Aluminum Product Integration System

Team #2

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Engineering Design 100

Section 017

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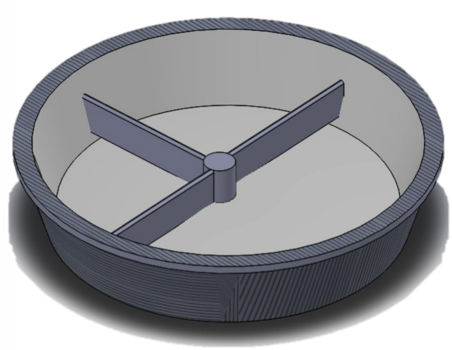


The purpose of this design challenge was to apply aluminum to the design of a product around Pennsylvania State University’s campus to improve the efficiency of energy use and/or increase sustainability of the campus. In this case, a food container that utilized aluminum’s infinitesimally recyclable property was developed along with a program that encourages students to recycle more intelligently.

Contents

Introduction

Alcoa Inc., the largest integrated producer of aluminum worldwide, presented the challenge of integrating aluminum in the design of a product around the campus of Pennsylvania State University. This product must ensure that campus will benefit in some way to the introduction of aluminum, as well as utilize readily available material.

Aluminum is crafted from many different abundant metals found in the earth's crust. In order to make pure aluminum, the ore bauxite is mined and refined into alumina hydroxide (Al_2O_3). This product then goes through a process called electrolysis to extract the aluminum metal. The process used to make aluminum metal can be quite costly because of the high amounts of energy it takes for electrolysis, and that the ores that make aluminum are mostly found in foreign countries. However, the price of aluminum has been falling over time as seen in figure 1 below. What makes aluminum so cost effective, is that it can be effectively recycled. When aluminum is recycled, it does not lose any of its properties or quality. In recycling the aluminum, the process only uses about 5% of the energy it would take to make the aluminum from scratch. In fact, about 75% of the aluminum in existence today is recycled.

The process of recycling aluminum begins with shredding up the aluminum and putting it into a furnace at $7000^{o}C$. Chemicals are added to the furnace to correct the composition of the aluminum and any impurities come to the top and are scraped off. The molten aluminum then passes into the holding furnace where it drips into a mold and is showered with water to cool it off. The mold slowly moves down as it gets heavier when it cools and more aluminum is able to flow in until it forms into an ingot. For making simple things like cans, the ingot is rolled into a very thin sheet and from there can be formed into the shape of the can. Alloys of aluminum can be made by mixing it with other metals such as copper, manganese, silicon, magnesium, and zinc. These alloys are put into use in products like buildings, transportation, and rigid yet flexible packaging.

Aluminum is a good choice in industry production because it is significantly cheaper than most other metals as well as lighter and more durable than other metals. Aluminum is also less corrosive than other metals such as iron, because the oxygen in the air reacts with the aluminum to form a film on its surface that prevents corrosion. Iron and many other metals do not have this property and can easily corrode over time.

To begin development of this product, the team had to first recognize an opportunity around campus that would benefit from the implementation of aluminum. The team also must understand how aluminum is recycled on campus. Aluminum along with other recyclable materials are collected from recycling centers and taken to University Park's Recycling Center (commonly known as the Barpit). At the center materials are sorted and moved to Centre County Recycling and Refuse Authority (CCRRA) located in Benner Township. They are packed and sold to manufacturers that use the material. The final product must be beneficial to campus, while also being sustainable, recyclable, and affordable. Sustainability is meeting the needs of the present without jeopardizing the needs of future generations. A product must be environmentally, socially, and economically sustainable as well as technologically appropriate.

Problem Statement

Alcoa Inc., the largest integrated producer of aluminum worldwide, presented the challenge of integrating aluminum in the design of a product around the campus of Pennsylvania State University

Mission Statement

The goal for this product is to improve the efficiency of energy use and/or increase the sustainability of the campus.

