# END OF TERM REPORT

## ESI / BIO-CUBE


### Abstract

End of term report summarizing Bio-Cube's design cycle and current standing leading in to Phase Two of project lifecycle.


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|---|---|---|---|
| A | BIO-CUBE | 12/13/18 | 12/14/18 |


TEAM 47

# 1 Executive Summary

This document outlines the theoretical and engineering framework for Bio-Cube's proposed design. The contents include technical background and documentation pertaining but not limited to the project management framework and critical decision criteria used to guide the current design, as well as financial documentation. It is Bio-Cube's intent to design an optimized and cost-effective solution to combat plastic pollution in areas that have strong growth potential with the process of repurposed recycling processes. The process of repurposing plastic, known as upcycling, is a process that has gained momentum and popularity in consumer markets. Upcycling is the process of taking used plastic and re-inserting it into a product life-cycle by reshaping it into usable items. The team has identified this solution to have a tangible impact on plastic pollution by directly inserting another step into the plastic life-cycle before it has a chance to fall into delicate ecosystems.

Based on the teams' technical analysis and investigation towards optimized systems pertaining to plastic molding, the following design will highlight the benefit of a non-automated and naturally heated system. The report will outline the iterations that have led to the current solution, how each iteration was analyzed for its positive aspects and where there were identified opportunities for improvement.

Bio-Cube's End of Term Report outlines the engineering theory required to support the claims made towards the systems efficiency and feasibility. The overall system is broken down into four subsystems: input, pressure arm, heating funnel, and mold. The interactions between each sub-assembly have been thoroughly investigated to ensure the continued functionality and lifespan of the product for continuous usage. The assumptions used along with the fundamental supporting calculations can be found within the respective subsystem section of the report.

Further elaboration of the Phase Two timeline is discussed in later sections of the report. Bio-Cube's project structure was organized by critical path assessments to outline what project activities would cause critical delay to the end of term deliverables. Bio-Cube will provide a fully functional prototype as a project closure deliverable by the end of Phase Two as outlined in the Project Gantt chart.

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# 5 Units

*Table 1. Units*

| Variable Measured | Unit |
|---|---|
| Temperature | °F |
| Pressure | Psi |
| Vacuum | mmHg |
| Weight | Lb. |
| Volume | US gal |
| Density | lb./ft$^3$ |
| Mass Flow | lb./hr |
| Gas Volume Flow (Actual) | ACFM |
| Vapor Volume Flow (Standard 60°F & 1 atm) | SCFM |
| Liquid Volume Flow (Standard 60°F) | gpm |
| Enthalpy | Btu/lb |
| Heat Duty | Btu/hr |
| Power | Kw |
| Viscosity | Cp |
| Velocity | ft/s |
| Chemical Volume | Gal |
| Noise Level | Db |
| Equipment Size | In |

# 6 Codes and standards

The following regulations have been taken into consideration during Phase One of the Bio-Cube project. The team recognizes the importance of abiding by federal and international standards to ensure that the system is safe towards the user and the environment.

