

5-10-2019

Repurposing Plastic Waste in El Cercado

Joseph Dooling

Loyola Marymount University, jdooling@lion.lmu.edu

Kirby Townsend

Loyola Marymount University, ktownse2@lion.lmu.edu

Brendan Smith

Loyola Marymount University, brendan.smith@lmu.edu

Follow this and additional works at: <https://digitalcommons.lmu.edu/honors-thesis>

 Part of the [Heat Transfer, Combustion Commons](#), and the [Manufacturing Commons](#)

Recommended Citation

Dooling, Joseph; Townsend, Kirby; and Smith, Brendan, "Repurposing Plastic Waste in El Cercado" (2019). *Honors Thesis*. 180.
<https://digitalcommons.lmu.edu/honors-thesis/180>

This Honors Thesis is brought to you for free and open access by the Honors Program at Digital Commons @ Loyola Marymount University and Loyola Law School. It has been accepted for inclusion in Honors Thesis by an authorized administrator of Digital Commons@Loyola Marymount University and Loyola Law School. For more information, please contact digitalcommons@lmu.edu.



Repurposing Plastic Waste in El Cercado

A thesis submitted in partial satisfaction
of the requirements of the University Honors Program
of Loyola Marymount University

By

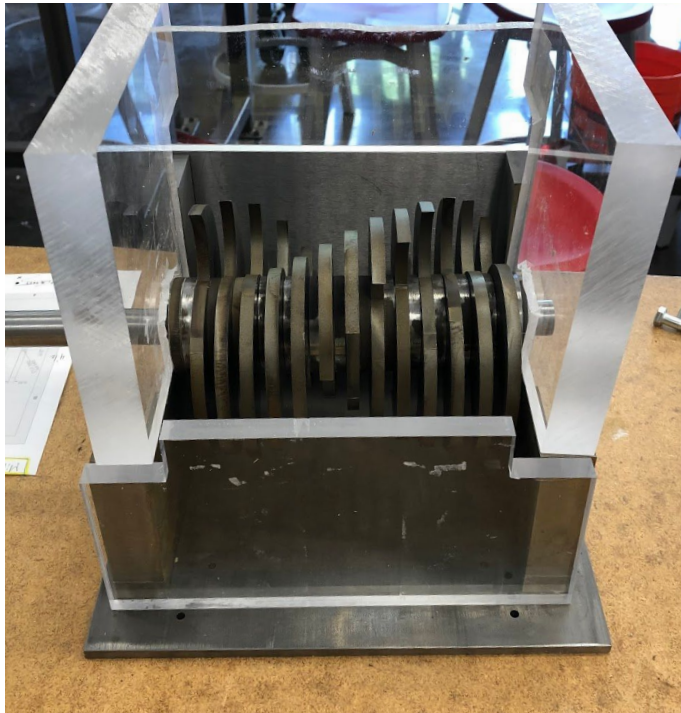
Joseph Dooling

May 10th, 2019

Repurposing Plastic Waste in El Cercado

Final Design Review

Prepared by
Meghanne Clark, Joe Dooling, Marcus Lui, Kirby Townsend



Faculty Advisor: Dr. Brendan Smith Ph.D
Loyola Marymount University
Mechanical Engineering Department
Spring Semester 2019

Abstract

This project aims to assist the community of El Cercado in the Dominican Republic in turning their plastic waste into useful products. The design team developed a first iteration shredder, injector, and aluminum mold which future design teams could further iterate in order to make products out of waste plastic. Different products were researched to ensure that they can be sold or used in the community. The goal of producing these items is to stimulate economic activity in the community by creating economic opportunity. The design shall also be sustainable in three ways. It shall reuse plastic waste while also ensuring that the energy used is sustainable. Additionally, it shall be designed to have long term impact in the community. The first iteration machines were modified versions of schematics published by a non-profit organization called Precious Plastic. The design team borrowed a shredder from LA Precious Plastic for experimental testing, which successfully shreds the plastic waste into small pieces. For the team's shredder, all of the metal, all of the acrylic, the motor, and the reducer were bought, and manufacturing was completed on the teeth, spacers, shaft, and partial casing for the team's shredder. For testing on the first-iteration injector, plastic chips were melted and injected into a mold. For the shredder, future teams should first find the optimal motor, and then design the parts in the following order: teeth, spacers, comb, motor, reducer, bearing, base, housing, hopper. Better heating and increased pressure are two clear paths that would lead to a more effective injector and ultimately expand the amount of plastic that can reach the mold.

Table of Contents

Abstract	2
Table of Contents	3
1-Design	5
1.1.0 Objective	5
1.2.0 Background	5
1.2.1 El Cercado, Dominican Republic	5
1.2.2 Logistics	6
1.2.3 Plastic Manufacturing	6
1.2.4 Vacuum Forming:	6
1.2.5 Extrusion Molding	7
1.2.6 Compression Molding	8
1.2.7 Injection Molding	8
1.3.0 Prior Work	9
1.4.0 Design Specifications	10
1.5.0 Concept Development and Selection Methods	13
1.5.1 Process Design	13
1.5.2 Power Supply	14
1.5.3 Product Design	14
1.5.4 Mold Selection for Experimental Testing	15
1.6.0 Innovation	16
1.6.1 Shredder	16
1.6.2 Injector	17
1.6.3 Mold design	18
1.7.0 Description	19
2-Analysis	22
2.1.0 Failure Modes and Effects Analysis (FMEA)	22
2.1.1: Shredder Failure Modes	22
2.1.2 Injector/Mold Failure Modes	23
2.2.1 Heat Transfer	24
2.2.2 Fluid Flow	25
2.2.3 Stability and Stress Analysis	25
2.2.4 Motor and Torque Analysis	26
2.3.0 Cost Analysis	26
3-Testing	27

3.1.0 Developmental Testing	27
3.1.1 Shredder	27
3.1.2 Heating element on the injector	27
3.1.3 Mold/injection	28
3.2.0 Performance Testing	28
4-Safety and Ethics	29
4.1.0 Safety	29
4.2.0 Ethics	30
5-Conclusion	31
5.1.0 Comparison	31
5.2.0 Evaluation	31
5.3.0 Recommendations	32
References	33
APPENDIX A: TIMELINE	35
APPENDIX B: BILL OF MATERIALS	37
APPENDIX C: PART DRAWINGS FOR SHREDDER ASSEMBLY	38
APPENDIX D: PART DRAWINGS FOR INJECTOR ASSEMBLY	45
APPENDIX E: HEAT TRANSFER ANALYSIS	50
APPENDIX F: MOMENT ANALYSIS	53
APPENDIX G: SHREDDER ANALYSIS	55

1-Design

1.1.0 Objective

The overall goal of this project is to design a prototype to deliver to the community of El Cercado, in the Dominican Republic, as a way to convert their plastic waste into usable products. In doing so, the team hopes to also create gainful labor opportunities in the community, which currently transports plastic waste to a recycling facility an hour away by car that pays between two and three pesos per pound of plastic. The final design and production process should provide adequate economic incentive to make using the machines to recycle plastic attractive. The team's contacts in the community will advise the development process to ensure that each iteration of the machine is more equipped to stimulate economic activity and to address the high unemployment rate.

In order to effectively service the community the final design must be safe to use, reliable in the long run, and capable of making quality products. It is difficult to design a machine that adequately addresses these requirements without multiple iterations and extensive performance testing. Therefore, the goal of this particular report will be to design a first iteration of the machine upon which performance testing can be conducted. This testing will advise future designs, ensuring that they are safe, reliable, and efficient.

1.2.0 Background

This section will discuss the background information regarding the project including important aspects of El Cercado that are relevant to this project including potential logistical issues such as transportation, power sources, and different types of plastics available as well as different methods for manufacturing plastics. By examining different methods for manufacturing plastics, the design team can gain knowledge on what solutions already exist to transform recycled plastic into usable products. The goal of the project is to install a machine that will be able to convert recycled plastic into products that the community can use. It was important for the design team to fully understand the background and culture of El Cercado in order to ensure that the project will have a long term benefit to the community. To gain more information about the community, the group has been in contact with a correspondent stationed in El Cercado.

1.2.1 El Cercado, Dominican Republic

The team aims to make a long lasting impact in the community of El Cercado; therefore, it is important to consider all aspects that will affect the community, including culture, demographics, economics, and current unemployment rates. El Cercado is a small city in the Dominican Republic, consisting of 15,000 to 30,000 people. Aside from teachers, farmers and government workers, there aren't many steady jobs available in El Cercado. According to official census information, unemployment rates in El Cercado have been reported to be around 75% [1]. As a result, over the past few years, people have been moving to the capital to find work. If economic opportunities were created in El Cercado, it would benefit the existing community and might bring in revenue to more rural areas.

Currently, some of the community members earn 2-3 pesos per pound of plastic by transporting plastic waste to a facility in San Juan de la Maguana. It should be noted that this price does not account for the travel costs to get to the facility. The team is aiming to create a machine that can produce high-demand products so that the community members operating the

machinery can profit from converting plastic waste into goods. Therefore, it's critical for the group to create a machine that can manufacture products that produce sustainable demand.

Since one of the main goals is to create products that are useful to the community, it's imperative that the group get direct input from the people of El Cercado about which products will be the most beneficial. The correspondent stated that items that the community uses on a daily basis would be most beneficial to the members of the community such as kitchenware and tools. Since a large majority of available jobs involves farmwork, tools could potentially have a large market since its an item the community uses on a daily basis. Similarly, kitchenware is another stable item of all households and would potentially have a large market.

1.2.2 Logistics

The future logistics of the project should take meticulous planning in order to strategize how the machine with be transported, where the machine will operate, and different types of plastics available. Transportation is easily accessible in the community since most of the roads are paved, with a few dirt roads. The local rental car companies in the Dominican Republic have the option to rent a variety of vehicles including flatbed trucks. Upon arrival to the destination, a facility or building will be needed to install the machine and set up the manufacturing process. Given the limited options available, the team considered investing in a small facility, which would cost approximately \$70 a month.

In order to ensure that the machinery is designed to accommodate the types of plastics available, the shredder and injector will need to be designed to operate with the most commonly used plastics in the community. In El Cercado, a variety of plastic are used in the area to package commonly sold products including water bottles, oil jugs, soda bottles, apple juice containers, aloe bottles, and plastics bags. The team would like to find a way to reuse all of these items, however, the main focus will be on finding a way to use water and soda bottles. Water and soda bottles make up the highest percentage of plastic used in El Cercado [1]. However, they are made using PET that is more difficult to decontaminate and would add an additional process to the project.

Another major consideration of the project is how to power to the machines. The outlets in El Cercado produce 110V through hydroelectricity from a nearby dam. However, the correspondent reported that the power is not reliable and may turn off periodically throughout the day. She also mentioned that some of the smaller electronics become damaged over time due to low power quality. More analysis needs to be done to determine if the low quality would negatively affect the motor in the machine.

1.2.3 Plastic Manufacturing

The following section includes background information on different ways of manufacturing products with plastics including vacuum forming, extrusion molding, compression molding, and injection molding. By examining how plastic is currently being manufactured, the team can base their design off of currently used plastic manufacturing processes.

1.2.4 Vacuum Forming:

Vacuum forming is the most common thermoforming manufacturing process and is commonly used to manufacture thin plastic pieces. As seen in Figure 1, the vacuum forming

process manufactures plastic products by heating a plastic sheet and using a vacuum to pull the material to the mold's shape [2].

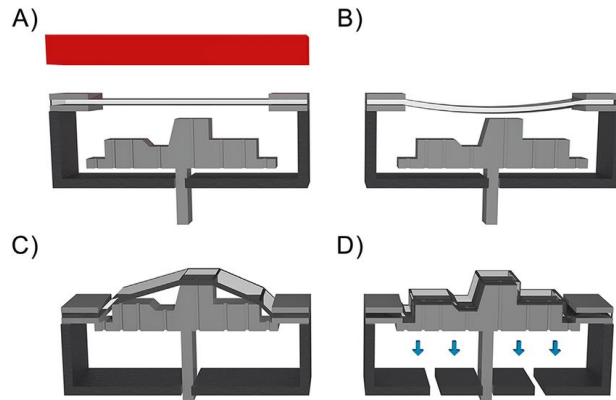


Figure 1: Vacuum Forming Process [3]. The first step of the vacuum forming process is to apply heat represented by the red bar so that the sheet of plastic starts to droop. Next, the plastic is pulled over the mold in a swift motion. Lastly, a vacuum pulls into the mold so that the plastic forms completely around the shape [2].

According to the British Plastics Federation, in order to use vacuum forming, a flat sheet of plastic must be created beforehand. Only products that have a uniform thickness throughout the surface can be created, making it difficult to produce tiles or tools. Furthermore, both creating the plastic sheeting and trimming the excess plastic off the final product would create two additional processes. Overall, vacuum forming is a process that would be easier to operate but would provide limited products and requires an extra pre and post processing step [2].

1.2.5 Extrusion Molding

Another method that is commonly used in manufacturing plastics is extrusion molding. Figure 2 shows a schematic of what an extrusion machine screw looks like. Overall, the extrusion machine heats the plastic into a liquid state and then applies pressure through a screw extruding the plastic as it cools [4].

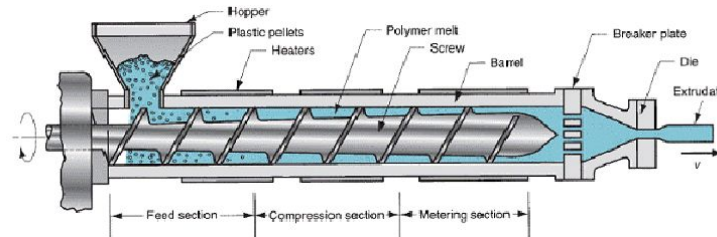


Figure 2: Schematic of Extrusion Molding Screw [5]. The extrusion screw feeds plastic pellets through a heater so that it transforms into a liquid state. Then, that material is fed through a die tool which cools the plastic. In its final state, a solid filament of plastic is ejected from the machine [4].

There are a few different options for what can be done with the extrusion molding manufacturing process which makes it easy to adapt to different types of simple products. The liquid can be poured into a mold and then solidified. Furthermore, if air is injected into the mold after the plastic, a variety of hollow products can be produced [6]. While extrusion molding can produce a variety of different products such as tiles and tools, it requires high amounts of

pressure at the extrusion tip. The pressure is applied by a motor pushing on the extrusion screw which is costly to build. Furthermore, when the plastic chips are heated and then cooled again, the heated plastic may undergo shrinkage or expansion making it difficult to manufacture [6]. Overall, extrusion molding can provide a variety of products, however, it would require more pressure to form the plastic into the molding.

1.2.6 Compression Molding

Compression molding is another common method for manufacturing plastics that produces products that are typically stronger than its counterparts [7]. Compression molding produces plastic products by placing plastic pellets onto a mold. As seen in Figure 3, half of the mold is heated while the other half is pressed down, compressing the pellets [7]. Then, the product is ejected and then sent through a cooling process.

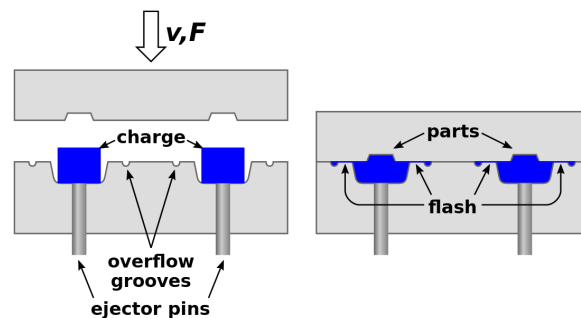


Figure 3: Compression Molding Process [7]

According to the manufacturing company, TranPak, the resulting product of compression molding tends to be stronger and lighter than other methods [7]. However, the machine requires high amounts of heat and pressure to run because the entire bottom of the mold has to be heated [7]. In conclusion, compression molding creates better products, however, serious consideration would be required to build a functioning machine with the available resources in El Cercado.

1.2.7 Injection Molding

The injection molding process is another method that is used to manufacture plastic products. As seen in Figure 4, plastic pellets are placed in a feeder at the top of the machine. Then, a lever is pulled that pushed the pellets through a series of heaters that transforms the plastic into a liquid state. The liquid plastic then is compressed into a mold and is cooled into a solid state [8].

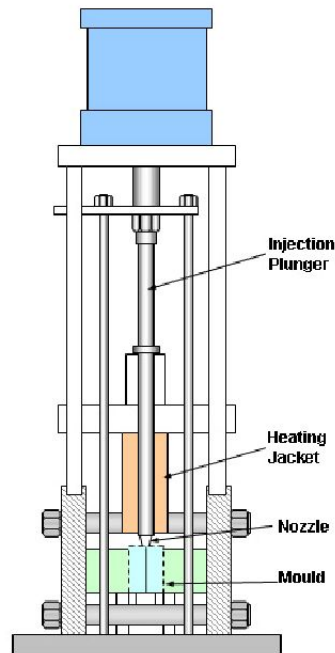


Figure 4: Injection Molding [9].

According to the British Plastics Federation, most thermoplastics can be used in injection molding but ABS, PA, PC, PP, and GPPS are most commonly used [8]. Injection molding can create a wide variety of products making it a desirable option for manufacturers. Various groups such as Precious Plastic, have also posted detailed instructions on how to build the machine including materials, overall costs and blueprints [9]. Overall, the injection molding machine requires a simpler process than the other processes observed, yet still provides a variety of products that can be manufactured.

1.3.0 Prior Work

The overall recycling process used in industry today is normally broken down into five main processes: collection, sorting, shredding, cleaning, and melting [10]. Collecting is the process of obtaining materials for recycling. Sorting is categorizing and separating bottles and other objects based on the type of plastic. Shredding cuts the plastic into smaller pieces and allows for the materials to be easily transported and handled. Cleaning ensures the recycled material is not contaminated. Melting converts the plastic to a liquid state and allows for reuse of the material.

For this project, the process follows the main recycling process but there are a few key details to address. Sorting can be done by examining the recycle number placed on the bottom of most plastic containers. The plastic must also undergo a light cleaning so that there are no contaminants in the plastic. If the goal was to produce kitchenware, the plastic must undergo a thorough and extensive chemical bath to remove all impurities.

Precious Plastic defines itself as a “community working towards a solution to plastic pollution” by performing small-scale plastic recycling [11]. The LMU design team decided to use this company as a source for inspiration because they use similar machines to produce similar products for economic benefit. Precious Plastic has demonstrated injection molding as a

viable way to repurpose plastic into useful products which include, small accessories, kitchenware, and tiles. They have facilities in Latin America, South America, along the coast of Africa, and in many European countries. Looking at different Precious Plastic facilities, one facility in Sri Lanka repurposed plastic from hessian sacks, rice sacks, and low density polyethylene bags to make a variety of products including frames for glasses and keychains as seen in Figure 5 below [11]. The products produced at the Sri Lanka facility are then sold in Sri Lanka and also overseas in Switzerland and Spain. The work being done at the Sri Lanka facility provides an example for product production and economic success stimulated by sales in Sri Lanka, Switzerland, and Spain.



