual Lettuce Production	54,000 - 90,000 heads	90,000 - 150,000 heads
Annual Fish Production	4,800 lbs.	4,800 lbs
Footprint	2 Bays, 30' x 140' (8,400 sq. ft.)	3-4 Bays, 30' x 120' (10,800 -14,400)
Estimated Labor/day	18 hours/day	24 hours/day
Electrical requirements		
Base price	$85,000	$98,000
Palleting Charge	$1,150	$1,250

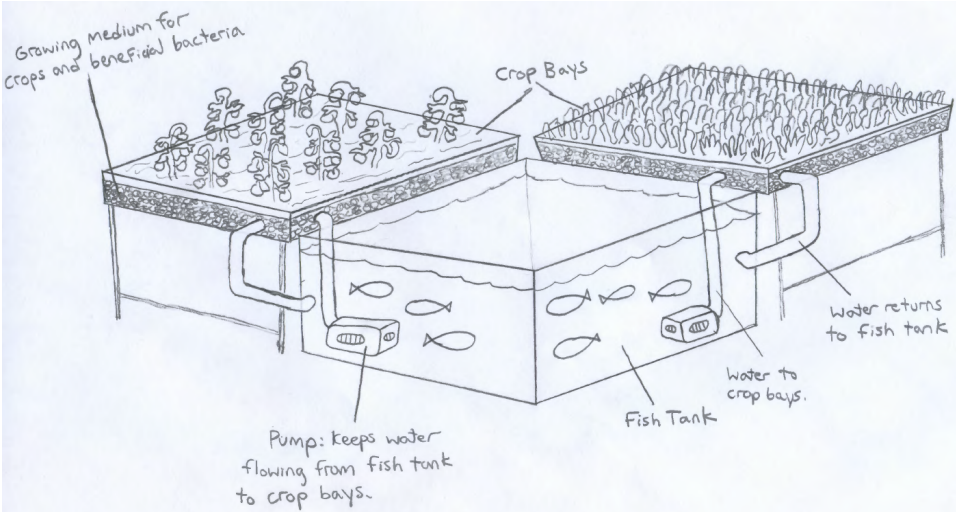
Chart 4: Sizing and annual yields for the C1200-Z aquaponics system [3]

The C1200-Z combines the methods of hydroponics and aquaculture into one efficient system. The growing areas for the fish and crops are separated, but share the same water. In order for the aquaponics system to work, three things must be kept alive; the fish, crops, and beneficial bacteria. All three of these living organisms are essential to each other's survival.

Once the system is up and running, the only input into the unit will be fish food and light. The fish, or tilapia in our case, produce waste in the form of ammonia (urine) and fecal matter. Decaying plant matter and the fish fecal waste are converted into ammonia by heterotrophic bacteria. Large amounts of ammonia is dangerous to the health of plants and fish. Nitrifying bacteria converts most of the ammonia produced by the fish, plants, and heterotrophic bacteria into nitrites and then nitrates. The nitrates produced by the bacteria are essential to the growth of the crops in the system. In this way, all three organisms rely on each other to survive.[3] A visual

of what we imagine the ideal PSU Aquaponics system unit has been sketched and presented in **Image 2**.

Image 2: Single 14,000 sq. ft. Aquaponics Unit Sketch



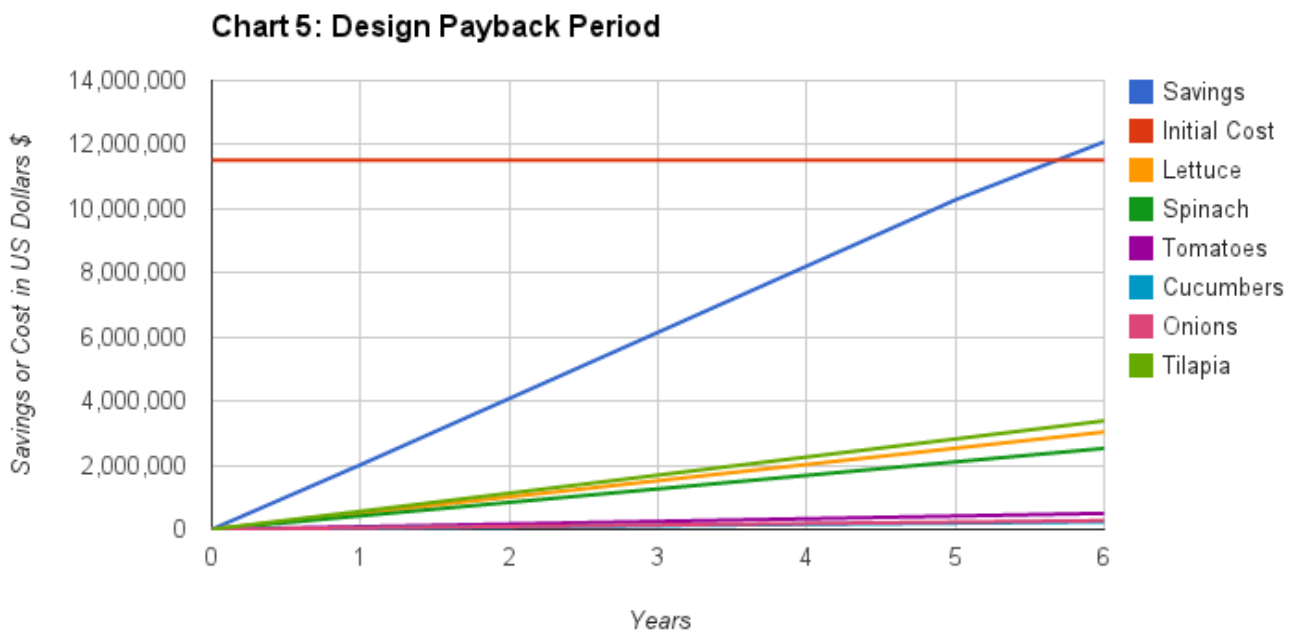
Since the values for how many heads of lettuce could be produced using a single C1200-Z system were most clearly given by the website, this was the good from which we based most of our unit needs. One unit could produce an average of about 120,000 heads of lettuce per year, or 160,000 pounds per year. From tedious calculations where we split the annual yields by need, making the lettuce and tilapia the largest priority to match the current campus purchases, a design of forty C1200-Z units was determined to be the most efficient. Since productivity and costing were the two most important criteria from the AHP Matrix, we went with a unit value that would yield the most closely to the current needs and paid little attention to any aesthetics or versatility issues. These issues could be left to the school since this proposal is for researching practicality in the design more than how it looks.