*Table 2 Codes and Regulations Pertaining to Design*

| Code/Standard | Title | Description |
|---|---|---|
| **Air Quality** | | |
| **2.1** Clean Air Act – Section 129 | Waste Incineration Rule | Requires the Environmental Protection Agency (EPA) to set emissions limits for 9 pollutants for certain non-hazardous solid waste incinerators. |
| **Plastic Burning Laws** | | |
| **2.2** TSCA | Toxic Substances Control Act | Any person who manufactures (including imports), processes, or distributes in commerce a chemical substance (including, generally, dioxin) or mixture and who obtains information which reasonably supports the conclusion that such substance or mixture presents a substantial risk of injury to health or the environment to immediately inform EPA, except where EPA has been adequately informed of such information |
| **2.3** 40 CFR 49.131 | General Rule for open burning | A person must not openly burn, or allow the open burning of, the following material: … (v) plastics, plastic products, or Styrofoam |
| **2.4** 42 U.S.C. *§7429* | Solid Waste Combustion | The Administrator shall establish performance standards and other requirements pursuant to section 7411 of this title and this section for each category of solid waste incineration units. |
| **2.5** 40 CFR 60 | Title V Operating Permit | Under the new regulations set forth in CAA Section 129 (40CFR60), all incinerator locations are required to obtain a Title-V Operating Permit (TVOP) |
| | Air Pollution Control Division: Open Burning | The state of Colorado regulates open burning to help protect public health and the environment in Colorado |
| **2.6** ASME PT 34 | Waste Combustors with Energy Recovery | The objective of this Code is to provide a test procedure for evaluating the performance of waste fuel combustors with energy recovery using the boiler as a calorimeter |
| **2.7** ASME PTC 19.10 | Flue and Exhaust Gas Analyses | This Document specifies methods, apparatus, and calculations which are used in conjunction with Performance Test Codes to determine quantitatively, the gaseous constituents of exhausts resulting from stationary combustion sources |

# 7 Introduction

## 7.1 Introduction and Background

On average, one million plastic bottles are bought by consumers around the world per minute. A staggering ~ 80% of these bottles are not recycled. The growing plastic landscapes are suffocating environmental and societal ecosystems at unprecedented rates with no foreseeable end. Government and non-profit efforts are leading a shift in cultural approach to the global health crisis with a call to action for businesses and citizens alike to be mindful and conservative in using single-use plastics.

As a response, numerous industries have integrated the upcycling of plastic borne materials into various apparel, footwear, and load supporting objects. The direct correlation between increasing brand value and repurposing of plastics has created a positive narrative trend that not only raises awareness over social media mediums but is also working to permanently shift the narrative around plastic usage. This has opened the doors for more funding to be distributed from small ventures to larger ones that hope to attack the plastic epidemic from all angles. Alhassan Baba Muniru is a graduate student from Ghana who is currently studying in Berlin, Germany and working with various government and non-profit entities to start a recycling hub for his local community back home. Alhassan has experienced the crippling impacts of plastic pollution first-hand in his local community in Ghana, and has been researching the effects and limitations of plastic upcycling through his work in construction with reused plastic based schools and eco-homes. Other motivated entrepreneurs around the world are working to start their own ventures to have similar impacts in their own communities. However, a common limiting factor in many stories is the lack of awareness and an initial funding hurdle that must be overcome.

Developing nations, whom readily engage in the usage of single-use plastics, have seen the most notable impacts from the accumulated masses of free-floating plastics. The south-east Asian region is the most significantly impacted, as 17.34 metric tons of annually generated plastic waste [3] are occupying coastlines and domestic regions of the territory. Federal organizations are actively seeking solutions to mitigate the situation while motivated youths continue to create start up solutions to modify the upcycling industrial processes to fit the direct needs of their communities.

## 7.2 Project Mission

Bio-Cube's solution is to develop a small scale, structural block manufacturing device. This device will boast a low energy requirement and naturally heated system to increase the potential reach and impact to fit nearly any community's needs. Bio-Cube's solution uses proven technology to compress shredded plastic into a set mold. The system output allows for a customizable application up to the discretion of the user by creating small cubes that can be joined together using simple mechanical junctions. This flexibility in application allows for a Lego like design, resulting in a myriad of different final products that can be created by the user. Bio-Cube hopes to maintain this flexible application as it gives power and value towards the user's design intent.

# 8 Target Population

The intended user population of the device are developing in coastal regions of SE Asia. There are over 17.34 metric tons of plastic waste in the top 5 countries for waste including China, Indonesia, Philippines, Vietnam and Sri Lanka, all located in the target region. This device introduces the prospect of upcycling to local ventures, while incentivizing the local people to not only change the eco-system, but also to create a useful product that could bring in an income through scaled business ventures. These communities have a large resource of single-use plastic and are searching for affordable and low energy requirement solutions.