Figure 5: Sri Lanka Case Study [11]

Low volume products are desirable for injection molding because the process can get quite complicated once larger volume products are produced [11]. As a product increases in volume, distortion becomes a concern because cooling throughout the product does not happen simultaneously. The task of injection molding takes quite a bit of skill to master, so the design team contacted companies throughout the Los Angeles area for assistance and guidance. Jet Plastics, Quality Plastics, and Universal Plastic Mold are all relatively close and specialize in injection molding. The design team will also be contacting Precious Plastic LA to understand shortcomings of the Precious Plastic shredder and injector machines and successes and failures that Precious Plastic had with product manufacturability.

1.4.0 Design Specifications

The design specifications that will inform the final design are listed below in Table 1. The machine should be small enough to fit in an F-250 pick-up truck. The injector must be able to melt multiple types of plastic which have melting points ranging from 400-500 degrees Fahrenheit [11]. Instead of a particular melting temperature, most plastics have a range of melting temperatures. The difference between the high and low temperatures in the range are usually around 10-20 degrees. Therefore the heater must have a least a +/- 10 degree precision. It also must be safe to work with. The ANSI/PLASTICS B151.1-2017 Safety Requirements for Injection Molding Machines (IMM) states that contact with any surface in excess of 140 F can cause burns or reflexive reactions leading to falls or inadvertent contact with other hazards. This

means that the external temperature of the heating apparatus must be at or below 140 F. The machine must be capable of applying pressure that causes melted plastic to fill the mold entirely. Larger and more complex molds will require more heat and pressure. The mold must also have venting holes to allow any air inside the mold to escape.

The shredder must be easily assembled and disassembled for portability reasons as well as for maintenance and repair. It will have to be shipped, assembled, and disassembled several times during testing at Loyola Marymount and for installation in El Cercado. Quick disassembly must be possible, such that if the machine jams or individual parts break, it will be easy to repair or replace the parts. Oftentimes, shredding machines have trouble shredding certain kinds of plastic. Some plastics are harder and some objects are oddly shaped, making it so that they do not “catch” on the shredder blades causing the plastic to “bounce” on top of the rotating blades.

Both the shredder and injector must be capable of withstanding the loads that will be applied to them. The shredder must be capable of withstanding loads resulting from shredding plastic, and the injector must not break or tip when forces are applied to the lever arm. The designs will run on 110 V since this is the current operating AC voltage in the Dominican Republic. The actual rate of production will have to be decided based on the size of the chosen product. Larger objects will require more plastic and time to produce and the expected rate of production will be adjusted accordingly. The rate of production must allow for users to feel that their time is well spent using the machine. The products must be competitive with comparable products in the community. Ideally, the final product would cost less than its competition so as to provide consumers an incentive to purchase the product. Additionally, the products should be high quality relative to the competition.

Table 1: Overall Design Specifications					
Subsection	Parameter	Requirement	Capability	Margin	Basis
Travel	Size of Machinery	Should fit in the back of a F250 pickup truck < 71” x 99” [13]	Final shredder and injector design can be disassembled so that each individual part meets this requirement.	The longest part of either subsystem is the injector upright measuring 48” leaving a minimum clearance of 51”	By design
Injector	Applied Injection Pressure	Injector shall apply adequate pressure to ensure mold is entirely filled with plastic.	The injector was not able to fill the mold and a lack of adequate injection pressure is one potential cause	N/A	Testing
	Thermal insulation	Heating element insulation shall reduce external temperature to 140 F [14]	Future Work	N/A	Analysis and Experimental Testing
	Heating of plastic	Heating elements shall heat plastic to 400-500 degrees Fahrenheit with at least a +/- 10 degree precision [11]	Capable of heating to 900 degrees Fahrenheit. No testing was done in regards to degree precision.	Heating margin: 400 degrees Fahrenheit Degree precision:	Analysis and Experimental Testing

				unknown	
	Injector Stand	Injector stand shall not break under 150 lb loads or tip under a load of 150 lbs applied at 30 degrees off the vertical axis of the injector.	Machine was tested under a 165 lb load and did not break although bending did occur in the plunger shaft Analysis shows that 150lb 13 degrees off axis will tip the injector.	Injector can withstand 15 more lbs of loading but tips 17 degrees before intended	Analysis
Shredder	Part Replacement	Shaft and box should be designed so that teeth can be easily replaced should they break or wear	Complies	N/A	By Design
	Plastic bounce	The shredder should be designed to not allow for the plastic to bounce on top	Future Work	N/A	Experimental testing
	Safety	Fully operable without users needing to put their hands near moving parts			Experimental testing
	Teeth Strength	Should endure a year under standard loads			Analysis and Experimental testing
	Box Rigidity	Able to resist deflections that would cause critical failures under normal loading conditions.	Usage of 1" steel on sides	N/A	Analysis
	Motor Specification	Should have enough hp, torque, and rpm to effectively shred plastics. Capable of forward and reverse rotation	Future Work	N/A	Analysis
Shredder/ Injector	Types of Plastic	Should be capable of shredding, heating and injecting PET, LDPE, HDPE, PP, PS	Does not comply. PET was unable to be shredded. PP was most successful filling the mold followed by blow- molded HDPE.	N/A	Experimental Testing
	Modularity	Should be capable of full assembly/disassembly within a week	Injector can be completely assembled and disassembled in 30 minutes.	6 days, 23 hours, 30 minutes	Experimental testing
	Power	Both machines shall work at 110 V	Future Work	N/A	By Design
Molding	Product Diversity	Injector should be able to operate with interchangeable molds	Any mold with the proper concave radius on its top plate is compatible with the injector.		Experimental testing
	Mold Features	The mold shall ventilate through a tapped hole in	The aluminum mold has three air vents to prevent	By design	

		the mold plate to avoid air pockets forming during product formation	air pockets from forming within plastic in the mold.		
Overall	Length of Process	The economic reward for a product must be reasonable given the amount of time spent producing it.	No parts were successfully manufactured therefore there is no way to know how economically rewarding the process would be with a working design	N/A	Experimental testing
	Economics	Product pricing should be comparable to other products in the community and produce revenue for people working with the machines	No parts were successfully manufactured therefore there is no way to determine the price point for products produced.	N/A	Analysis

1.5.0 Concept Development and Selection Methods

Four elements of the design required decision making: overall process design, power supply, product selection, and mold selection. A scoring matrix was used for each decision to help determine the best course of action.

1.5.1 Process Design

Four processes were feasible for making products out of waste plastic: a roller/compression method, a shredder/injector method, a shredder/extruder method, and a vacuum molding method. Each category was scored on a 10-point scale with 10 being the best score. It was concluded that the shredder/injector method was the most viable. Since this project is focused on recycling used plastic products, it is favorable to have a process that can function with multiple types of plastic. The roller/compression method requires ideal cylindrical plastic bottles, whereas the shredder/injector, shredder/extruder method, and vacuum molding method functions with all shapes and sizes of plastic due to the nature of shredding and reheating the plastic. The vacuum molding method also relies on shredding and reheating plastic, but the products that can be made from vacuum molding are limited. Out of the four processes, the shredder/injector method was estimated to be the least expensive option. In addition, when comparing the number of processes required for each method, the shredder/injector method has the fewest processes, and the roller/compression method has the most processes.

Selection		Shredder/Injector		Shredder/Extruder		Vacuum Molding		Roller/Compression	
Criteria	Priority	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Price of Machinery	20%	9	0.9	8	0.8	6	0.6	3	0.3
Plastic Shapes	30%	8	2.4	8	2.4	8	2.4	3	0.9

Process Duration	20%	9	1.8	8	1.6	6	1.2	3	0.6
User Difficulty	30%	7	2.1	5	1.5	4	1.2	5	1.5
Total		7.2		6.3		5.4		3.3	
Rank		1		2		3		4	
Continue?		Yes		No		No		No	

1.5.2 Power Supply

The second element, power supply, had a few directions by which it could go: wall outlet, solar power, and bike power. The selection criteria for power included continuous supply, renewable, cost, and ease of use. Continuous supply is judged by how many hours per day a solution could theoretically be shredding product. The selection criteria, renewable, is defined as how environmentally friendly a solution is. Cost included initial startup costs and price for using a source of energy for long term. Ease of use considered the amount of training needed to set up, maintain, and operate each source. All three energy sources are renewable, which allowed for all three to score highly as seen in Table 3. The electricity supplied by the wall outlet is generated from a hydroelectric dam. The solar power option was considered early on but was decided to be unreliable because it can only collect energy during daylight hours. In addition, the average efficiency of solar panels falls between 15 to 17 percent. The highest efficiency solar panels can achieve is 22.2 percent [16]. The bike power solution was also not viable. The application of a bike will require a turbine that can convert the bike power to electricity. This way, it can power both the shredder and the injector. In addition, this selection relies on human abilities, which is not a continuous supply of energy. It was decided that the wall outlet would be the best solution due to its availability and reliability.

Selection		Wall Outlet		Bike/Manual		Solar	
Criteria	Priority	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Continuous supply	20%	9	1.8	5	1	5	1
Renewable	30%	10	3	10	3	10	3
Cost	20%	6	1.2	6	1.2	4	0.8
Ease of Use	30%	8	2.4	5	1.5	7	2.1
Total		8.4		6.7		6.9	
Rank		1		3		2	
Develop?		Yes		No		No	

1.5.3 Product Design

The third element of the design process is deciding what product to manufacture. Since, the scope of the project has changed, the design team will be doing further experimental testing on viable products from injection molding in Spring 2019. During Fall 2018 the design team consulted with advisors in the Dominican Republic for selecting possible products. The four main options are listed in Table 4 are based on basic factors such as part complexity and size. Currently, the selection criteria considered are cleaning intensity, community input, ease of production, and product volume. Cleaning intensity is based on how clean the plastic needed to be before melting. Kitchen utensils must be clean enough to uphold FDA standards [16]. For this reason, kitchenware scored low. Roofing shingles, tiles, and chairs still did not get a perfect score in this category because some cleaning is still required to remove residue. For community input, this section was scored based on preliminary feedback provided from the correspondent on her initial thoughts for the need of different products. Sara had mentioned chairs as a first idea that came to mind, but she has been waiting to provide further recommendations until she can perform a market feasibility study. Ease of production scoring was determined based on difficulty of injection molding needed for production. Injection molding becomes quite difficult as features become long and slender. which is why it was another selection criteria. Chairs received low scores in both ease of production and product volume category because of difficulties in manufacturing and producing a high volume product. From the weighted scoring, small tiles seem to be most feasible. It should be noted that product scoring is still in the preliminary stages, and the scoring and product considerations may change. The focus for spring 2019 will be exploring more potential product options through experimental testing and continued communication with advisors in the Dominican Republic.

Selection		Roofing Shingles		Tiles		Chairs		Kitchenware	
Criteria	Priority	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Cleaning Intensity	10%	9	0.9	9	0.9	7	0.7	4	0.4
Community Input	30%	8	1.6	7	1.4	10	2	8	1.6
Ease of Production	40%	6	2.4	8	3.2	3	1.2	7	2.8
Product Volume	20%	6	1.8	8	2.4	3	0.9	7	2.1
Total		6.7		7.9		4.8		6.9	
Rank		3		1		4		2	
Continue?		No		Yes		No		No	

1.5.4 Mold Selection for Experimental Testing

In order to effectively choose a mold material for prototype product testing, Table 5 displays the five materials considered. The mold will have a threaded input valve that screws onto the tip of the injector. The prototype molds will have three parts: two ¼” thick pieces for

outside casing and a middle section, also a ¼” thick, with a 3” by 4” rectangular cutout. The selection criteria include cost, durability, ease of production, and ease of release. Durability and ease of production were given priority at 30 percent and 40 percent, respectively, because of the experimental testing the molds will undergo. The molds will need to withstand multiples tests and also different shapes and modifications to the molds might need to be made, depending on testing results. LMU machine shop equipment including: the mill, electric discharge machining, and grinder, make aluminum and steel easiest to work with. Since the design team is wanting to do the mold production for experimental testing in-house, those two scored highest for ease of production. Silicone allows for the easiest product release, so tin cured silicone and platinum cured silicone scored highest for that selection criteria. However, the prototype product, a rectangle tile, the design team has decided to make is not complex, so the ease of release is not a priority and is only 10 percent of the total scoring. The two materials that scored highest were aluminum and steel with scores of 6.4 and 6.8, respectively. Ultimately, aluminum was selected due its heat conductivity. For future experimental testing, an epoxy or silicone based mold will be reconsidered for products with more complex shapes.

Table 5: Mold Material Selection for Experimental Testing Weighted Scoring

Selection		Aluminum Frame w/ Epoxy Filling		Aluminum		Steel		Tin Cured Silicone		Platinum Cured Silicone	
Criteria	Priority	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Cost	20%	9	1.8	6	1.2	5	1	5	1	4	0.8
Durability	30%	3	0.9	6	1.8	9	2.7	7	2.1	8	2.4
Ease of Production	40%	6	2.4	7	2.8	6	2.4	4	1.6	4	1.6
Ease of Product Release	10%	5	0.5	6	0.6	7	0.7	9	0.9	9	0.9
Total		5.6		6.4		6.8		5.6		5.7	
Rank		3		2		1		3		4	
Continue?		No		Yes		Yes		No		No	

1.6.0 Innovation

1.6.1 Shredder

A shredder is used to reduce large pieces of plastic into more manageable pieces for melting and injecting. Further detail of the design can be found in the description section. Since the concept of a plastic shredder is not an original idea, the design team concluded to draw inspiration from the design of Precious Plastic’s shredder; although, improvements were made.

Unlike the shredder of Precious Plastic, the team designed the shredder to have easy access to the shaft, teeth and blades. This allows for easy removal of the shaft and teeth for maintenance or repair. Clear cast acrylic was selected as the material for the top half and the frontal bottom piece of the shredder so that the operator will be able to see into the machine to

clearly identify issues that may arise during operation, i.e. jamming, dulling. This choice was also made to reduce the overall weight of the shredder.

During shredding, the teeth and comb knives may not always catch the plastic, causing the bottles to “bounce” on top of the spinning teeth and, potentially, falling out of the shredding area. In order to prevent any plastic from bouncing out, a clear cast acrylic hopper and a plunger combination was implemented, which is secured to the top of the shredder by bolts. The material choice for the hopper allows for full visibility of plastic bounce. A manual force, supplied by the plunger, is required to ensure that the plastic will be caught by the teeth and comb. It is implemented so that the user does not reach into the shredder to push plastic towards the rotating blades with the user’s hand. The fasteners that secure the hopper to the top half of the shredder act as a stopping mechanism for the plunger to prevent the teeth from damaging the plunger.

At the end of each blade is a flat section that measures 0.5 inches. This flat surface was implemented so that the blades and spacers assembly can rest on a table when removed from the housing unit.



Figure 6: Example rectangular hopper and plunger [11]

1.6.2 Injector

The injector design will also be largely based off of Precious Plastic’s design. However, modifications for enhanced performance will be made. The current Precious Plastic design uses four separate coils spaced evenly along the injector to melt the plastic. To experiment with heat distribution along the piping, the design team will conduct experimental testing using heating tape, shown in Figure 7. The heating tape is 1” wide by 10’ long, so it can wrap around the entirety of the tube and the tip of the injector. The heating tape was wrapped around the tip of the injector to ensure that plastic did not cool and harden before it was injected. The experimental testing regarding the heating tape is discussed further in the experimental testing section. The heating tape melted the plastic effectively during experimental testing and due to time constraints was used on the final iteration machine. Future teams should pursue further experimental testing to determine if heating coils would be more effective.

After experimental testing the team decided to change the apparatus that attaches the heating tube to the injector upright. Instead of being stationary, the apparatus in the final iteration machine is capable of moving up and down the injector upright. This is different from the

Precious Plastic design and allows for faster and more efficient operation and mold removal. Pictures of this design change can be seen in section 1.7.0.



Figure 7. Gamut heating tape [17]

1.6.3 Mold design

The mold design that was used in the Precious Plastics model and in the developmental testing for this project involved a mold that was directly screwed on to the sprue coming out of the injector. This project used a three part steel mold held together by six fasteners with a tapped hole in the top plate. This mold screwed into the sprue can be seen in Figure 8. Ultimately this design was changed for the final iteration of the injector. The steel mold was useful for initial testing but challenges arose that made a change in the mold design necessary. The final design of the mold is significantly different from the precious plastics model. The final mold design includes two aluminum blocks that are held together by two guide pins. The top half of the mold has a concave indent with the sprue hole at the bottom. This indent is designed to match a rounded sprue head thereby aligning the injector sprue channel with the channel entering the mold. Aluminum was chosen to replace steel due to the fact that aluminum conducts heat more effectively than steel. Replacing the fasteners with guide pins and changing the mold material meant that the mold was easier to take apart and heated up faster. The final mold design can be seen in Figure 9.