Customer Needs

During the design process, deciding on how the project was to progress was dependent on the needs of the customers. The customers of the project include the stakeholders who would benefit most from the realization of the conceptual design. The stakeholders are listed below:

- Alcoa
- Students/residents of State College
- OPP (Office of Physical Plant)

As a fully functional healthcare institution, OPP already has set standards for how the requirements and regulations of construction of projects around the Penn State University. The design of the project must follow these standards as well as improve on the pre-existing designs. To gauge the desired view of prospective students and residents of State College, a short survey was done asking how each student would prefer to see more items around campus replaced with a more innovative and efficient aluminum design. Most students made positive comments on how they would like to see some of the project's brainstormed ideas implemented throughout the university. A detailed analysis of each idea is described in the later sections of the report. The specifications from Alcoa are similar to those stated in the problem statement. Aluminum is to be integrated into an already existing design in order to become more efficient and improve sustainability.

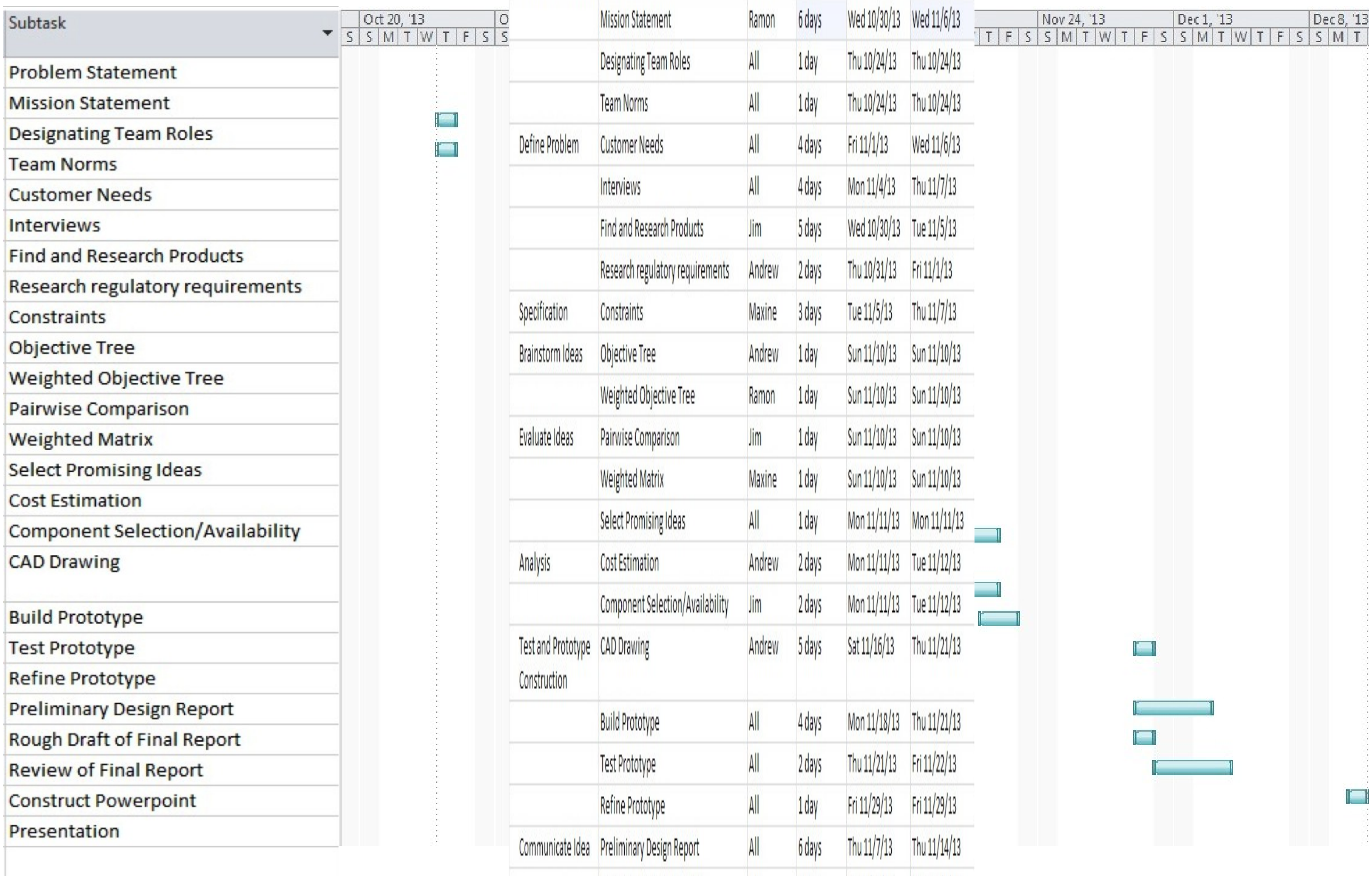
Specifications

In order to decide which concepts to use, different principles were established to help choose the concepts that best met the project requirements. A key principle is the ability of the system to reduce energy needs. This is important because the new concept must require less energy than the one currently in use in order to be beneficial. Another factor is durability which is important because the concept should be stronger or last longer than the current system. Increased durability will also reduce the demand for resources in our continuously growing world. Research from OPP's website shows exactly what the structures around Penn State are made out of. In addition a comparison between different types of metals and the advantages and disadvantages of each. Cost is another important factor because college costs are already high enough and cannot be raised any further. Also, the system must be relatively easy to integrate and install into the current system without many problems because campus will not shut down for the implementation of the concept. Lastly the concept should be aesthetically pleasing in order to attract prospective students to Penn State, while at the same time keeping current students content. These five principles were deemed to be the most important in making a decision. In summation:

- The product must use less energy than the current system in use.