## 8.1 Project Requirements

The project requirements are centralized around the engineering theory concepts of heat and force. This device has purely mechanical inputs, therefore it requires a user who is able to exert the necessary force to push the plastic through the central system. Since no electronics will be used, all heating must be done by natural heating methods, in this case coals or equivalent thermally conductive stones. The following table describes the top five priorities that have been set for the project.

*Table 3. Project requirements*

| **Criteria** | **Requirements** |
| --- | --- |
| Cost | Total cost of materials will be below $599.00 (excluding labor). |
| Safety | Product will be stable with no risk of tipping, and all heat will be contained to reduce human interaction/harm caused by heating stones. |
| Energy Efficient | Less than 10% parasitic loss. |
| Project Simplicity/Usability | The system will be purely mechanical with natural heating. |
| Maintenance/Repeatability | System will allow for max repeatability with limited output variation.<br>[Maintenance of plastic heating tube will be determined during the testing phase] |

# 9 Design Iterations

## 9.1 Preliminary Design One

Bio-Cube began the design process with the motivation of reusing plastic waste in an economically friendly and desirable way. The first design was a pyrolysis process, where the plastic would be processed through a Rankine cycle and essentially turn into biodiesel fuel at the end. As this design continued to develop, it became apparent it was too large of an idea given the scope of this class. To accomplish this design, the team had to make a decision between designing a fully specified theoretical plan for an industrial scale plant, or focusing on one part of the process to design and manufacture. After discussion, the team decided to pivot from this idea as it wasn't well suited for this class and did not allow for the team to design a full product.

## 9.2 Preliminary Design Two

After the pyrolysis design was deemed out of scope, Bio-Cube maintained focus on reusing plastic in an effective way. One of the initial thoughts behind the plastic upcycling was educational or structural use within developing countries. This led to a new design focused on creating brick shapes made out of plastic pieces. To accomplish this, the team designed a plastic injector molding device which used controls to analyze temperature, linear actuators to moderate the movement of the plastic and electricity and heating coils as the heat source.

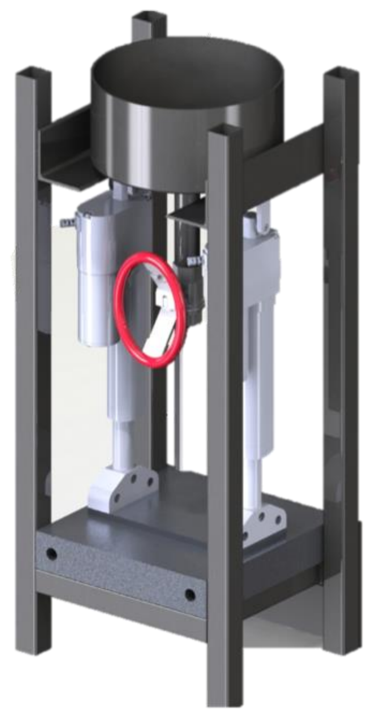


*Figure 1. Full assembly rendering of the preliminary design*

As shown in Figure 1, this design used a hot water bath to heat up the plastic, allowing it to become molten before dropping down through the heating tube into the mold. The linear actuators would then move the compression plate into place on top of the mold, creating a brick.

This design was presented at the teams Preliminary Design Review, and was largely disliked because of safety issues and complication of the whole process.

## 9.3 Final Design

After revisiting the issues with the previous design, the Bio-Cube team decided to finalize a target user group, and base the design around the needs and capabilities of this group of people. During the research process, it was discovered that SE Asia has the largest amount of plastic pollution on their coasts, with limited resources or incentives to behaviors. This kick started the final design with the mission of creating a plastic molding device that uses no electricity and can be implemented anywhere in the world for a realistic price. To accomplish this, natural heating sources were designed around (any type of biomass), and the design was created to replicate an injector molding device before modern updates. This means the plastic is pushed into a heated tube, and once it reaches an adequate temperature, a compression rod with and end cap will be pushed down through the tube, forcing the plastic down into the mold. The mold is connected by a threaded stud, and can be easily removed for retrieval. The heating chamber will be a two part system, with a removable bottom. This allows for easy maintenance of burnt material and a way to continuously add fuel to run the system.