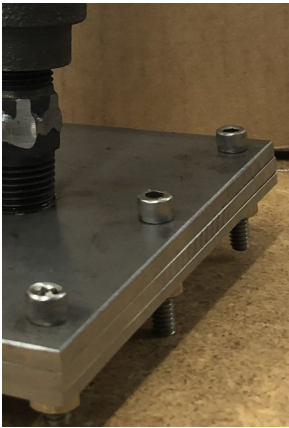


Figure 8. Prototype mold

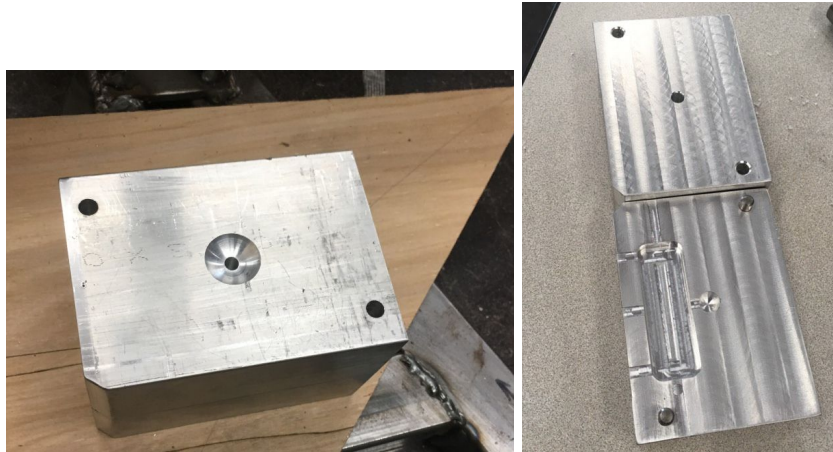
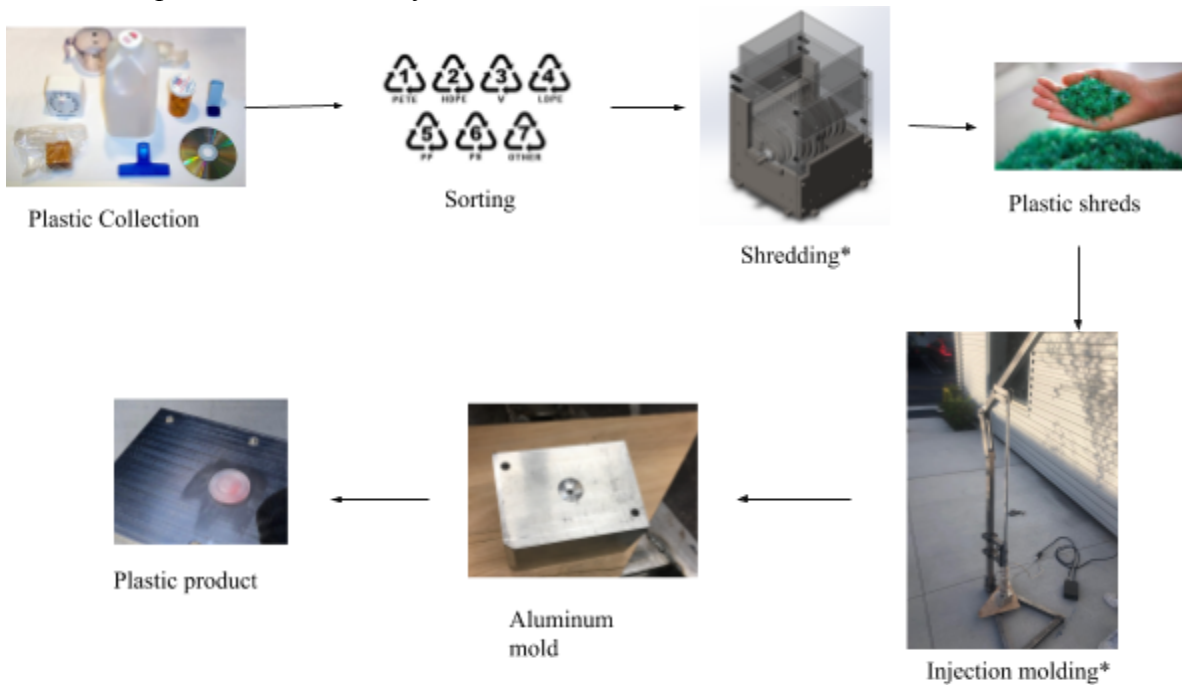


Figure 9. Final aluminum mold

1.7.0 Description

The flowchart below in Figure 10 depicts the start to finish process for the shredder and injector method. First, plastic is collected, then sorted and briefly cleaned. Once clean, the shredder reduces the plastic into flakes that must be washed and dried. The dried flakes are then heated by heating coils and are pushed into a mold. The melted plastic will then cool and harden to take the shape of the mold cavity.



*Detailed discussion below

Figure 10: Method Process Overview

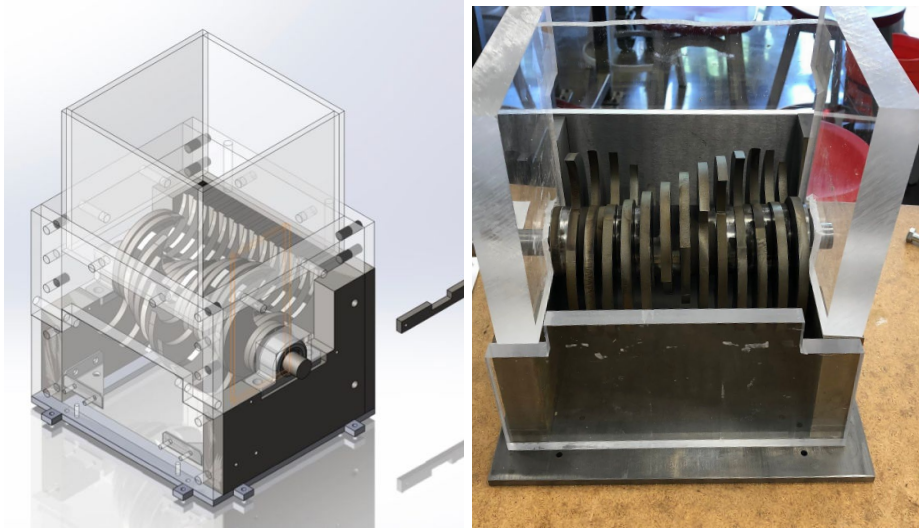


Figure 11: Shredder Assembly

Modeled Shredder: The final design will comprise a shredder (Figure 11), injector (Figure 12), and mold (Figure 9). The shredder is designed to be approximately 9” wide, 8” long, and 14” tall. A 2kW motor, as suggested by Precious Plastic, powers the shredder and turns a hexagonal shaft. The shaft is designed to be hexagonal so that it axially locks the blades and spacers in place and prevents the blades from any unwanted rotation. Shims will be added along the shaft in the event that the teeth and spacers have lateral rotation. There is a clearance of 0.01 inches between the hexagonal shaft and the hexagonal bore of the blades and spacers. Spacers are inserted between the blades so that the teeth do not collide with the comb knives. Similarly, the comb knives are separated by comb spacers. Since the spacers do not experience a shearing force, its hexagonal bore was slightly altered such that the new design has two flat surfaces which allows for the shaft to turn the spacer in sync with the blades. The clearance measured between the blades and the comb knives measure 0.01 inches and 0.05 inches. The back sides of the comb knives and the comb knives are flush against the back wall of the shredder. The comb knives and spacers are connected to the shredder via two 5/16-18 inch threaded bars that will be secured by fasteners by bolts and washers on both sides. Attached to the shaft inside the main compartment are thirteen ¼” rotating blades, each having two teeth on opposite sides. There are three separate blades designs that are slightly offset from one another by a twenty degrees rotation of the hexagonal bore. Having this 20 degrees offset creates a continuous wave-like cutting motion which shears the plastic against the comb knives.

In order to make the machine transportable, the housing unit is divided into two parts, the top and the bottom. The two halves are fastened together by five 5/16”-18 thread screws, two on the front side and three on the back side. These screws were used to maintain screw consistency throughout the shredder’s outer housing. There will be leftover screws in case the thread is stripped. A base connects the bottom half of the shredder to the table, which prevents movement of the shredder and will prevent the possibility of motor and shaft misalignment. On top of the shredder is a hopper that guides the plastic into the blades and prevents plastic from bouncing out of the shredder. The hopper and the top half of the shredder are made from a transparent acrylic so that jammed plastic can be identified immediately. If a part such as the teeth, comb or spacers were to break or malfunction, the entire machine is designed to use interchangeable part

replacements. The LMU team will leave the El Cercado community with spare parts, but in the future, the community has access to the detailed drawings so that they can contact a manufacturer if more replacement parts are needed. The desired part could be manufactured and then shipped to the community.

Manufactured Shredder: The team ran into issues with excessive manufacturing requirements. In house, the teeth, spacers, base, bottom walls and shaft were able to be manufactured without any holes. The team also cut the acrylic parts out with a jigsaw due to time constraints, however, these pieces were oversized. Overall, the comb, spacers and bearing stoppers were unable to be manufactured completely. Additionally, due to safety concerns the motor and reducer could not be connected to the shredder. The bearings were delivered oversized and had to be machined to the correct size. Although the shredder was unable to be fully completed, it was clear that the shaft and teeth moved smoothly, the acrylic housing provided easy visibility, and it was easy to change out any interchangeable parts.

Due to the multitude of parts in the shredder, the parts must be within the correct tolerance to ensure that misalignment does not occur. In this design, the team has allowed for at least one side of the blades and the comb knives to have a clearance of 0.01 inches and the other side measuring 0.05 inches. Having this tolerance allows for at least one reliable shearing plane. Unfavorable tolerancing will lead to misalignment which will damage the motor as well as the teeth and comb knives. When assembling the teeth and spacers together, it was noted that instead of measuring 7 inches—the desired length of the teeth and spacers—the assembly measure 6.90 inches. This offset of 0.1 inches means that the blades will overlap with the knives and collide, causing major part damage.



Figure 12: First iteration modeled injector design, final injector, and zoom in of reducer and mold

Modeled injector: The purpose of the modeled injector, as seen on the left in Figure 12, is to efficiently melt the plastic flakes and inject them into a mold. The piping where the plastic shreds is melted has a 1” ID and 1.5” OD which is based off the Precious Plastic design. The first iteration modeled injector has a threaded sprue which screws onto the reducer.

Manufactured injector: During experimental testing, two issues appeared- the reducer, sprue, and mold were getting clogged once the plastic cooled and the tolerance needed to be tight between the heating pipe wall and plunger being used to push the plastic. The manufactured injector changed to address these issues as seen in the middle picture of Figure 12. A new curved sprue head now fits within a concave slot within the mold to simplify the reducer, sprue, and

mold connection as seen in the right picture of Figure 12. An aluminum tube replaced the steel piping used for the main heated shaft because aluminum tubing has a smooth, circular ID when compared to steel piping which has a welded seam in the ID.

2-Analysis

2.1.0 Failure Modes and Effects Analysis (FMEA)

When looking at the overall process that the plastic goes through, there are a few areas where systematic issues may arise. These issues are summarized by subsystem in the tables below. The most severe failure modes included injury and misalignment for the shredder and cooled plastic clogging and high heat surface exposure for the injector. The least severe failure modes were teeth dulling for the shredder and injector frame stability for the injector.

2.1.1: Shredder Failure Modes

Table 6. FMEA for the Shredder					
Potential Failure Modes	Potential Effect(s) of Failure	S E V	Feasibility	Potential Causes	Design Implementation
Teeth Dulling	Unable to shear plastic	2	6	Teeth or comb knives may dull due to wear over time	Interchangeable parts, box is designed to give easy access to the teeth, heat treatment
Non-rectangular Parallelogram	Multiple part damage	4	2	Plastic jamming	One piece base frame, corner reinforcing brackets
Jamming	Motor failure, part damage	3-7	9	Plastic jamming or incorrect shredding material	Visible acrylic housing, Future implementation of control system that allows motor to reverse
Mixing of non-plastic and plastic flakes	Clogged injector	4	3	Plunger reaches too far down and is chipped by the shredder blades	Lip is created by the inner screws of the hopper attachment to stop plunger from touching the blades
Misalignment	Teeth and comb collision	8	5	Tolerancing of individual parts and possible deflection	Box has features that helps align it, the FEA showed that there is only a 0.003 inch deflection at max stress
Injury	Severe injury	10	1	Manual force applied by user's hand instead of plunger	Plunger provides a way to push down plastic without using an arm

The most severe failure mode is injury. As a preventative measure, a hopper and plunger combination was implemented so that the operator will not have to expose their hands to the rotating teeth. If plastic has to be removed, the shredder can be unplugged to prevent the shredder from accidentally turning on. The second most severe failure mode is alignment. If the teeth and the comb knives are even slightly offset caused by jamming, they may collide and cause damage to both parts. Misalignment and tolerancing are further described in section 2.2.1. It may be caused by plastic jamming the machine or by trying to shred unsuitable materials. It may also result in causing the housing to shift and take on a rhombus-shape. Jamming may also cause motor failure and part damage. If jammed by plastic, it will result in only motor damage. If the shredder catches something that cannot be sheared, it will result in motor damage as well as

part damage. To prevent this from happening, the design team implemented a control system that will stop the shredding process if the shaft experiences a torque greater than 200 lbf.

Since the shredder is designed to cut up thousands of plastic flakes, the teeth and comb knives may experience dulling over time. Although dull blades are a problem when it comes to shearing, this issue is easily solved. In order to prevent dulling in the first place, the teeth and the comb knives will be heat treated. This will increase the strength and durability of the low carbon steel. In addition, the shredder also implements interchangeable parts. If one of the teeth or comb knives were to dull, then the machine can be taken apart quickly and could sharpen the teeth with a sander.

2.1.2 Injector/Mold Failure Modes

Table 7. FMEA for the Injector/Mold					
Potential Failure Mode	Potential Effect of Failure	SEV	Feasibility	Potential Cause/ Mechanism of Failure	Design Implemented
Cooled plastic clogging	Inability to continue injection and molding	8	7	All of the plastic in heating component is not discharged into mold leaving residue that cools and hardens	Movable heating tape that can be used to reheat clogged components
Injector frame stability	Machine tipping and/or failure	9	3	Too much force applied to lever arm could cause the failure in attachment piece or instability in base	Triangular base was implemented to keep stand upright despite minor horizontal forces. Steel used as structural member to ensure strength.
High heat surface exposure	Users could be burned	8	6	Hot, exposed piping	Insulating foam layer
Injector plunger tolerance	Plastic build up along wall	6	8	The tolerance between the plunger (rod) and piping is not tight enough	EDM was used to smooth inside of pipe; experimental testing will be used to evaluate the performance
Injector plunger jamming within piping	Improper functioning of machine	6	7	Excess plastic cools and dries within piping causing the plunger to get stuck	Plunger will be flush with piping; performance will be evaluated with experimental testing

One potential failure for the injector is cooled plastic getting clogged in the in the piping or sprue. The design team gave the failure a severity of eight because if the piping or sprue were to clog, plastic could not be extruded and products would not be produced. One of the main objectives for the project is to allow for economic stimulation in the country, so products need to be able to be consistently produced. To overcome the issue, movable heating tape will be used to reheat the plastic to allow for unclogging. During experimental testing, clogging within the reducer and sprue did occur. Once plastic had cooled within these portions, it was quite difficult to remove the hardened plastic and in one iteration of experimental testing, we were unable to remove the hardened plastic. The team decided to change the design of the sprue head and reducer to mimic a system used in the injection molding industry and hopefully minimize the clogged plastic issue [12].

Injector frame stability is another potential failure. It was given a severity of five because the machine has the potential to tip if too much force is provided to the lever arm or if the

applied force is off center at too high an angle. However, CAD simulations and calculations shown in Appendix F justify a stable base was designed. The only concern is that the frame may tip if the lever arm rotates off the center more than 13 degrees. In order to increase this 13 degrees to the required 30 degrees, sand bags or bricks will be placed on top of the injector base. If the injector frame were to break at any location the machine would fail, hence the severity rating of 9. Analysis of the stresses in the injector frame can be found in section 2.2.4. After assembling the frame for further experimental testing, the lever arm did not rotate off center enough to cause the injector to tip. The design team is not worried about the machine tipping, but a sand bag could still be placed on the base of the injector frame for extra stability.

To avoid high heat surface exposure where the user could potentially be burned, an insulating layer should be applied around the piping shaft. The team did not have time to add the insulation. The insulation will also decrease heat from dissipating from the system. Less heat loss will make the heating of the plastic more efficient and will reduce the maximum temperature of the exposed parts of the heating element, keeping operators safe. The team did not have time to add the insulation; however, a future team should incorporate insulation over heating tape for added safety and help with

Depending on the injector plunger tolerance, plastic may build up along the walls of the piping. The wire EDM was used to smooth the inside piping surface and create a tight tolerance between the injector plunger and piping. Experimental testing was conducted to evaluate the performance of the injector plunger. The tolerance for the plunger became an issue. The pipe seam for the final piping was unable to be placed in the wire EDM due to the length of the piping. The design team decided to change the main heating shaft to an aluminum tube to help alleviate the tolerance problem. Tubing does not have the weld seam, so it has a circular, smooth ID.

There is also potential for the injector plunger to jam within the piping if excess plastic cools and dries within the piping. The tight tolerance between the injector plunger and piping was implemented to overcome the problem and experimental testing will be used to evaluate the performance. During experimental testing, the injector plunger got jammed when the team left the plunger inside the heating pipe once the plastic began to cool. Future teams need to make sure to remove the plunger from the main heated tube prior to the plastic cooling within the shaft.

2.2.1 Heat Transfer

Analysis must be done to ensure that the injector fulfills its requirements and that possibility of the above failures occurring is limited or eliminated entirely. The heat transfer occurring in the heating element must be understood to ensure that the heater effectively melts the plastic and fills the mold while still meeting safety requirements.

The heating pipe will experience conduction, convection, and radiation. There is conduction between the environment, the insulation, the heating coils, the steel tube, and the plastic inside. Additionally, there will be radiation and convection will occur between the steel pipe and the surrounding environment. Heat transfer analysis can be found in Appendix E. The analysis was done based on the assumption that convective heat transfer can be neglected due to insulation on the heating coils and radiation is negligible. Standard foam piping will be used to insulate the pipe. The equation for conductive heat transfer is below.

$$q_x'' = -k \frac{dT}{dx}$$

where q_x'' is the heat transfer rate. The constant k represents the thermal conductivity corresponding to the material through which the heat passes. A sample heater power was then used to calculate how much time it would take to apply the necessary heat to the plastic. This calculation was done without taking into account any possible losses first, then the power of the heater was decreased by 50% and the time was recalculated. This represents the time it would take to melt plastics while taking into account some loss. Taking loss into account, it was found that a 144W heater would take 491 seconds to melt ~42 cubic inches of plastic. Heaters rated to a higher power will decrease the time that it takes to heat the plastic. If the power of the heating element is not high enough, then the plastic in the injection tube will not melt to the desired temperature for molding. If the temperature of the heater is greater than expected and the thickness of the insulating layer is not thick enough, then people operating the machine may end up getting hurt via burns. Transient heat transfer analysis was done using finite element analysis in Solidworks. Insulation was excluded, but conduction was taken into account for all other aspects of the heating element. The heating tape was approximated using bands set to 400 degrees Fahrenheit with a power of 144W and the temperature of the environment was set to 70 degrees Fahrenheit. The results can be found in Appendix E and show that after 10 minutes the plastic inside the steel tube reaches the temperature of the heating coils. This is about 2 minutes longer than the initial calculations. The final heating tape selected was more powerful, 1045 W, and the time that it took to heat the plastic in the final injector was approximately 210 seconds. The final piece of heat transfer analysis that is left for future teams to complete is designing the thickness of the insulation layer to both minimize heat loss thereby melting the plastic quicker, and reduce the temperature of the exposed temperatures to 140 degrees Fahrenheit.

2.2.2 Fluid Flow

The volumetric flow rate of the melted plastic can be found using the equation below.

$$Q = \text{Volumetric Flow rate} = \frac{\text{Volume of injected plastic}}{\text{time}}$$

The volumetric flow rate may change based on the type of plastic that is being injected. Performance testing will be conducted on different mold sizes and different plastics. The volume of plastic that is injected into the mold will be divided by the time it takes to inject that plastic to estimate the average volumetric flow rate.