- The product must cost less than the current system in use.
- The product must last longer than the current system in use.
- The product must be visually appealing.
- The product must be able to be installed within two months (one summer).

Schedule of Project

The project schedule up to this point was laid out over the course of around a month. After receiving the project description, the first goal was to recognize the problem and determine the problem statement. A few days were devoted to understanding the project and the problem. From there the group then came up with design criteria by studying the requirements supplied by Alcoa. The group came up with more specifications, did research, explored campus, and asked other students for input, trying to think of ways in which the campus could improve on the efficiency and sustainability of systems. This research took about two to three weeks and resulted in our five possible concepts. After this, the three best ideas were selected and put into a weighted matrix and the top solution was discovered. . The calendar for this process is shown on the next page.



Task Name	Subtask	Responsible Person	Duration	Start	Finish
Recognize Problem	Problem Statement	Maxine	6 days	Wed 10/30/13	Wed 11/6/13
	Mission Statement	Ramon	6 days	Wed 10/30/13	Wed 11/6/13
	Designating Team Roles	All	1 day	Thu 10/24/13	Thu 10/24/13
	Team Norms	All	1 day	Thu 10/24/13	Thu 10/24/13
Define Problem	Customer Needs	All	4 days	Fri 11/1/13	Wed 11/6/13
	Interviews	All	4 days	Mon 11/4/13	Thu 11/7/13
	Find and Research Products	Jim	5 days	Wed 10/30/13	Tue 11/5/13
	Research regulatory requirements	Andrew	2 days	Thu 10/31/13	Fri 11/1/13
Specification	Constraints	Maxine	3 days	Tue 11/5/13	Thu 11/7/13
Brainstorm Ideas	Objective Tree	Andrew	1 day	Sun 11/10/13	Sun 11/10/13
	Weighted Objective Tree	Ramon	1 day	Sun 11/10/13	Sun 11/10/13
Evaluate Ideas	Pairwise Comparison	Jim	1 day	Sun 11/10/13	Sun 11/10/13
	Weighted Matrix	Maxine	1 day	Sun 11/10/13	Sun 11/10/13
	Select Promising Ideas	All	1 day	Mon 11/11/13	Mon 11/11/13
Analysis	Cost Estimation	Andrew	2 days	Mon 11/11/13	Tue 11/12/13
	Component Selection/Availability	Jim	2 days	Mon 11/11/13	Tue 11/12/13
Test and Prototype Construction	CAD Drawing	Andrew	5 days	Sat 11/16/13	Thu 11/21/13
	Build Prototype	All	4 days	Mon 11/18/13	Thu 11/21/13
	Test Prototype	All	2 days	Thu 11/21/13	Fri 11/22/13
	Refine Prototype	All	1 day	Fri 11/29/13	Fri 11/29/13
Communicate Idea	Preliminary Design Report	All	6 days	Thu 11/7/13	Thu 11/14/13
	Rough Draft of Final Report	All	2 days	Fri 11/29/13	Mon 12/2/13
	Review of Final Report	All	1 day	Fri 11/29/13	Fri 11/29/13
	Construct Powerpoint	All	3 days	Sat 11/30/13	Tue 12/3/13
	Presentation	All	1 day	Tue 12/10/13	Tue 12/10/13
Refine Project as Needed					