*Figure 3. Full assembly render of the final design.*

*Figure 2. Full assembly section view.*

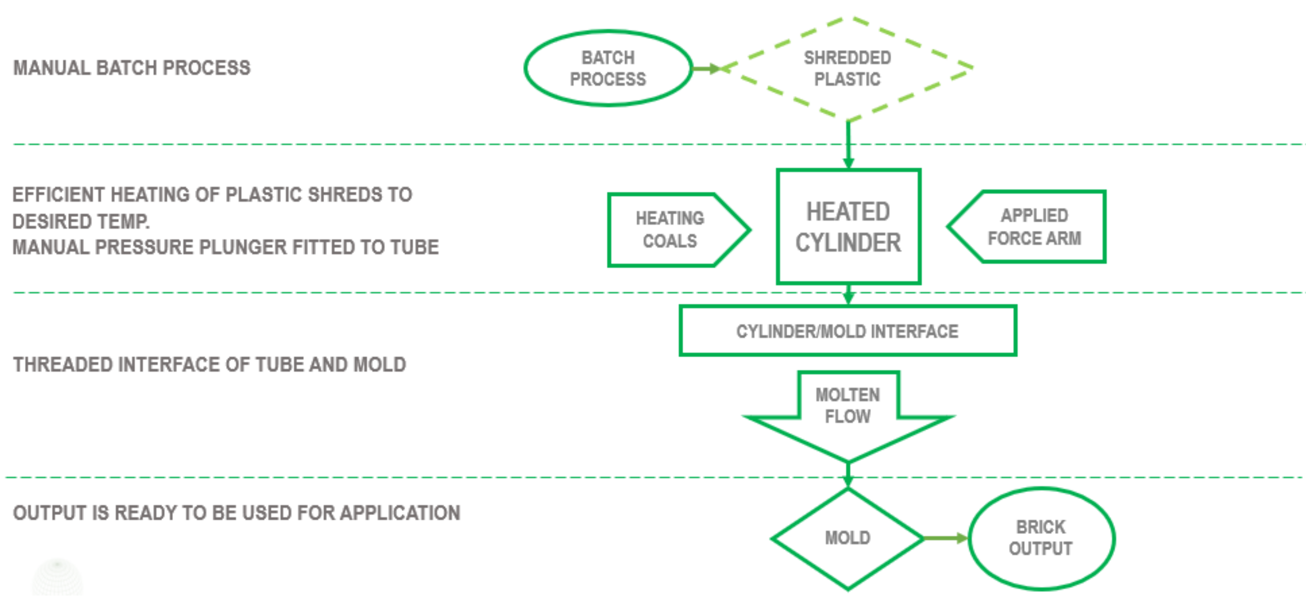
## 9.4 Decision Matrix for Final Design

| | | Compression-based injection molding | | | | Automatic Injection Molding | | |
|---|---|---|---|---|---|---|---|---|
| Criteria | Weight | Low Score | High Score | Weight * LS | Weight * HS | Low Score | High Score | Weight * LS |
| **1. Cost** | 4 | 8 | 10 | 32 | 40 | 3 | 7 | 12 |
| **2. Energy Efficienty/CO2 Production** | 3 | 6 | 9 | 18 | 27 | 5 | 7 | 15 |
| **3. Process Simplicity** | 3 | 8 | 9 | 24 | 27 | 3 | 5 | 9 |
| **4. Safety** | 4 | 5 | 9 | 20 | 36 | 4 | 6 | 16 |
| **5. Repeatability/Maintenance** | 2 | 4 | 9 | 8 | 18 | 5 | 7 | 10 |
| Durability | | | | | | | | |
| Manufacturability | | | | | | | | |
| Plastic Quality | | | | | | | | |
| Reliability | | | | | | | | |
| Waste Output | | | | | | | | |
| **Total** | | | | **102** | **148** | | | **62** |
| **Median & Range** | | | | **125** | | | | **82** |