2.2.3 Stability and Stress Analysis

Analysis was done in order to understand what kind of forces would cause the injector stand to tip or break due to stress. For both the moment and stress analysis, a maximum force of 150 pounds was used to simulate a reasonable worst case scenario. 150 lbs represents a person hanging, suspended from the lever arm, which should never happen during actual operation. The hand calculations for the moment analysis can be found in Appendix F. It was found that a 150 pound force applied at 13 degrees from the vertical axis of the injector will cause it to tip. In order to increase this 13 degrees to the required 30 degrees, sand bags or bricks will be placed on top of the injector base.

Static stress and deflection simulations were done in solidworks on the welded joints that attach the plastic receptacle to the base. The results of the simulation can be found in Appendix

F. The maximum stresses permitted by the AISC Code for Weld Metal are $0.6 S_y$ in tension and $0.4 S_y$ in shear. The greatest simulated stress was found to be 12.2 ksi and the estimated shear strength of the steel tubing can be estimated at 40% of the yield strength of the steel. This gives the steel a shear strength of 21.6 ksi and the connection a safety factor of 1.7. More analysis must be done to ensure that the welded joints of the frame meet the AISC standards in standard and overloaded conditions.

2.2.4 Motor and Torque Analysis

The motor used in the precious plastics design was a 2.5 horsepower motor geared to run at 70 rpm. Their combination of motor and gearing works well, but is not documented or specified. This makes it very difficult to select a motor and gearing pair that is sure to be effective in shredding plastic. To inform the motor selection of future designs, A 2 hp engine rated for 1725 rpm was selected. A 30:1 gear reducer was paired with the motor to reduce the motor rpm to 58 rpm. The max output torque of the reducer and therefore maximum possible torque on the shredder is 2026 lb.in.

2.3.0 Cost Analysis

Table 8: Cost Analysis		
Category	Item	Cost
Machine	Shredder Raw Materials	1432.64
Machine	Injector Raw Materials	526.58
Machine	Shredder Electronics	162.82
Machine	Injector Electronics	663.09
Machine	Prototype	162.82
	Total	3775.74

As seen in Table 8, the total cost of this project was around \$3,800 including parts and materials for the shredder, injector and molding. A more detailed description of how much each individual item was budgeted can be found in Appendix B: Bill of Materials including and overview of how much the logistics and travel would cost for teams in the future. Both the materials and electronics are broken down by each machine. We were able to save costs by using equipment provided by the university and machining all of our own parts, however, in the future the team might be unable to produce functioning moulds for the specified without help from professionals since the machine shop has limited capabilities. If a future team looks further into molding it should cost around \$1,500 according to Rex Plastics. Overall, the shredder cost around \$1,600 while the injector cost around \$1,200. Precious Plastics was able to produce a shredder for about 300 euros because they used junkyard materials and did not have to buy many

expensive items like the motor. Overall, both of the machines cost around \$3,800 with \$1,600 allocated for the shredder materials and electronics, \$1,200 dedicated towards the injector materials and electronics and \$160 for prototyping.

3-Testing

3.1.0 Developmental Testing

There are three parts of the overall system that will need to be tested.

3.1.1 Shredder

1. Test how many cycles it takes to reduce plastic parts to the desired size.
Result: Using polystyrene, it was discovered that plastic should be fed into the shredder a minimum of four times. This testing was performed with the shredder loaned from Precious Plastic. The thickness of those blades measure 5 mm. The team's designed shredder utilizes blades that measure 0.25 in. Using the team's shredder may require more cycles to achieve the desired plastic size. Using other types of plastic may require different numbers of cycles as well. In addition, the method by which the plastic waste was originally formed must also be taken into consideration.

3.1.2 Heating element on the injector

1. Test to determine how long it takes for the heating chamber to completely melt plastic and bring it to the set temperature. Use a stopwatch and thermometer to measure the time elapsed when plastic is melted and at desired temperature.
Result: With the steel piping, heating tape and three part mold used for the developmental testing the plastic inside was melted after 10-15 minutes depending on the type of plastic. Plastics that had a higher melting temperature took longer because the heating tape took longer to reach the set temperature. Additionally, adding more plastic resulted in a longer melting time simply because there was more plastic to melt. The point at which the plastic melted was determined visually by looking in the top of the injector tube and examining the consistency of the plastic inside. The time was determined using a clock or stopwatch. It was determined that this 10-15 minutes was too long so the final injector design used an aluminum tube with a thinner wall to cut down on the heating time. Using the final injector design and polypropylene, the heating tape melted the plastic in approximately 210 seconds (2 minutes and 30 seconds).
2. Test the heat of the exterior of the heating element at its maximum temperature setting for safety purposes.
Result: Due to the fact that the machines are prototypes and are not actually going to the Dominican Republic this test was not performed. The heating tape was adjusted and put into many different configurations to test which configuration would be most effective for melting the plastic. To reduce disassembly and reassembly time, the insulation was ordered but never attached to the heating tube.
3. Test to see above what temperature setting each type of plastic begins to burn at. Measure the temperature or range of temperatures at which certain kinds of plastic begin smoking or burning.

Results: Three different plastics were tested in the prototype, PP, PS, and HDPE. It was found that the optimal injection heat was approximately 50 degrees fahrenheit above the published melting temperature of each type of plastic. The reason that the results of this experiment are not precise is because there was no reliable way to determine the temperature of the plastic in the middle of the injection tube without drilling a hole in the side of the tube and inserting a thermocouple.

4. Test the temperature at different points along the injector to determine if there are any cold spots.

Result: The team was not able to complete this testing but it would be vital for any future teams. The temperature at the tip of the sprue nozzle would be of particular interest because the team believes that a relatively cold sprue may be the reason that plastic was not injected into the final mold.

3.1.3 Mold/injection

1. Test to make sure that plastic is hot and viscous enough to fill the entire mold.

Result: No plastic was able to fill the entire prototype mold. Polypropylene was the only plastic that successfully traveled through the sprue and into the mold.

2. If fluid plastic has trouble filling the entire mold, test different levels of overheating the melted plastic to see if that fixes the problem.

Result: As previously mentioned, plastic was heated to 50 degrees fahrenheit more than its published melting temperature. Regardless, polypropylene is the only plastic that made it into the prototype mold.

3. If fluid plastic has trouble filling the entire mold, test methods of heating the mold prior to injection in order to ensure that the whole mold fills.

Result: The heating tape was wrapped around the prototype mold for several tests including the most successful test in which a small amount of plastic was able to reach the mold. This implies that heating the mold in some way prior to injection impacts the plastic flow into the mold.

4. Test volumetric flow rate of plastic by weighing injected plastic and comparing its volume to the time it took to inject the plastic.

Result: Because plastic did not enter mold there was no data that could be used to determine the volumetric flow rate.

5. Test the tolerance and fit of the plunger and heating cylinder. Visually examine inside of tube after injection to determine if plastic build up is left behind. If there is a large amount of plastic build up consider design alternatives such as a flexible plunger.

Results: Plunger tolerance was ten thousandths of an inch. Despite this tight tolerance plastic build up did occur along the side of the piping. This made it more difficult but not impossible to move the injector inside of the heating pipe.

3.2.0 Performance Testing

1. Test to make sure the hopper and plunger design eliminates the problem of bounce. Put plastic objects of different types in the hopper and use the plunger to ensure that the plastic objects “catch”. If the design does not give the user the ability to make every plastic object “catch” the design must be modified.
2. The shaft will be tested for fatigue. This will determine how long the shredder is expected to operate.
3. A 3” x 4” prototype mold with a 0.25” depth, as seen in Figure 13, will be tested in order to determine the the maximum mold sizing. If the mold is filled during experimental testing, the team will know that tiles and/or other products up to that size can be produced with the injector. If the injector is incapable of filling the prototype mold, the mold size will be reduced to be a 2” x 2” tile with 0.25” depth. If the injector is capable of filling the prototype mold then the mold will be expanded in both width and depth until the injector can no longer fill the mold or the mold can no longer be expanded. Different plastics will be tested in the injector so the team can determine capabilities of the injector with respect to each type. The team must be confident that they are delivering high quality machines that have a long life.

Result: The mold was used for performance testing but only a small amount of plastic was able to enter the prototype mold. This made it unnecessary to expand the mold and was part of the cause of the final design changes.



Figure 13: Prototype mold (middle and bottom plates)

4-Safety and Ethics

4.1.0 Safety

Overall there are three main sources of safety concerns regarding the injection molding machine design: hot exposed parts, sharp rotating members, and harmful emissions resulting from the plastic melting process.

Machines that melt plastic bring a risk of hot exposed parts and consequently, the risk of physical harm. The heated portion of the injection machine has the potential to reach 400-500 degrees Fahrenheit. In order to protect workers, all heated parts of the machine will be covered in

an insulating material. The external, heated parts of the injector shall be prevented from reaching 140 degrees Fahrenheit, as that is the temperature defined in section 7.4.3 of the ANSI/PLASTICS B151.1-2017 Safety Requirements for Injection Molding Machines. Additionally, the standards will be used to ensure that workers near the injection molding machine will be safe. This means that the devices will have proper awareness devices, such as signs or labels that identify which parts of the working injector are hazardous and operators will be given training on safe operating procedures as defined in section 7.1.4 and 7.1.5 from the aforementioned standards. One example of such training will include training on how long it takes the heater to cool after operation. To add another level of safety, workers will also be advised to wear personal protective equipment. With respect to the heating element of the injector, operators will be advised to wear heat resistant gloves. Due to there being molten plastic under high pressure in the injection molder, users will also be advised to use safety glasses to protect from splatter.

The shredder and the injection molding machine both have exposed moving parts. Operators who are untrained or are not paying attention are at risk of bodily harm. Utilizing the shredder involves manually dropping plastic waste into the machine. If that plastic bounces on top of the shredder blades instead of catching, uninformed operators may decide to use their hands to push plastic further into the machine. This puts operators at risk of injuring their fingers, hands, and arms. The shredder's hopper and plunger design allows for full operation of the shredder without any need for operators to put their hands near the blades while they are moving.

Finally, the process of melting plastic releases volatile organic compounds (VOCs) into the environment [18]. VOCs are compounds that can easily exist as vapor or gas at ordinary room temperature. They are known to have negative health effects [19]. The amount and variety of VOCs produced depends on many factors including the type of plastic, the temperature it was melted at, and its surrounding environment [18]. There are plastic identification codes developed by the Society of the Plastics Industry which can be used to easily identify what kind of plastic is in a given product. The ANSI/PLASTICS B151.1-2017 Safety Requirements for IMM and the Occupational Safety and Health Administration (OSHA) both describe plastic fumes as a potential workplace hazard. OSHA specifically states that plastic fumes irritate the eyes and respiratory tract [20]. Both OSHA and the ANSI standards recommend ventilating the injector area. Instead of using the machine inside and providing ventilation, all testing on the prototype will be done outside. When the injection molder is installed in El Cercado, ventilation must be provided. Personal protective equipment relating to the plastic fumes would involve respirators. Some sources say that standard N95 dust masks are enough [21], while others state that self-contained breathing apparatuses must be used [22]. It is unclear whether or not respirators are necessary if ventilation is provided or the plastic melting process is performed outside. More research must be done in this area or testing must be done on the prototype.

The design team will also train the operators when visiting El Cercado to install the machines. Training will include information on how to operate the machines, potential health hazards, and best practices to avoid harm.

4.2.0 Ethics

The ethics of the project hinge on how sustainable the project truly is and how the design requirements are informed by the community and people of El Cercado. The most important ethical considerations that the project will have to consider are those pertaining to the people of

El Cercado and how the design will ultimately impact them. The final product has the potential to do real good for the community of El Cercado and the design process should reflect that. The National Academy of Engineering (NAE) argues that engineering problems aimed at assisting developing communities must focus on providing these communities with "appropriate technology" [23]. Appropriate technology is defined as technology that is small scale, energy efficient, environmentally sound, labor-intensive, and controlled by the local community [23]. The NAE is not the only organization that promotes this approach to engineering in the developing world. In 2016 Peter Logan, a professor from the University of Sydney wrote that technologies for developing communities "should meet the technical, social and economic needs of the community by: being a capital-saving, employment-generating technology; being a small-scale technology; using local materials and energy resources; using existing or easily transferable skills; minimising social and cultural disruption; producing goods appropriate for mass consumption in adequate quantity and acceptable quality; and involving a rational sustained use of the environment" [24]. The concept of appropriate technology should really be applied to all engineering projects regardless of their location. It must be emphasized when referring to projects in the developing world because of how aid has been provided to developing communities historically.

It is generally agreed upon that aid in response to natural disasters or other catastrophes is warranted and necessary. How engineers can best conduct humanitarian projects in developing countries is a topic of debate. A report from the Colorado School of Mines details a common critique of engineering projects in developing countries stating, "The concern is that the more engineers conceptualize their relationship with communities or the 'underserved' in terms of need/help, the more they see communities as problematically 'other' and defined by what they lack, while re-affirming themselves as 'problem-solvers' or 'planners' with solutions" [25]. The article does not say that a need/help relationship is intrinsically bad. The engineering profession as a whole is based off of need/help relationships. Generally, clients approach engineers with desires, needs, or requirements and engineers apply their knowledge to meet them. The article does however condemn thinking of developing communities as problematic or other. The relationship between Loyola Marymount University and the community of El Cercado must be one of collaboration. It must emulate the client-engineer relationships that dominate the engineering profession. The technical, social, and economic requirements of the community must dictate the design requirements of the project.

In order to accomplish this, the project team at Loyola Marymount must maintain constant communication with their advisors in the community. These advisors must consistently inform, and be informed of, design decisions. This will ensure that the final product effectively addresses all components of the definition of appropriate technology, and that the design is optimized for use in El Cercado.

5-Conclusion

5.1.0 Comparison

Table 1 includes design specifications complete with analytical performance predictions and experimental results. This table can be found on pages 10 through 131 in the Design Specification section.

5.2.0 Evaluation

Overall, the team met the objectives of designing a shredder with interchangeable parts. The shredder, however, was not operational at the expected project end date, as only half of the system was able to be machined and assembled. Experimental testing was performed on the loaned shredder due to this setback. See the Recommendations section below for how this problem can be avoided in the future.

The final injector subsystem did half of what it was designed to do. It is clear that the injector melted the plastic and caused it to flow to the end of the sprue nozzle. The final design was ultimately not able to force plastic into the mold. This could be due to ineffective heating from the heating tape or inadequate pressure from the plunger. If the design were altered in order to allow for the proper filling of the mold it would still be important to test the functionality of the injector as an actual manufacturing machine. Evaluating how many parts could be made in an hour and ease of operation would be critical in determining whether the machine would be effective if deployed.

5.3.0 Recommendations

Shredder Future Recommendations: There were several problems that arose while manufacturing the shredder. During the design phase, there were constant changes to the shredder housing that were dependent on the designs of the teeth, comb, and motor specs. It is suggested that future teams focus on functionality of the design, rather than trying to implement one or two innovations of their own. In addition, future teams should first find the optimal motor, and then design the parts in the following order: teeth, spacers, comb, motor, reducer, bearing, base, housing, hopper. Future teams should also research material properties of different kinds of plastics and the method of how each plastic type is made to determine which type of plastic will suit the entire process the best. Due to their unfamiliarity with the overall machining process, parts were not designed with manufacturing in their mind. If any future teams plan to manufacture parts in house, it is suggested that they consider the manufacturing process for each part while designing the part and discuss with the machinists. Future teams should order pre-made parts prior to ordering raw materials for machining because the pre-made parts may be oversized and unable to fit within the intended design.

Although LA Precious Plastic was contacted at the start of the design phase, it is suggested that future teams immediately seek them out for advice. The team should also seek to increase the number of team members by including an electrical support to implement safety control systems.

Injector Future Recommendations: Better heating and increased pressure are two clear paths that would lead to a more effective injector and ultimately expand the amount of plastic that can reach the mold. Any future team should determine if the heating tape is effectively melting the plastic. This could be determined by conducting experiments using thermocouples. If the heating tape is determined to be ineffective, the team should investigate using heating coils instead. Regardless of the heating device used, future teams should design to ensure that the mold and the sprue nozzle are adequately heated as these are points that have been identified as potential causes of failure. In addition to expanding the heating capacity, improving the amount of pressure that can be applied would be worthwhile for future interactions. Using some kind of

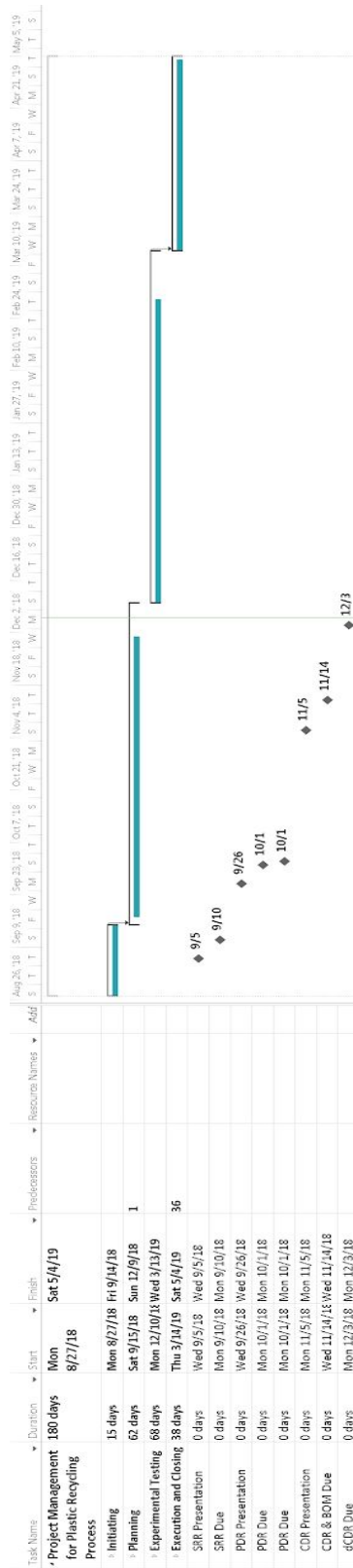
References

- [1] Census Pamphlet, “Tu Municipio en Cifras”, 2017, Peace Corps El Cercado, Dominican Republic]
- [2] Bpf, British Plastics Federation. “Vacuum Forming.” *Polyethylene (High Density) HDPE*, British Plastics Federation, 2018, www.bpf.co.uk/plastipedia/processes/vacuum_forming.aspx.
- [3] Plovie, Bart & Yang, Yang & Guillaume, Joren & Dunphy, Sheila & Dhaenens, Kristof & Van Put, Steven & Vandecasteele, Björn & Vervust, Thomas & Bossuyt, Frederick & Vanfleteren, Jan. (2017). Arbitrarily Shaped 2.5D Circuits using Stretchable Interconnects Embedded in Thermoplastic Polymers: Arbitrarily Shaped 2.5D Circuits using Stretchable.... *Advanced Engineering Materials*. 1700032. 10.1002/adem.201700032.
- [4] Screws, Extrusion. “What Is Extrusion Molding.” *What Is Extrusion Moulding?*, 2018, www.extrusionscrews.com/ExtrusionMoluding.php.
- [5] Technology, Manufacturing. “Extrusion Moulding Process for Plastic Machining.” *TechMiny*, 24 Oct. 2016, techminy.com/extrusion-moulding.
- [6] Dontigney, Eric. “The Advantages & Disadvantages of Extrusion Molding.” *Bizfluent*, 26 Sept. 2017, bizfluent.com/info-8544738-advantages-disadvantages-extrusion-molding.html.
- [7] TranPak, Manufacturing. “What Is Compression Molding?” *What Is Compression Molding?* , 2018, www.tranpak.com/tools/faq/what-is-compression-molding.
- [8] Bpf, British Plastic Federation. “Injection Molding.” *Polyethylene (High Density) HDPE*, British Plastics Federation, 2018, www.bpf.co.uk/plastipedia/processes/Injection_Moulding.aspx.
- [9] Chuankrerkkul, Nutthita & F. Messer, Peter & Davies, H.A.. “Powder Injection Moulding of Cemented Carbides : Feedstock Preparation and Injection Moulding.” *J. Metals, Materials*, 2017.
- [10] Conserve Energy, Future. “What Is Plastic Recycling and How to Recycle Plastic - Conserve Energy Future.” *Conserve Energy Future*, 25 Dec. 2016, www.conserve-energy-future.com/recyclingplastic.php.
- [11] Precious, Plastics. “Start Collaborating, Boost Plastic Recycling .” *Precious Plastic*, 2018, www.preciousplastic.com/.
- [12] Fattori, Jim. “Dealing with Sprue Bushings On the Production Floor.” *Plastics Technology*, vol. 63, no. 10, Oct. 2017, p. 40.
- [13] Raybuck, Auto. “Pickup Truck Bed Size Dimensions.” *Raybuck Auto Body Parts*, 2018, raybuck.com/pickup-truck-bed-size-dimensions/.