Brainstorming

In order to find the best possible concept to use in the project a detailed selection process was used. The first step was to brainstorm ideas to change campus in beneficial ways using aluminum. A list was made with various different structures and objects to integrate aluminum in. We started out with five potential concepts from our initial brainstorming. The list included an aluminum elevator, fan, blind/lamp, piping, and food containers.

While elevators are prevalent throughout every building on campus, it could be more efficient through the use of aluminum. Aluminum has a strong strength to weight ratio, therefore it could make for an energy efficient elevator. Since the elevator could be lighter, there would less energy needed to move it. An elevator in a three-story building uses about 3,800 kilowatt-hours a year. Steel weights over 2.5 times the weight of aluminum. Using this comparison, aluminum elevators would use roughly 1,280 less kilowatt-hours a year. Given that one kilowatt-hour is approximately 15 cents, we would be saving close to $200 per year. The price of aluminum is about 92 cents per pound compared to steel, which is about 14 cents per pound. Assuming a standard stainless steel elevator is about 4400 lbs, the cost of an aluminum elevator would be about $1000 more expensive (weight of aluminum elevator is 4400/2.5=1620lbs). The elevator would have to survive at least 5 years without replacement in order to not have a loss. However, aluminum is hard to weld and is susceptible to abrasions, which would increase costs, decrease aesthetics, and overall make an aluminum elevator the wrong choice.

Another solution was of replacing normal fans with aluminum fans. Fans are a part of every college student's dorm room and an aluminum fan would be aesthetically pleasing. The fan would also help clean the air with its EcoClean technology. However, in order for the cleaning to take place, the fan must be in sunlight. Another problem with this idea is that aluminum would be extremely expensive when comparing it to plastic. Lastly, there is not much of a problem to be fixed with the current use of plastic fans. Students are not disposing of or breaking fans enough for which the opportunity cost of the more durable aluminum fan would be greater.

An additional solution was to attach solar panels to aluminum blinds that would be on the outside of windows would be beneficial in energy reduction. Not only would the solar panels collect energy to power a lamp in a dorm room, the aluminum blinds would also contribute to the cleanliness of the air through its EcoClean technology. Each one of these units would produce about 1 Watt of power for every 0.79 cents of solar panel purchased for each window, depending on the surface area of each window. But again, the cost of using aluminum instead of plastic or cloth blinds would be tremendous.

Research from OPP's website show that Penn State is switching from coal to natural gas. They are installing 2.2 miles of 12-inch steel pipe with 0.375-inch walls and a protective coating. Our idea was to replace the steel piping with aluminum, but after further research we discovered that aluminum pipe or tube should never be passed through walls, floors or ceilings. On top of that, aluminum is far more expensive than steel, therefore this option was not viable. Equation 1 shows how these volume was calculated. The values are solves in the appendix. This volume was used in equation 2 to solve for the price of both aluminum and steel piping and then were compared against each other.