Notes:
Weight is 1-4 Scale with 4 high
LS is Low Score with 1-10 scale and 10 high
HS is High Score with 1-10 scale and 10 high

*Figure 4. Design matrix for the compression based design.*

## 9.5 System Flow Overview



# 10 Understanding the Design Assembly

## 10.1 Subassembly One

### 10.1.1 Description

The first subassembly is a stand and four-bar linkage that mounts the heat chamber and compression rod to inject the plastic materials into the mold. The main components of the stand assembly are the frame, linkages, lever arm, compression rod, plunger head, and hardware used to pin the system together. The stand assembly with the lever arm fully extended, will reach six feet high, but will only measure three feet when fully compressed. It has a footprint of two square feet ensuring the design is usable if space is limited. The lever arm will be used to drive the compression rod through the heating element into the mold. By incorporating a four-bar linkage design, the lever arm can sway and thus maintain the necessary linearity. The four-bar linkage system has three degrees of freedom which also helps the compression rod to maintain this linearity. The stand provides the framework for this operation to occur on a repeatable basis.

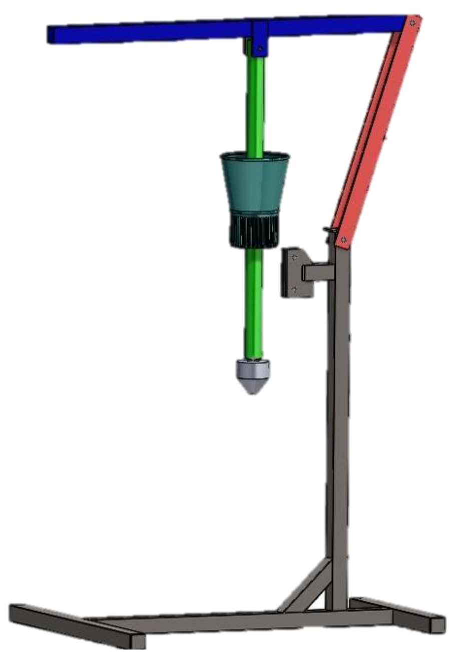
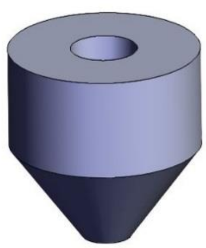


*Figure 5. Full stand render*

*Table 4. Subassembly one components.*

| Part Render | Material | Stock Size | Fabrication Time |
|---|---|---|---|
|  | ASTM A36 Steel | ⅛”x1”x6’ | 1 hour |
|  | ASTM A36 Steel | 1”x1”x0.083”x24L” | 2 hours |
|  | ASTM A36 Steel | 3’x1” OD | 2 hours |
|  | ASTM 6061 Aluminum | 2” DIAM. X 3” LENGTH | 4 hours |

### 10.1.2 Design Considerations

When designing the stand, the primary concern was creating an element that would not only be able to bear the system weight and input loads but that would also be able to effectively organize and integrate the other assemblies. The upright tube will have a modified endcap that will also act as a linkage stop to prevent the lever arm and compression rod from dropping suddenly. The design of the stand, although simple, is essential to the functionality of the entire system.

The linkages are incorporated into the stand assembly as the first link in the four-bar linkage design. With two pinholes at the ends, they provide the first two degrees of freedom required to have linear compression in the heat chamber. The two linkages are attached at the highest point on the stand and to the back end of the lever arm via partially threaded ¼”-20 bolts.