- [14] ANSI/PLASTICS B151.1-2017 – Plastics Machinery – Safety Requirements for Injection Molding Machines
- [15] Aggarwal, Vikram. “Solar Panel Efficiency: What Panels Are Most Efficient? | EnergySage.” *Solar News*, EnergySage, 3 Dec. 2018.
- [16] Center for Food Safety and Applied Nutrition, FDA. “Guidance & Regulation - Guidance for Industry: Use of Recycled Plastics in Food Packaging (Chemistry Considerations).” *U S Food and Drug Administration Home Page*, Center for Drug Evaluation and Research, 2018, www.fda.gov/Food/GuidanceRegulation/ucm120762.htm.
- [17]<https://www.gamut.com/p/heating-tape-with-adjustable-thermostat-control-controller-included-NTA0NDY0>
- [18] Yamashita, K., et al. *VOC EMISSIONS FROM WASTE PLASTICS DURING MELTING PROCESSES*. 2007.
- [19] Department of Health, DOH. “Indoor Air.” *Airborne Precautions - Minnesota Dept. of Health*, 2018, www.health.state.mn.us/divs/eh/indoorair/voc/.
- [20] United States Department of Labor, USDL. “Horizontal Injection Molding Machine Safety Tour.” *Occupational Safety and Health Administration*, 2018, www.osha.gov/SLTC/etools/machineguarding/plastics/himm_tour/himm_tour_fl.html.
- [21] Ariens Specialty Brands LLC, Gempler's. “How to Select a Respirator.” *Gempler's Making Hard Work Easy*, 2018, www.gemplers.com/tech/sresp.htm.
- [22] Sasol , Polymers. “Material Safety Data Sheet Polypropylene .” *SASOL Reaching New Frontiers*, 2018, www.columbus.co.za/downloads/MSDS_Packing_Materials.pdf.
- [23] National Academy for Engineers, NAE. “Engineering for the Developing World.” *Grand Challenges - Engineer Better Medicines*, 2018, www.engineeringchallenges.org/cms/7126/7356.aspx.
- [24] Logan, Peter. “Where Aid Fails, Appropriate Technology Can Succeed.” *The Conversation*, The Conversation, 19 Sept. 2018, theconversation.com/where-aid-fails-appropriate-technology-can-succeed-40569.
- [25] Schneider, Jen. “Engineering to Help: The Value of Critique in Engineering Service.” *Semantic Scholar*, 2018, pdfs.semanticscholar.org/80eb/d6139a61f727a7c06a83e85decca58a0eb7e.pdf.

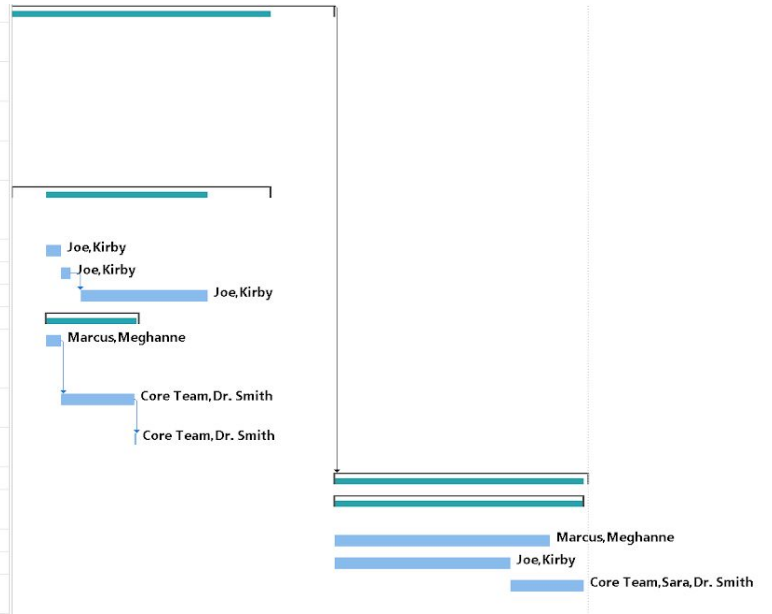
Master Timeline for Year

APPENDIX A: TIMELINE



Detailed Timeline: 12/10/18-5/11/19

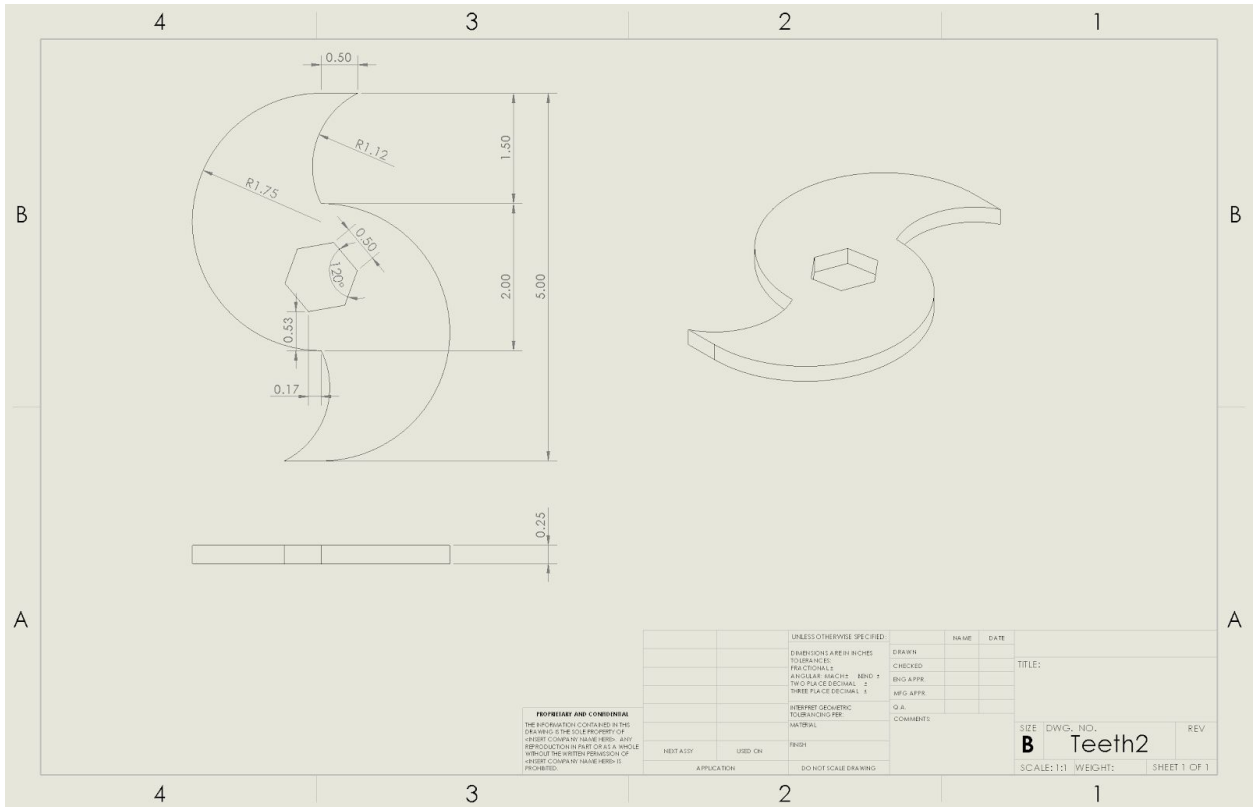
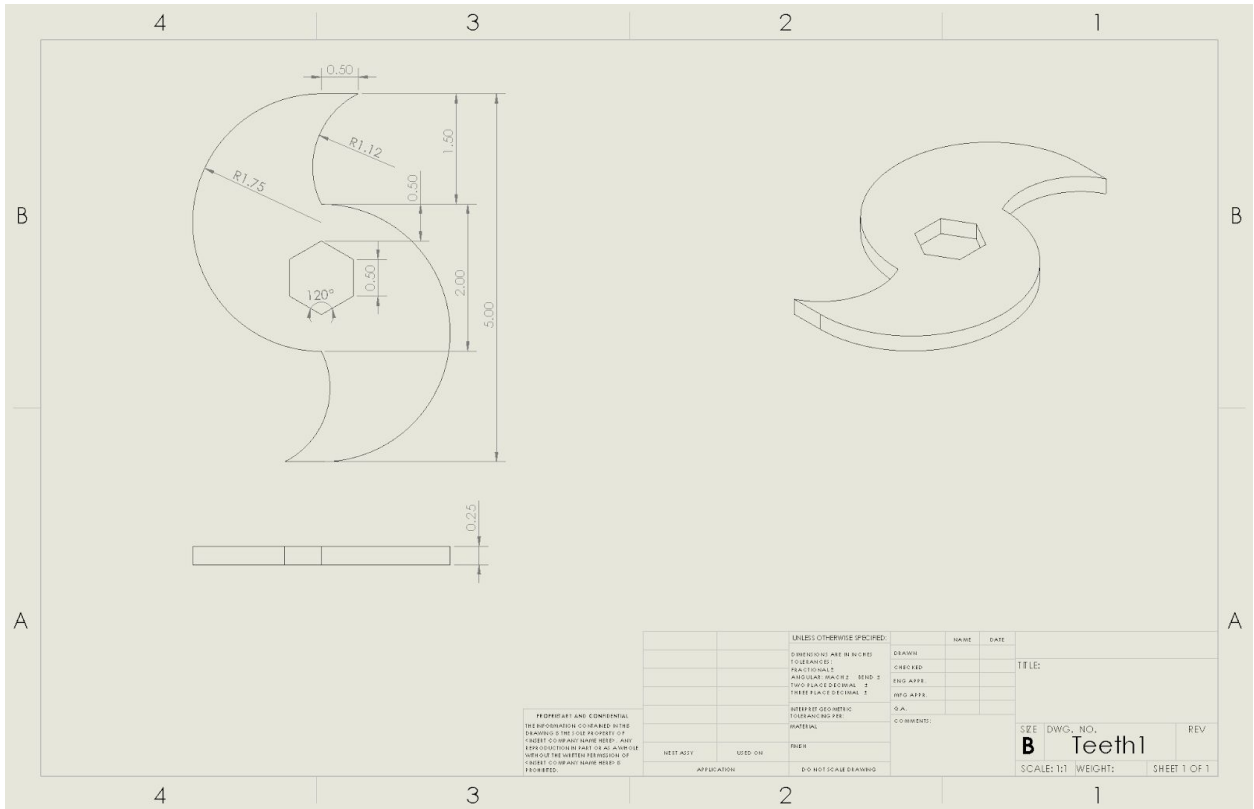
• Experimental Testing	68 days	Mon 12/10/18	Wed 3/13/19		
• Orders Placed for experimental testing	3 days	Mon 12/10/18	Wed 12/12/18		
Parts for Shredder	3 days	Mon 12/10/18	Wed 12/12/18		
Parts for Injection Molding	3 days	Mon 12/10/18	Wed 12/12/18		
Shipping of Machine	3 days	Mon 12/10/18	Wed 12/12/18		
• Injection Mold Experimental Testing	39 days	Mon 1/7/19	Thu 2/28/19		
Sprue diameter	3 days	Mon 1/14/19	Wed 1/16/19		Joe, Kirby
Heating taping	2 days?	Thu 1/17/19	Fri 1/18/19		Joe, Kirby
Product testing	20 days	Mon 1/21/19	Fri 2/15/19	43	Joe, Kirby
• Motor Testing	15 days	Mon 1/14/19	Fri 2/1/19		
Motor testing parameters selection	3 days?	Mon 1/14/19	Wed 1/16/19		Marcus, Meghanne
Testing	11 days?	Thu 1/17/19	Thu 1/31/19	46	Core Team, Dr. Smith
Reviews	0.5 days?	Fri 2/1/19	Fri 2/1/19	47	Core Team, Dr. Smith
• Execution and Closing	38 days	Thu 3/14/19	Sat 5/4/19	36	
• TBD: scope of building	37 days	Thu 3/14/19	Fri 5/3/19		
Shredder	32 days	Thu 3/14/19	Fri 4/26/19		Marcus, Meghanne
Injector	26 days?	Thu 3/14/19	Thu 4/18/19		Joe, Kirby
Organize material for next year team	11 days	Fri 4/19/19	Fri 5/3/19		Core Team, Sara, Dr. Smith