Where V is the volume, r is the radius of the pipe, and h is the length of the piping used. Equation 2 illustrated below shows the price of each material where V is the volume, ῤ is the density of the material, and P is the price per unit lb.

ῤ*P=Cost

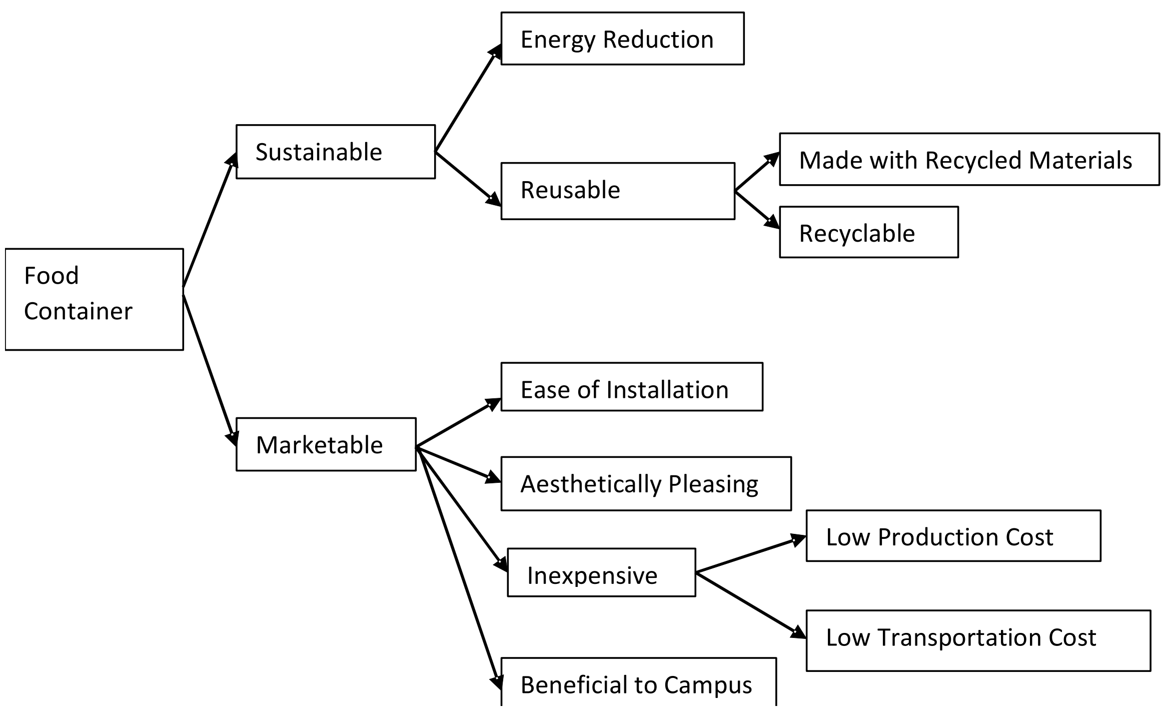
Lastly, the polystyrene containers given to students in dining commons can be replaced with aluminum ones in order to save energy. A polystyrene container of dimensions 9x9x3.5 costs around $32 per 200 containers, whereas an aluminum container of similar dimensions costs about $89 per 500 containers ($35.6 per 200). Although more expensive, if properly recycled, the aluminum containers will be cheaper to keep reusing in the long run, as aluminum is infinitesimally recyclable and polystyrene is more difficult to recycle. In order to be recycled, polystyrene buts be fed through a shredding matching then put through heat and pressure to melt into a continuous sheet. Unlike aluminum, polystyrene costs more to recycle than to make new. However continually making new polystyrene comes with a whole new set of complications. It is made from petroleum and a chemical called benzene. This chemical can be transferred to food and is dangerous to wildlife if not properly disposed of. Another advantage of aluminum over the current polystyrene is the aesthetics of the aluminum container.