After much research on unit prices for each good and approximating what Penn State would pay for these goods, we were able to begin the final estimations for cost of the project. Finding the base costs for the project was made simple by using an online construction cost estimator on buildingjournal.com where building type, region, and square footage could be used to estimate the initial project construction cost. The construction estimate came to be about $7.6 million. The second base cost that needed to be calculated was just as simple as the building construction. On the local Green Towers website, which is a research and business initiative focused on small-footprint organic agricultural production, they have reported that their cost to

run a twelve square foot system similar to our proposal is 0.3 cents.[9] So for our 560,000 sq. ft. design, this would cost about $51,000 per year to run the pumps, general maintenance, and lighting.

Next we needed to find and total all of the savings for the goods that this design would yield. We calculated an even split of the available square footage then researched on mysquarefootgarden.net the potential annual yield for each vegetable.[10] Then by multiplying each yield by the approximate cost per plant used earlier, we were able to calculate values for the produce savings. Both the data for the initial startup costs and annual savings have been compiled into **Appendix 2** at the end of the report.

The final part that needed to be found to test the plausibility of this design was to compare the annual savings to the annual costs and startup cost and find how long the plan would take to pay for itself, or the payback period. **Chart 5** below shows these datas over time and the point at which the savings line and initial cost line intersect is the point when the project begins to pay for itself. By our projections, this is after about five and a half years of continuous use of the system.



Conclusion

In the end, we were able to devise a system that would incorporate aquaponics here at Penn State that would be environmentally and economically friendly. We started our work by looking at the different costs for common foods served on campus, as well as the quantities in which Penn State purchases them. From there, we decided on the specific size that our aquaponics facility would need to be. As it turns out, the size we chose has the ability to supply Penn State with a substantial amount of crops. One of the most important aspects of our proposal is being able to cultivate enough crops to meet Penn State's needs for lettuce, spinach, tomatoes, cucumbers, onions, and tilapia on campus instead of having to purchase crops far away. We believe that this design solution could be adopted by Penn State and the Penn State community. The way the aquaponics facility is planned allows for the fastest payback time while still meeting the needs of the campus for a number of different crops. Beyond the obvious benefits of growing crops locally, we believe that Penn State would implement our design because the facility could also double as a research facility in which students could learn the basics of aquaponics and discover different ways to improve the process. Penn State could even become a major leader in aquaponics around the world! The students on campus would, as an effect of this plan, feel more green by having small presencing tools around the dining commons. Along with the goods provided from the plant, there would be noticeable signs along with the food information saying something like "Proudly Grown on Campus", therefore making the students aware that they are helping with food sustainability by eating these goods.

This project has taught all of us all a few lessons. Firstly, we all have a newfound understanding of how important it is to our world to start entertaining ecologically friendly solutions to everyday problems. Also, it seems that all of us have learned new ways to approach problems. For example, at the beginning of this project, when we were searching for a solution to make Penn State more ecological, we stumbled across many diverse ways that could accomplish this task. We believe that by researching these different ideas, we were able to have a more open mind when trying to decide on which idea we wanted to try and implement at Penn State. Overall, we feel that this project has opened us up to several different ways to make a more ecologically friendly world and has also allowed us to gain an understanding of the work that is involved with designing a plan to help this cause.

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Appendix 1: Current Spending on Goods Available Through Aquaponics Systems

	Approximate Pounds Purchased Per Year	Cost Per Pound at Wholesale	Cost Per Pound PSU Would Buy (x0.5)	Cost Per Year
Lettuce	450,000	$2.25	$1.13	$506,000
Spinach	187,000	$4.50	$2.25	$421,000
Tomatoes	62,000	$2.67	$1.34	$83,000
Cucumbers	47,000	$1.67	$0.84	$39,000
Onions	182,000	$0.50	$0.25	$46,000
Tilapia (fillet)	161,000	$7.00	$3.50	$564,000
Totals	1,090,000			$1,660,000

Appendix 2: Goods Production Under Design and Goods Remaining to be Purchased

	Production Values (lbs/ yr)	Value Saved Per Pound	Value Saved	Remaining Amount for Purchase (lbs/ yr)	Remaining Price for Purchase
Lettuce	435,000	$1.13	$489,000	15,400	$17,000
Spinach	250,000	$2.25	$562,000	0	$0
Tomatoes	312,000	$1.34	$417,000	0	$0
Cucumbers	115,000	$0.84	$96,000	0	$0
Onions	549,000	$0.25	$137,000	0	$0
Tilapia (fillet)	124,000	$3.50	$434,000	37,200	$130,000
Total	1,785,000		$2,135,000	52,600	$148,000