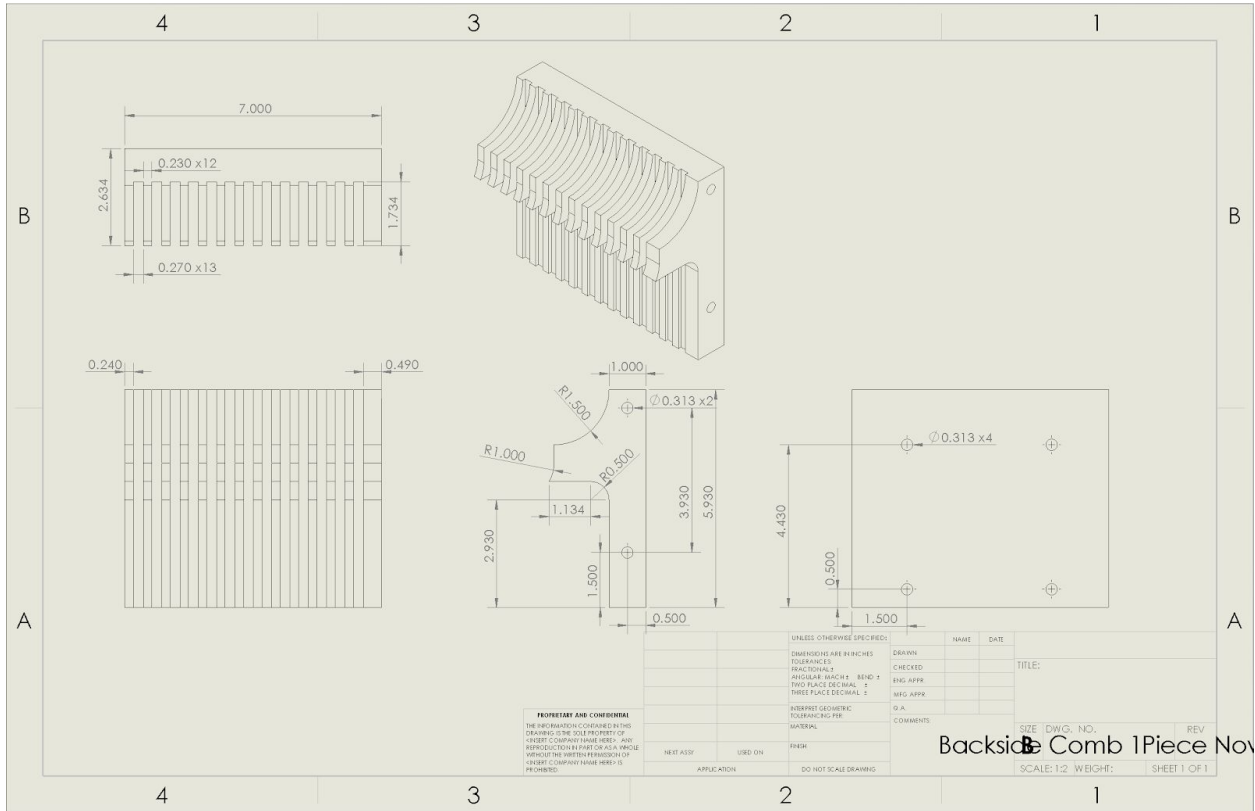


APPENDIX B: BILL OF MATERIALS

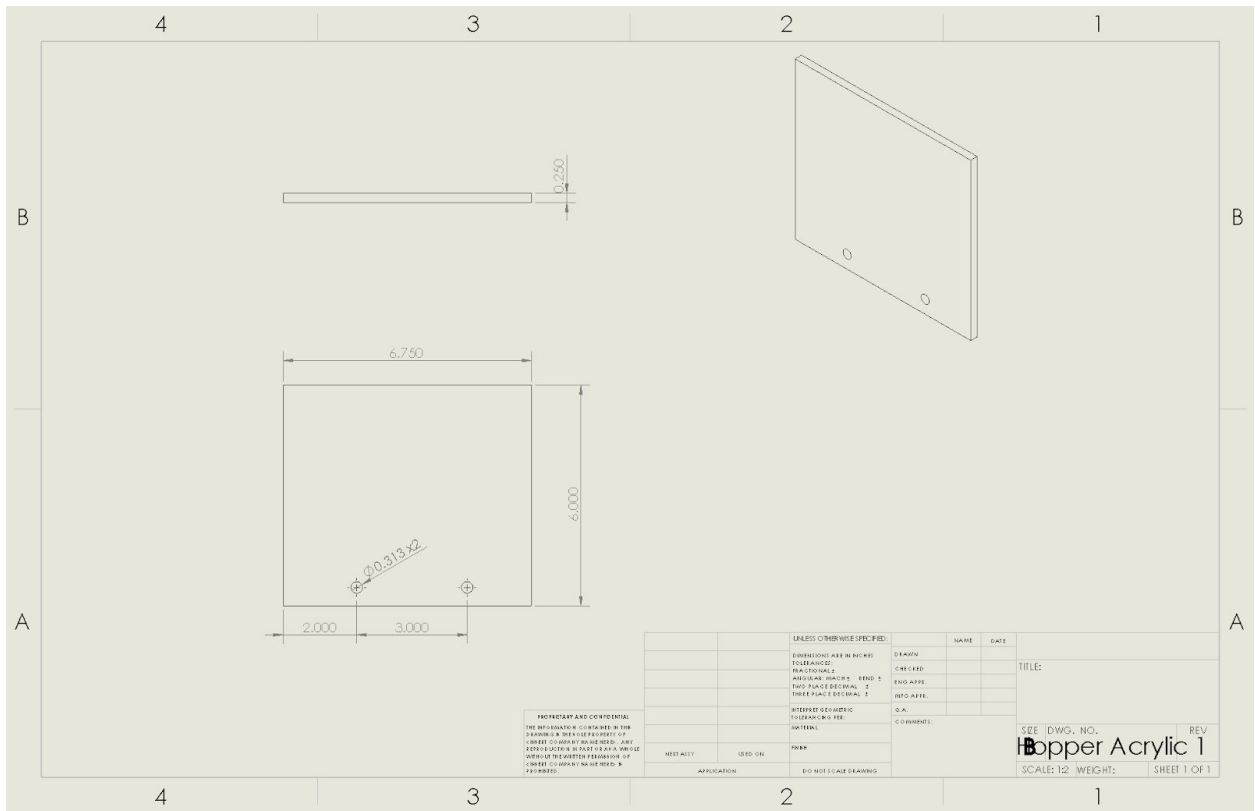
Budget:	\$4,500.00		
			Amount Left
			\$724.26
Name	Details	Amount	
Kirby	Prototype	162.82	
Kirby	Heating Tape	169.13	
Kirby	Heating Tape	179.45	
Meghanne/Marcus	Shredder Raw Materials	1166.4	
Kirby	Frame	407.5	
Joe	Motor	532.49	
Joe	Reducer	329	
Kirby	Temp controller	314.51	
Joe	Coupler + Switch	198.21	
Meghanne	Fasteners + Insulation	17.62	
Joe	PPE	52.68	
Joe	Hone	48.78	
Meghanne	Missing materials	168.21	
Joe	Wire+switch	28.94	
Marcus	key stock+threaded rod	9.82	
Meghanne	wood and tools	88.21	
TOTAL		0	3775.74

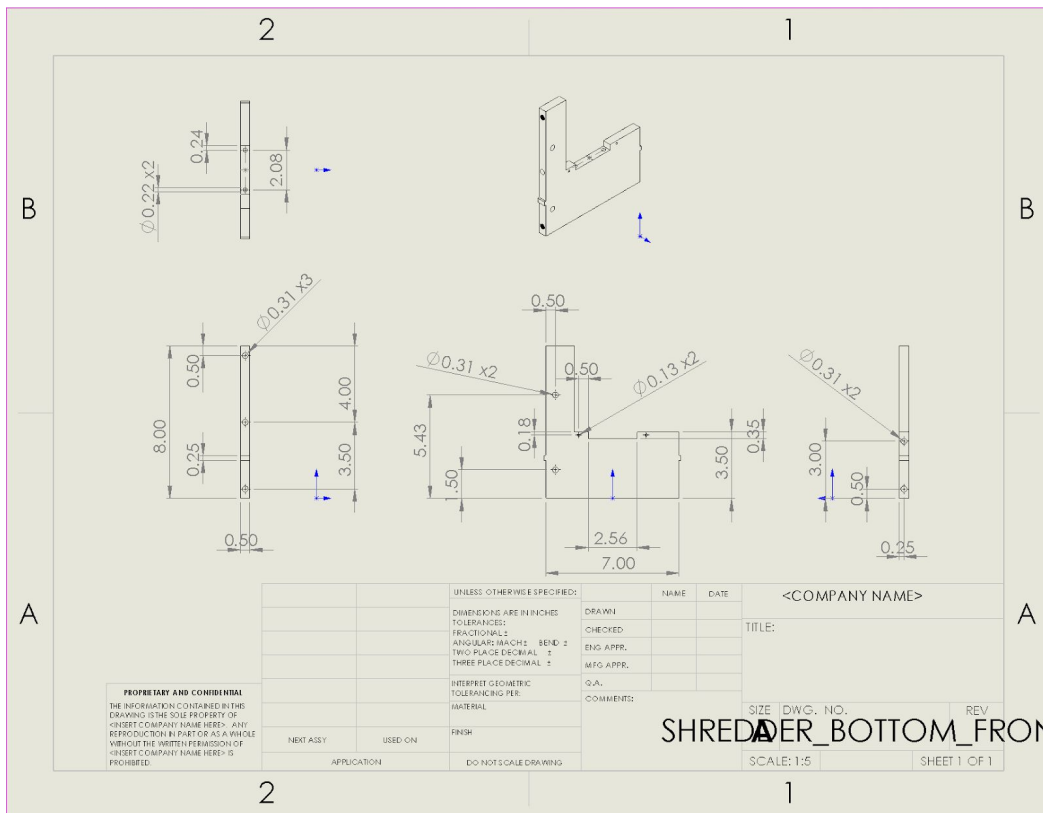
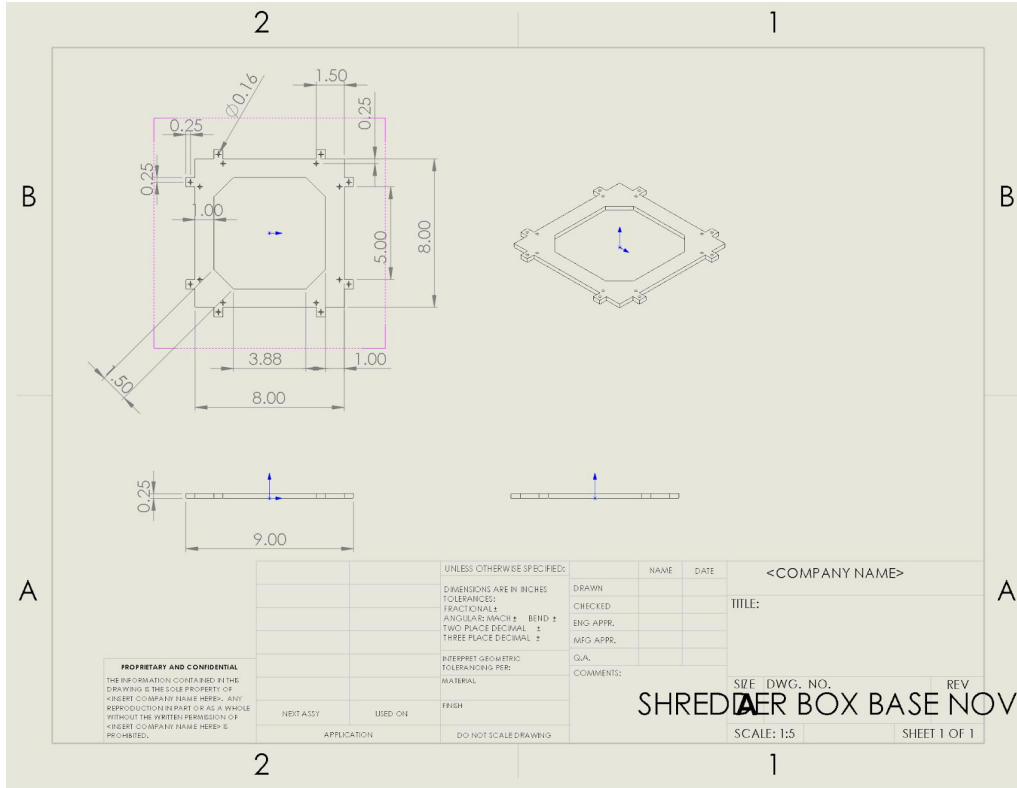
APPENDIX C: PART DRAWINGS FOR SHREDDER ASSEMBLY

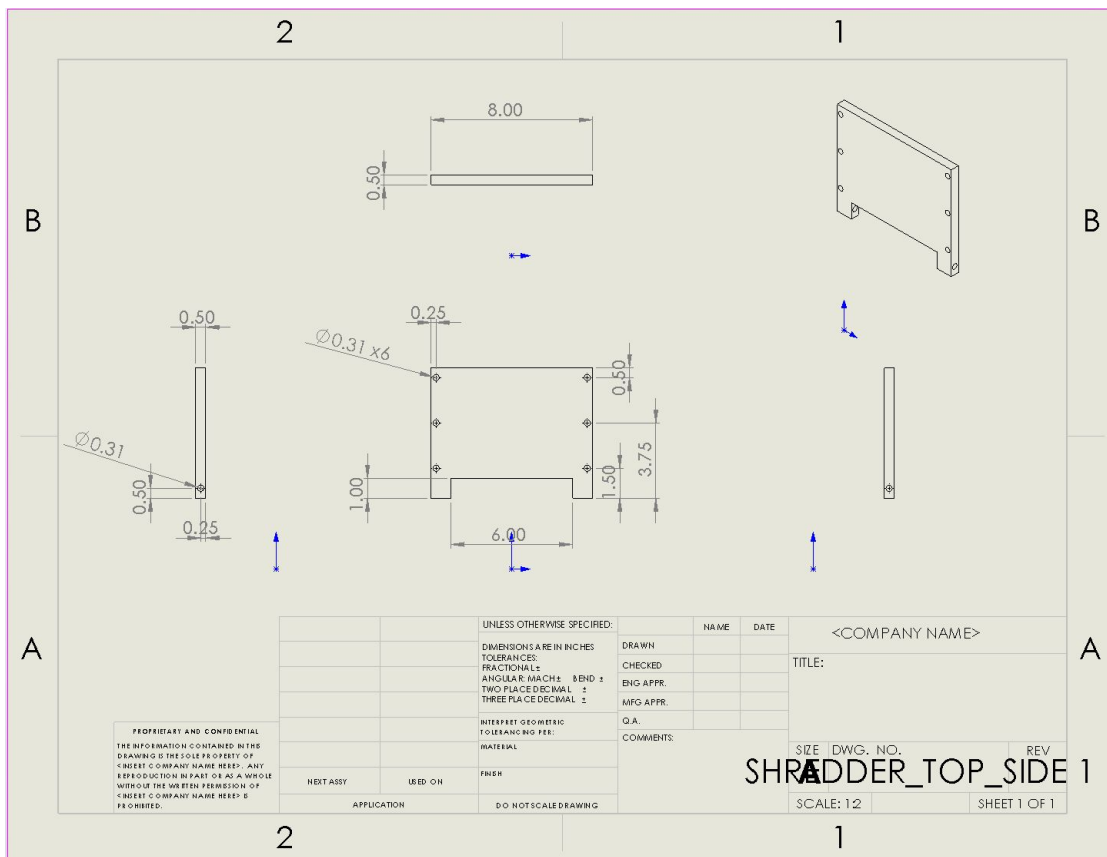
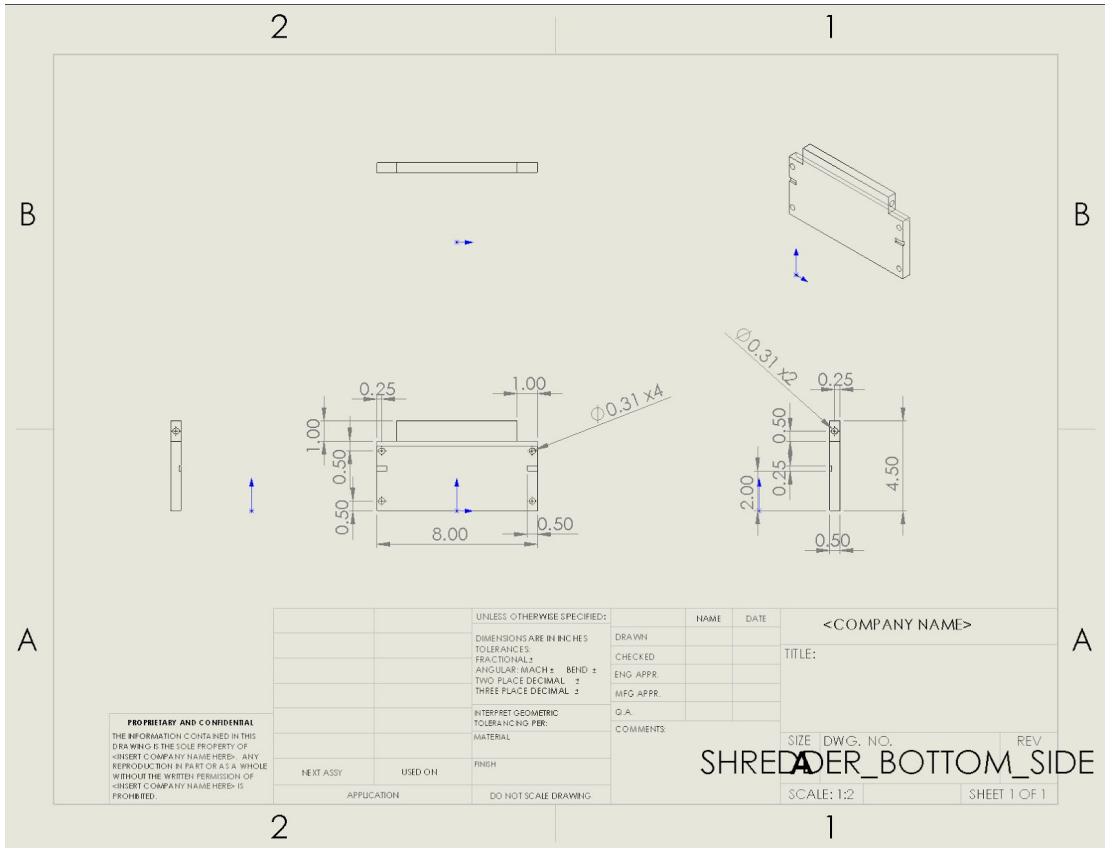


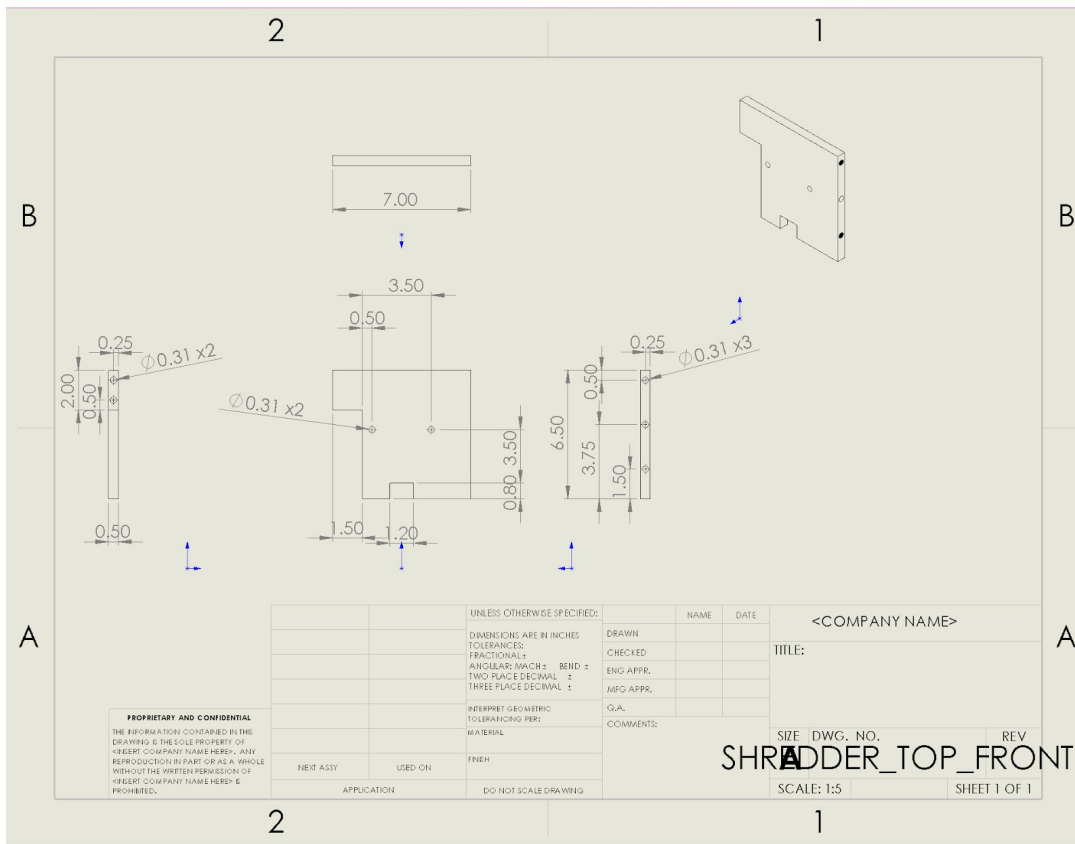
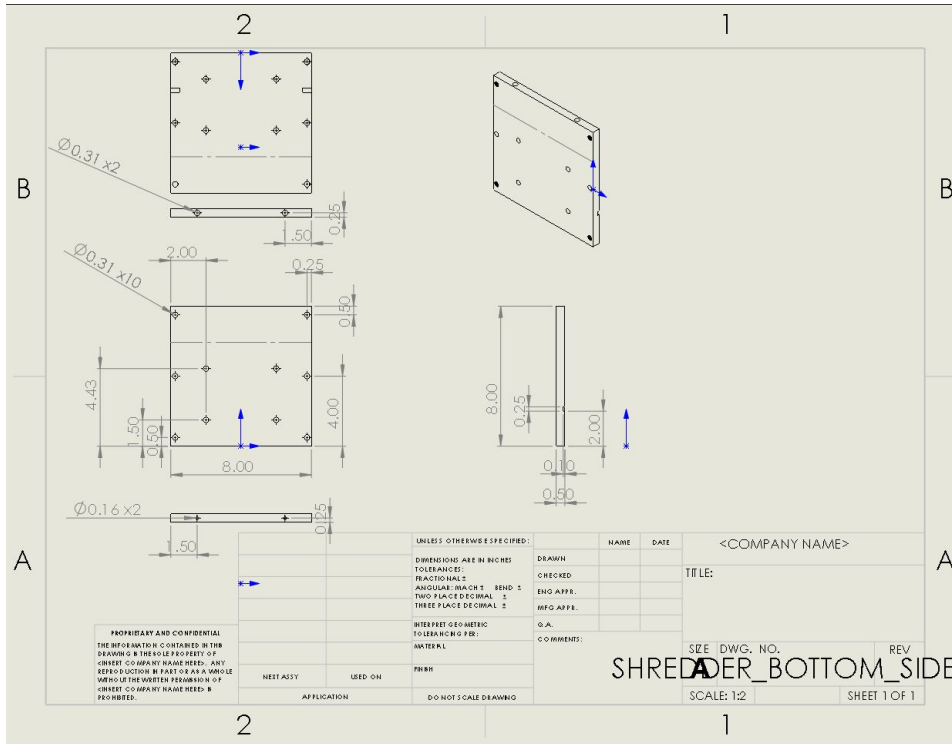