Idea Evaluation

Pairwise Comparisons							
	A	B	C	D	E	Row Totals	Row total/total
A	1	1/2	1	10/7	10/3	7.262	0.20
B	2	1	2	20/7	20/3	14.524	0.40
C	1	1/2	1	10/7	10/3	7.262	0.20
D	7/10	7/20	7/10	1	7/3	5.083	0.14
E	3/10	3/20	3/10	3/7	1	2.179	0.06
					Total:	36.31	
A- Cost							
B- Energy Reduction							
C- Durability							
D- Ease of Installation							
E- Aesthetics							

	Concept Variants				
Selection Criteria	Elevator	Piping	Fans	Blinds Light	Food Containers
Cost	-	-	-	-	0
Energy Reduction	+	0	0	+	+
Durability	0	-	+	0	0
Ease of Installation	-	-	0	-	+
Aesthetics	+	0	+	0	+
Pluses	2	0	2	1	3
Neutral	1	2	2	2	1
Minuses	2	3	1	2	0
Net	0	-3	1	-1	3
Rank	3	5	2	4	1
Continue?	yes	no	yes	no	yes

		Concepts					
		Elevator		Fans		Food Containers	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Cost	20%	2	0.4	4	0.8	2	0.4
Energy Reduction	40%	4	1.6	3	1.2	4	1.6
Durability	20%	2	0.4	2	0.4	3	0.6
Ease of Installation	14%	2	0.28	3	0.42	4	0.56
Aesthetics	6%	4	0.24	4	0.24	3	0.18
	Total Score	2.92		3.06		3.34	
	Rank	2		3		1	
	Continue?	No		No		Develop	



Design Overview

When it came to the overall shape of the container, we decided to make it circular rather than the square container currently in use. In making the container circular we can obtain the same volume capability, while also using less material. The current polystyrene container dimensions in inches are 9x9x3.5, which yields a volume of 283.5in^3 and a surface area of 288in^2. The dimensions of our new container in inches will be a radius of 5.078 and a height of 3.5, which yields a volume of 283.5in^3 and a surface area of 272in^2.

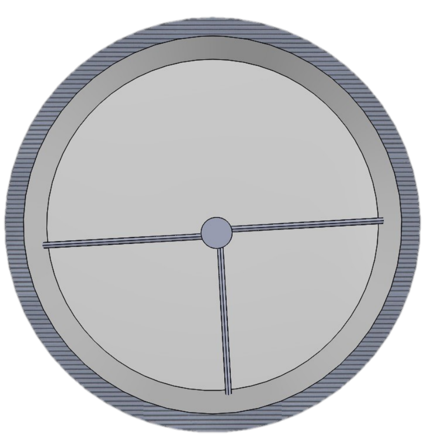
Another way to reduce the amount of material being used in the container was to make the design similar to that of a pie tin. A pie tin makes use of corrugated sides and a thicker lip. The corrugated texture of the side allows the force being acted on it to be spread out along the length of the fold. Corrugated paper can support an object of up to 600 grams. Since our container is now stronger through corrugation, we can allow the container to be thinner, which leads to less material being used. A thicker lip around the edge, called a tinners' joint, will also increase the strength of the diameter of the container. The lip is just aluminum folder over itself to form multiple layers. This will allow the container to keep its shape and increase durability. We also decided to make the bottom of the container slightly concave, similar to that of a soda can. This will increase the strength of the container in a similar way to the corrugated sides. The curved bottom has an increased moment of inertia, which leads to increased strength and ultimately reduces the amount of material needed.