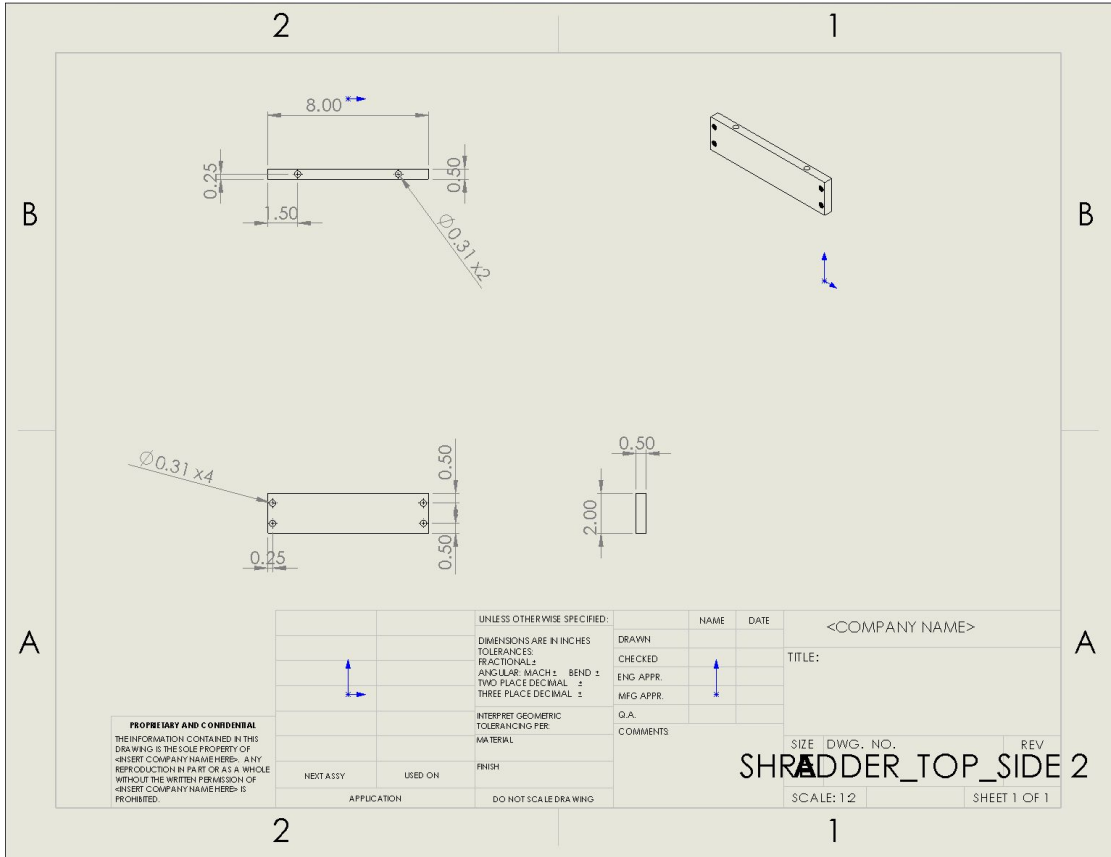
Backside Comb 1 Piece Nov







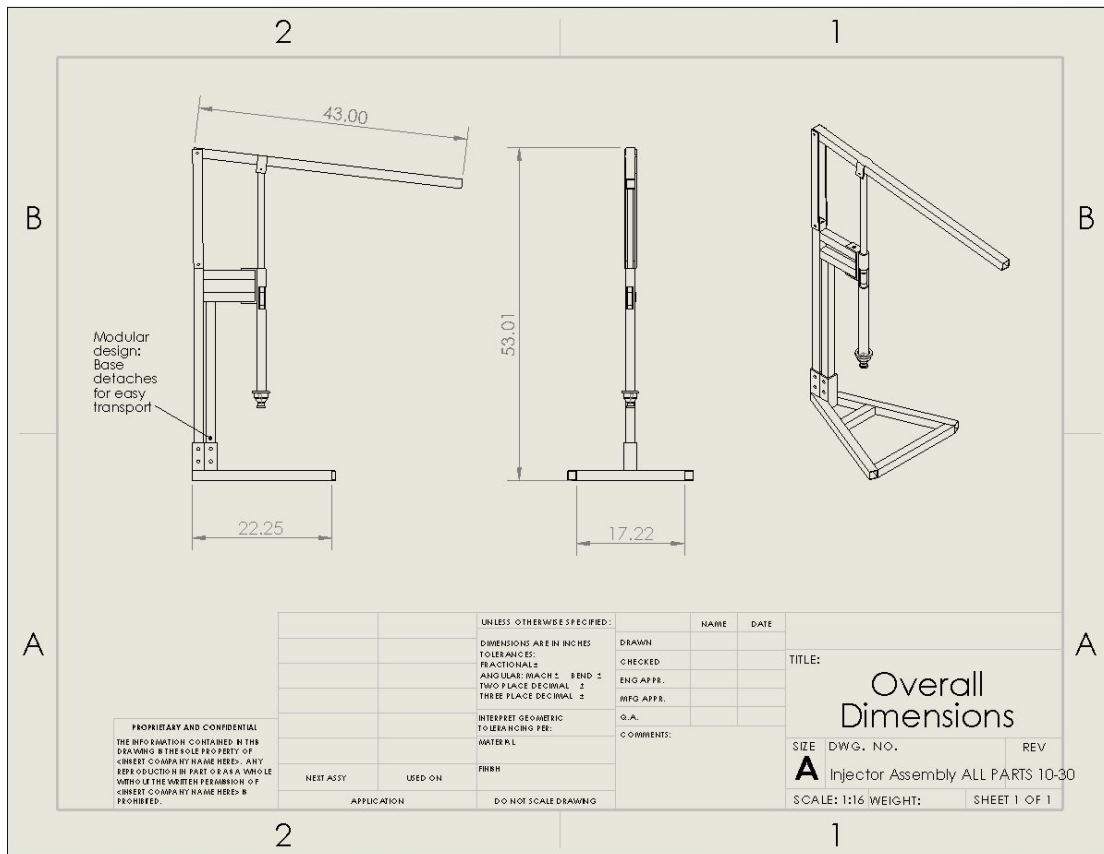
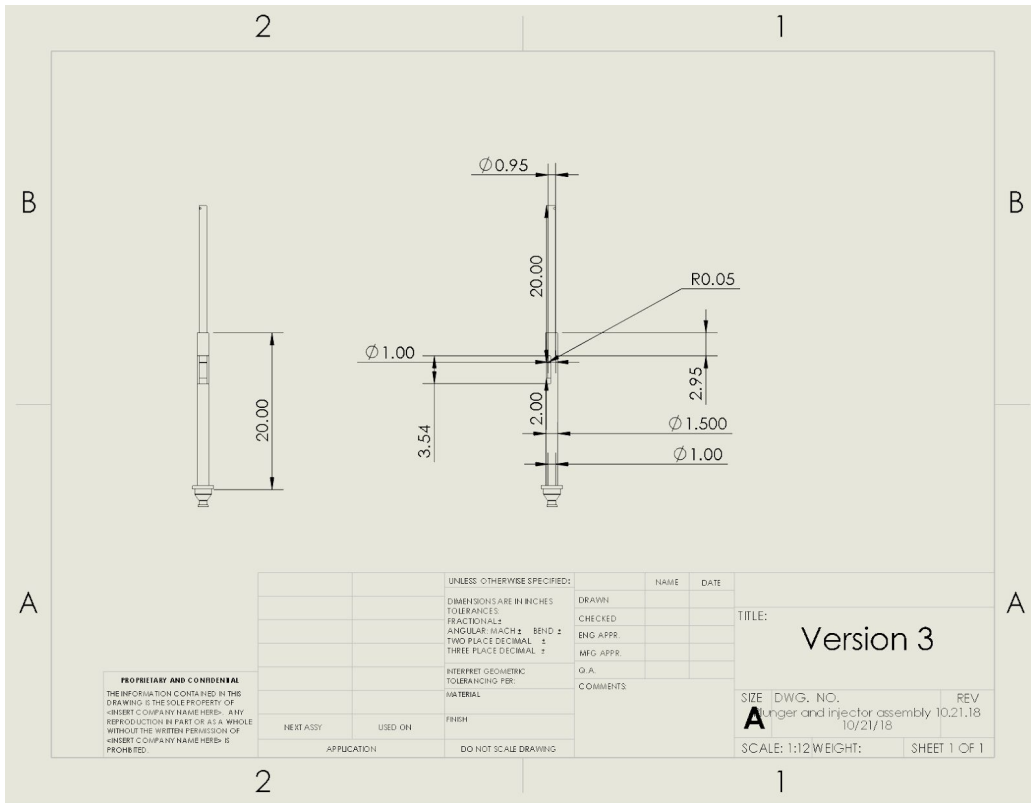


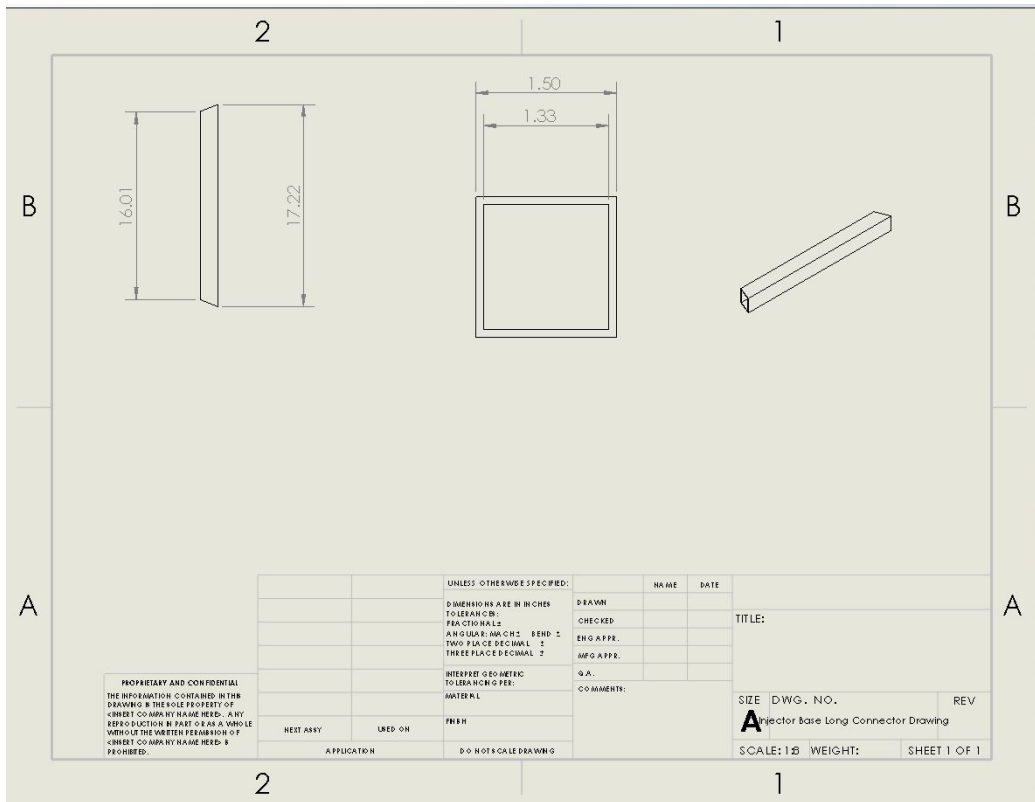
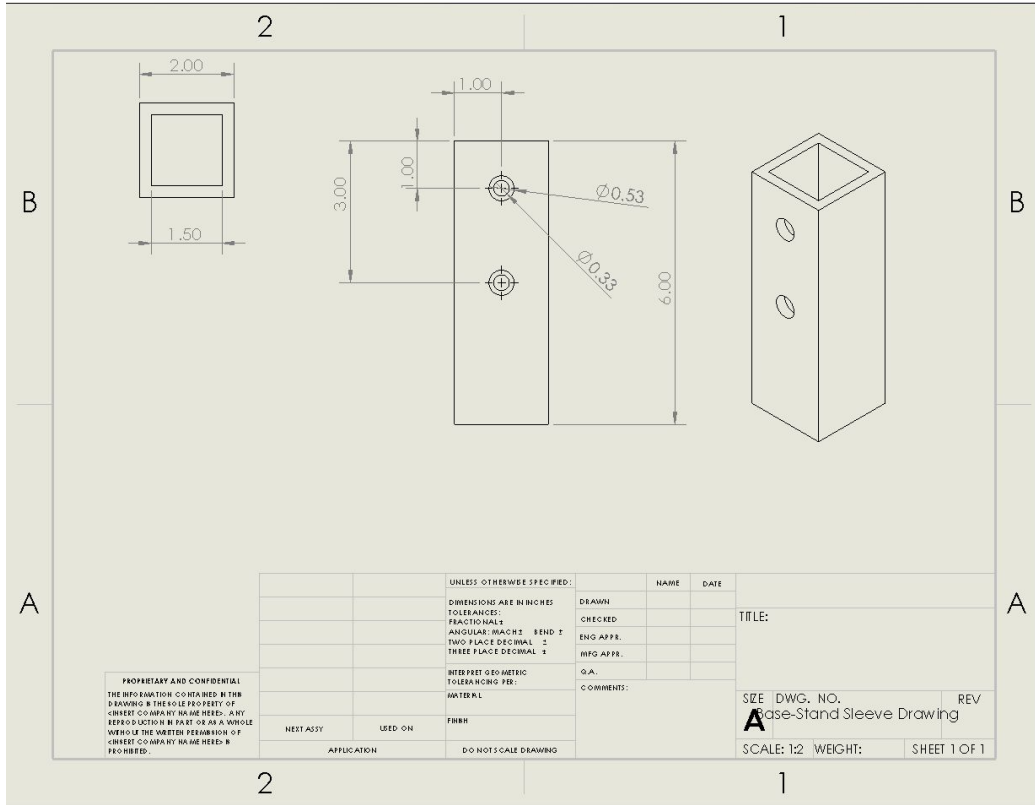


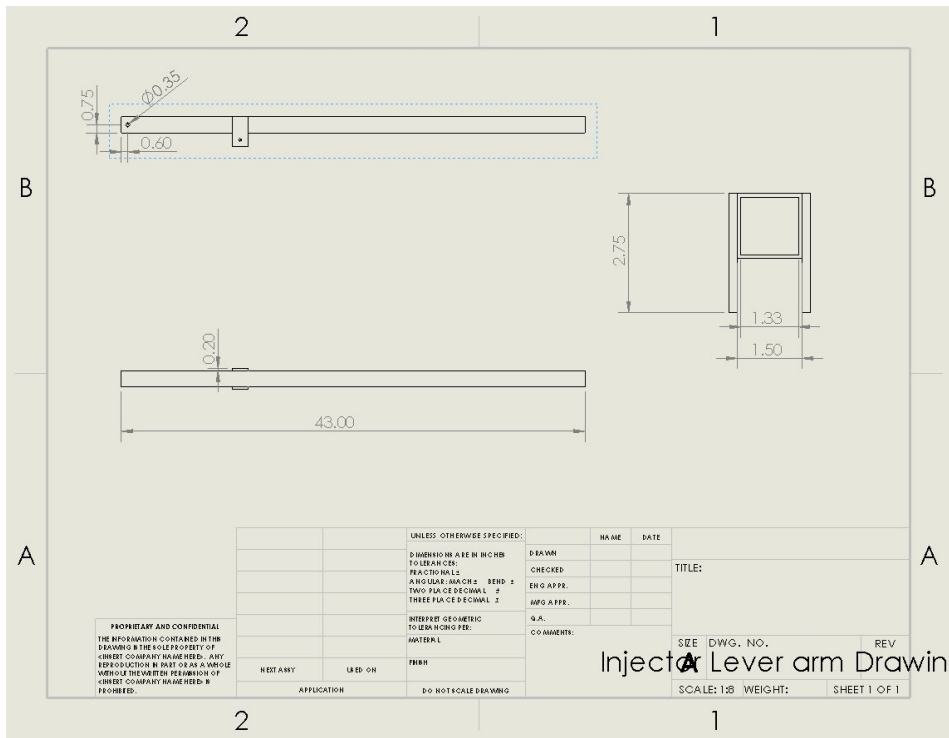
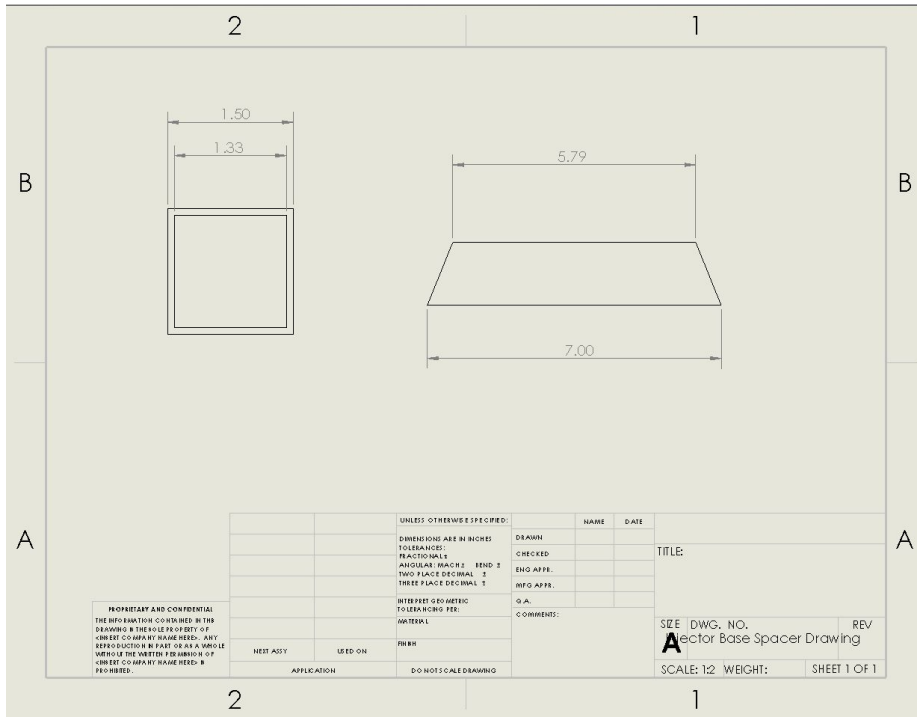
PROPRIETARY AND CONFIDENTIAL
 THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	<COMPANY NAME>	
		DIMENSIONS ARE IN INCHES		DRAWN		TITLE:	
		TOLERANCES		CHECKED			
		FRACTIONAL ±		ENG APPR.			
		ANGULAR: MACH ±		MFG APPR.			
		BEND ±					
		TWO PLACE DECIMAL ±					
		THREE PLACE DECIMAL ±					
		INTERPRET GEOMETRIC TOLERANCING PER:		Q.A.			
		MATERIAL		COMMENTS			
		FINISH					
NEXT ASSY		USED ON				SIZE DWG. NO. REV	
APPLICATION		DO NOT SCALE DRAWING				SHRADER_TOP_SIDE 2	
						SCALE: 1:2 SHEET 1 OF 1	