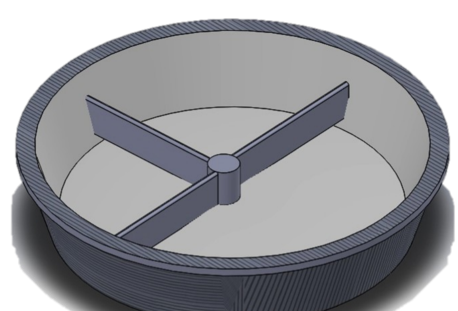
Not only are we changing the design and material of the current containers used in the commons throughout Penn State, we are also implementing an incentive program to encourage the proper recycling of the containers. On each floor there will be a recycling receptacle solely for these containers. At the end of each month whichever floor has the recycled the most containers will receive Berkley creamery coupons for everyone on that floor. Properly recycled aluminum means that the container would need to be quickly rinsed of any major food particles stuck to the container. Once the container is relatively clean, students would then take the containers to their Eco-Reps, who would keep track of how many containers each student has recycled. The idea of a reward for recycling on a daily basis will not only increase the amount of recycled aluminum, but also increase awareness about the benefits of recycling.

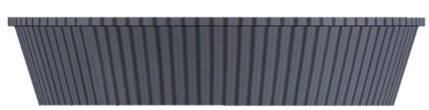
While the initial price of the aluminum containers may be more than the current containers, the new, overall system will be more sustainable and efficient in the long run. Allan Myerson, A professor from MIT's chemical engineering department, said, "The key with plastic recycling is that there must be both an environmental and an economic advantage". The energy required to compact these low-density polystyrene containers into usable material is more costly than to haul it to a landfill. These polystyrene containers also have to go through a wash cycle just to be prepared for compacting. However, the aluminum containers are much easier to recycle and it takes far less energy to recycle it than to produce new aluminum. The food and impurities on the recycled aluminum rise to the top of the liquid aluminum during the melting phase and are easily skimmed off the surface.

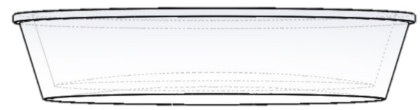
The cost of one aluminum container is about $0.23 compared to the cost of one polystyrene container which is about $0.16 (aluminum container is about 33% more expensive). However, after the initial cost to buy the aluminum containers the price to recycle the aluminum containers dramatically decreases to about $0.12 per container. Penn State would break even by recycling aluminum containers in about one year (calculations in Appendix).

The Model









Conclusion

For this project we decided to replace the Polystyrene to-go food containers offered in the dining commons throughout campus with aluminum ones. The container would have modified attributes to increase efficiency. In addition to the modified attributes, we will also modify the current recycling program to ensure these containers are properly recycled.

Appendix

Table 5. Price Comparison of Base Metals in \$/lb[6]

Base Metal Prices			
	chg|%		
Aluminum	USD/lb	0.79	0.00
Copper	USD/lb	3.17	0.02
Lead	USD/lb	0.94	0.01
Nickel	USD/lb	6.13	-0.03
Tin	USD/lb	10.40	0.03
Zinc	USD/lb	0.84	0.00

in^3

Steel Cost:

Weight of Steel: 0.2904 lb/in^3

Aluminum Cost:

Weight of Aluminum per Cubic Inch: 0.096 lb/in^3

Polystyrene Container Cost:

\$31.49/200 containers = \$0.16/container

Aluminum Container Cost:

(52.09/500, 7 inch container + 37.69/500, 7 inch lids)*(9 inches/7 inches)/500 containers = \$0.23/container

Cost to recycle aluminum containers

Recycling 38 million tonnes of aluminum takes 250PJ:

(38,000,000 tonnes/250PJ)*(1000kg/1 tonne)*(1000g/1kg)*(1lb/453.592g)*(1 container/0.0436lb)*(1*10^-15PJ/1J) = 3.4895*10^-7 container/J

→ 1/(3.4895*10^-7 container/J) = 2865736.842J/container

→ (2865736.842J/container)*(1KW*h/3,600,000J)*($0.15/1KW*h) = $0.119/container

Assuming each dining common uses about 500 containers per day:

(500 containers/day)*(60 days/recycling period)*5 dining commons =

157,500 containers/recycling period

Cost Aluminum vs. Polystyrene:

Cost(Aluminum) = (157,500*0.23) + (157,500*0.12)x

Cost(Polystyrene) = (157,500*0.16)x

Break even point = 5.75 recycling periods (about 1 year)

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