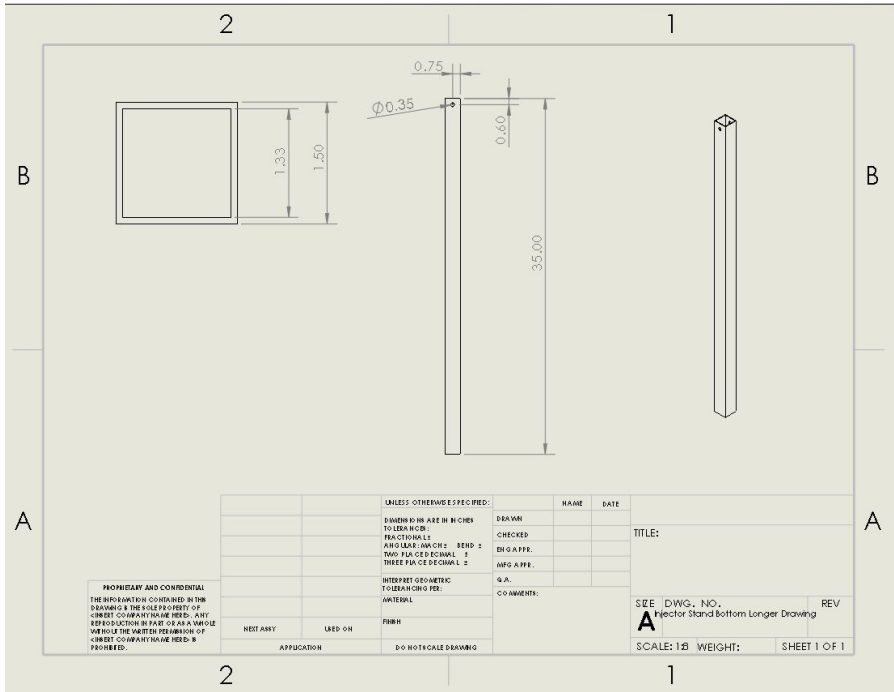
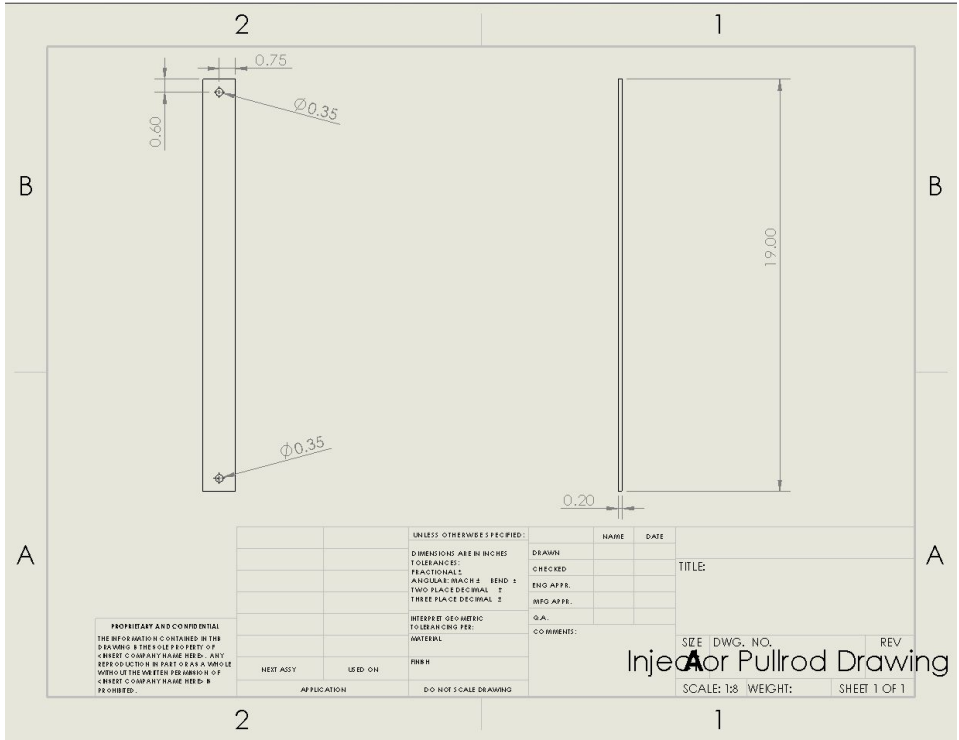
APPENDIX D: PART DRAWINGS FOR INJECTOR ASSEMBLY

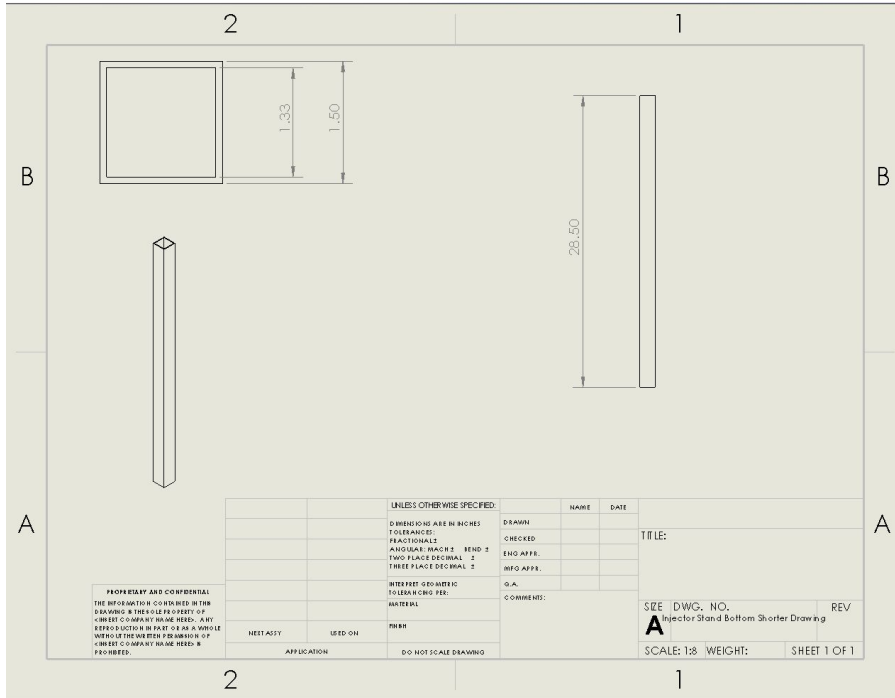






Injector Lever arm Drawing

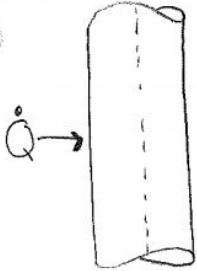




APPENDIX E: HEAT TRANSFER ANALYSIS

Heat Transfer:

$$T_i = 400^\circ\text{F} = 205^\circ\text{C}$$



* this analysis largely ignores convection and radiation.

Assume:

Pipe is filled up to 12" with room temperature plastic.



$$\text{Volume of plastic} = \frac{\pi}{4} (d^2) (h) = \frac{\pi}{4} (1.05^2) (12") = 10.4 \text{ in}^3 \approx 0.00017 \text{ m}^3$$

$$\text{mass assuming plastic is HDPE} : (0.00017 \text{ m}^3) (609 \frac{\text{kg}}{\text{m}^3}) = 0.1035 \text{ kg}$$

$$\begin{aligned} \text{Heat for plastic} : Q = mc\Delta T &= (0.1035 \text{ kg}) (1900 \frac{\text{J}}{\text{kg}}) (205 - 25) \\ &= 35,407 \text{ J} \end{aligned}$$

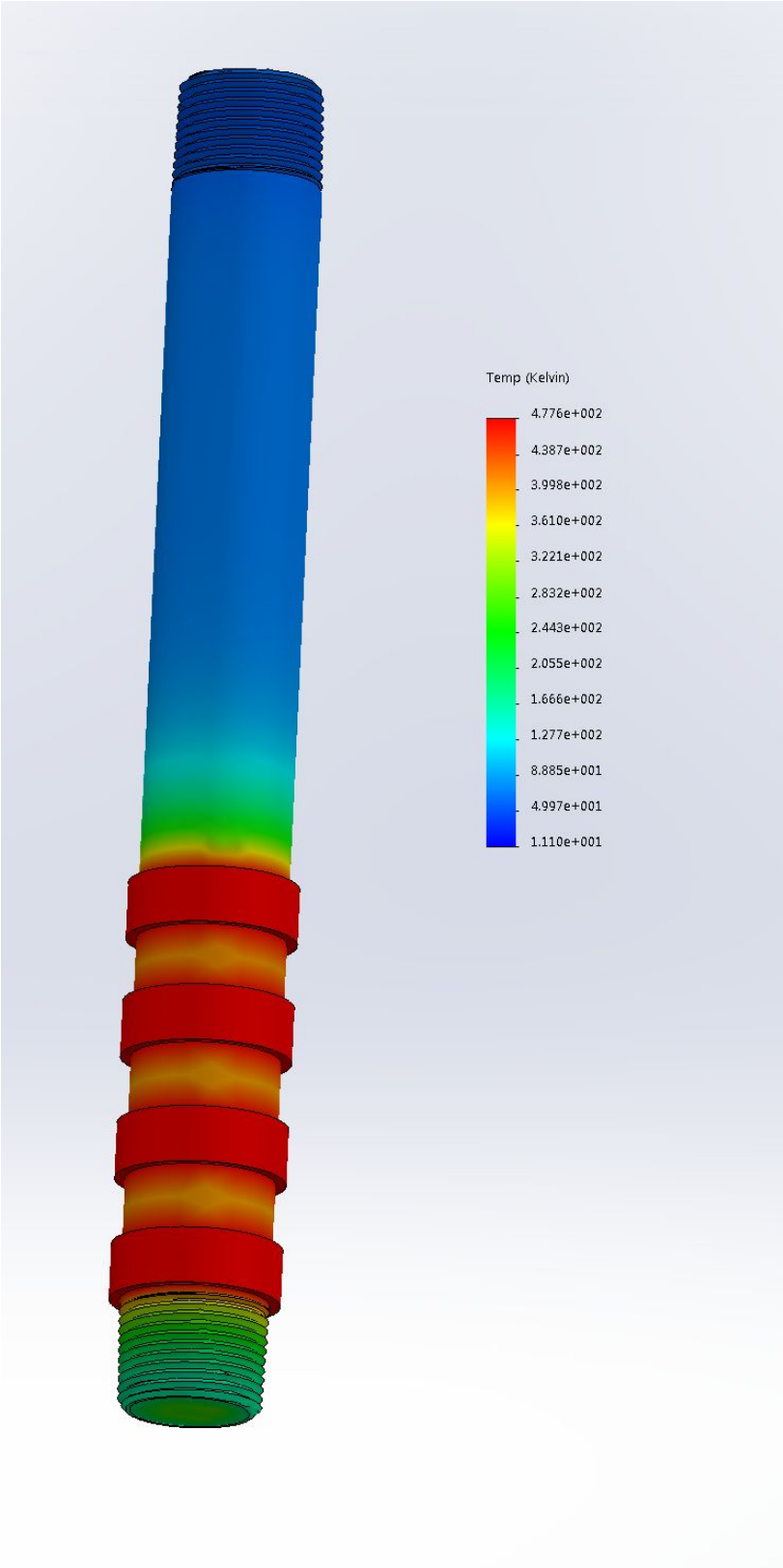
Assuming 144W heater:

$$\text{Time to Heat} = \frac{35,407 \text{ J}}{144 \text{ W}} = 245 \text{ sec}$$

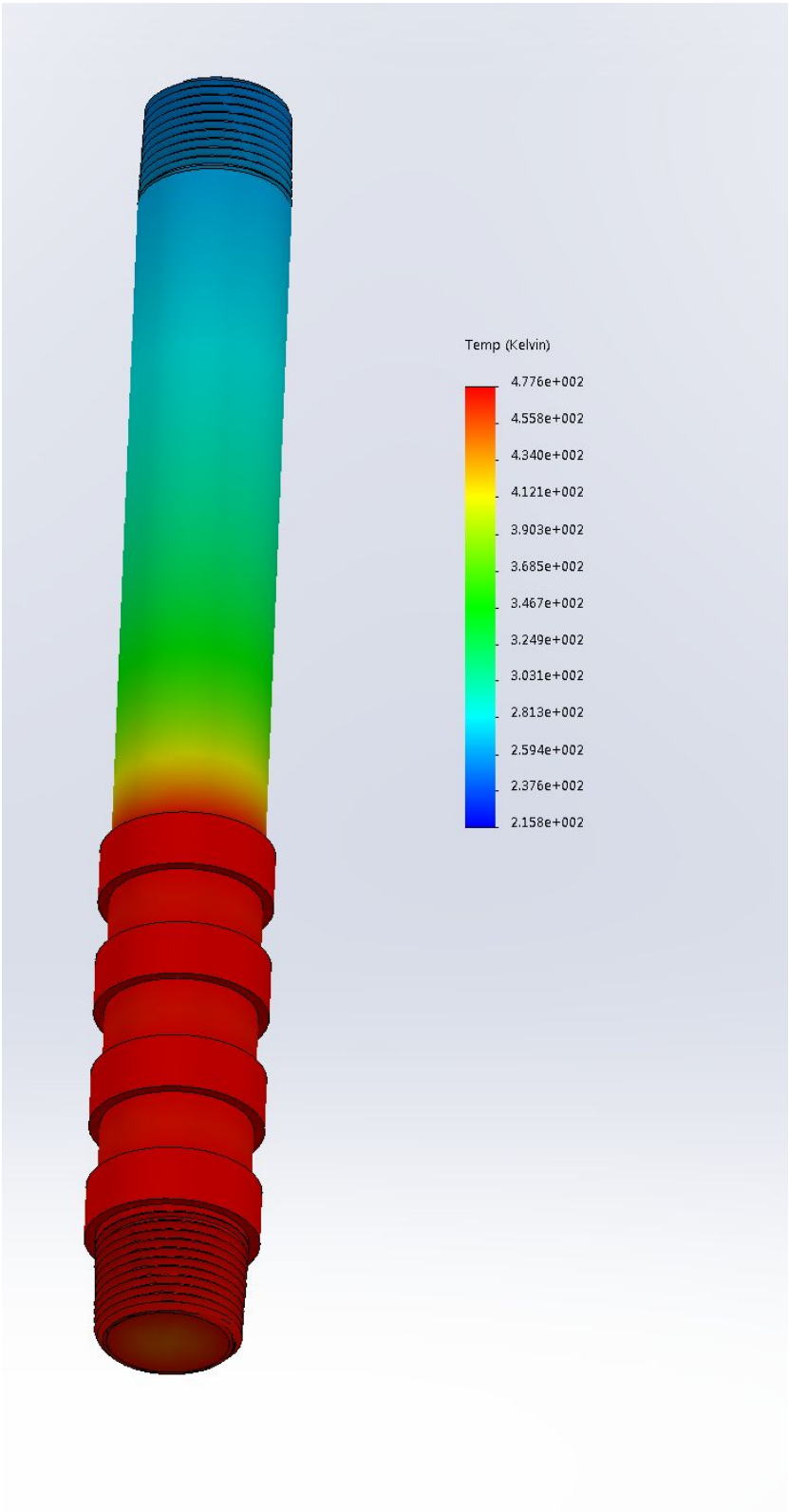
Assuming half of heater power is lost to steel/Environment:

$$\text{Time to Heat} = \frac{35,407 \text{ J}}{144 (.5)} = 491 \text{ sec}$$

Transient FEA:
FEA at start:



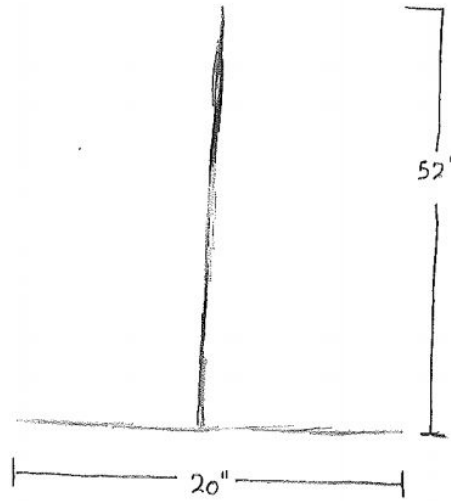
FEA at 600s (10 minutes):



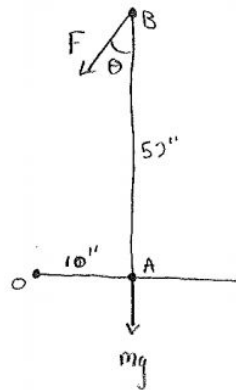
APPENDIX F: MOMENT ANALYSIS

Moment Analysis:

Front View:



FBD



$$\sum M_o = 0$$

$$= F \sin(\theta)(52'') - (W + F \cos(\theta))(10'')$$

For $F = 150 \text{ lb}$

$$\theta \approx 13^\circ$$

For $F = 100 \text{ lb}$

$$\theta \approx 14^\circ$$

Tubing:

$$V = 1.5^2 - 1.334^2$$

$$= 0.47 \text{ in}^2$$

$$f = 0.28 \frac{\text{lb}}{\text{in}^2}$$

$$L \approx 20 \text{ ft} \cdot \frac{12 \text{ in}}{\text{ft}} = 240 \text{ in}$$

$$W \approx (0.47 \text{ in}^2) (0.28 \frac{\text{lb}}{\text{in}^2}) (240 \text{ in})$$

$$\approx 32 \text{ lb}$$

APPENDIX G: SHREDDER ANALYSIS