The lever arm is also a simple component. The lever arm acts as the third bar in the four-bar linkage system bringing in the third degree of freedom. The arm is designed to provide an interface for the compression rod while minimizing the force required to drive the compression. An analysis on torque was performed on the model to assess the necessary design requirements to achieve the expected force output, in terms of dimensioning and material selection. Bio-Cube also had to ensure that the design of the lever arm would not the injection machine to tip over.

The final link in the stand assembly is the compression rod which is secured at a single point to the lever arm. At its base is the plunger head. The plunger head is threaded to the compression rod to ensure that it is well connected. To minimize wear on the inside of the head chamber, the compression rod was designed with a 1" diameter. This 1" diameter provides ½" of clearance all around when driven through the heat chamber. Designing the compression rod, helps prevent jamming due to lack of cylindricity and runout in the tube, or due to galling and cold welding that could occur from the abrasion of two similar materials. A 2" diameter aluminum plunger head will be secured to the base of the compression rod, which will have a slip fit within the heat tube containing the plastic. By minimizing the length of material that will be in contact with the walls of the heat chamber, the potential for jamming or galling is minimized. The large diameter of the plunger head and tight tolerance within the tube will prevent large quantities of plastic from being lost.

### 10.1.3 Motivation

The motivation behind the stand subassembly is to design an affordable, easy to manufacture, and well-engineered system that can keep up with the demands of Bio-Cube's customers. With the repeated use of the injection mold, the team plans to manufacture this system out of the best materials and with simplicity that allows users with little technical knowledge to operate the machine.

### 10.1.4 Material Selection

Linkages: The linkages will be made out of ⅛" x 1" x 15" ASTM A36 Steel due to their low cost and high strength. Very few steps will go into manufacturing this material to the designed specifications.

Lever Arm/Stand: When selecting the material for the stand and lever arm, finances, ease of manufacturing, and factor of safety were taken into consideration. The stand required a design that kept it relatively low weight, offered simplicity & repeatability in manufacturing, and was strong enough to withstand the loads that the system would experience. The best material for this was found to be 1" x 1" x 0.083" low carbon, square steel tubing. This material is low cost, lightweight for steel, and offers increased ease in welding. Endcaps and gussets welded to the frame will be manufactured out of ASTM A36 Steel plates as well.

Since the stand weldment's frame is going to be built out of the above square steel tube, for ease of manufacture, the same steel tube will be used to manufacture the lever arm. This also helps Bio-Cube meet financial requirements by minimizing the cost spent on unique materials. 1" x 1" x 0.083". Steel Tube will be purchased in bulk and will be used extensively throughout the design. Finally, the square tube ensures a safety factor of 2, which minimizes the chances of a user damaging the machine or causing injury.

Compression Rod: The material chosen for the compression rod is ASTM A36 Steel as this helps meet financial requirements, provides good machinability, and increases the potential for surface hardening after modification. As previously mentioned, the compression rod will have an aluminum attachment that will be the main surface in contact with the plastic when injecting the batch. The attachment is to be manufactured from 6061 Aluminum due to its incredible machinability and as a prevention against cold welding. This removable part can be easily replaced should any damage occur.

### 10.1.5 Manufacturing Plan

The stand weldment will be the first part assembled. The stand tubes will be cut to length using a saw and cleaned with a deburring tool. The flanges and end-caps will be manufactured using a mill and drill press. (All ¼" holes in the stand assembly will be drilled using an F size bit). Once all the parts are prepped, the stand will be outsourced to a local welding shop for quick assembly. Upon completion of the stand, the lever arm will be manufactured using the same process. The linkages will be manufactured using a mill and drill press to true the ends, round corners, and bore pin holes through the bars. The compression rod will require effective securement during the milling process of the ¼" pin hole through the diameter of the rod. The other end will then be tapped for the insert joining the plunger head. Finally, the plunger head will be secured in a mill, to cut the angular profile into the round disc.

### 10.1.6 Theoretical Validation Calculations

The force analysis performed on the lever arm shows the durability of the lever itself under heavy loads. When in the molten state, the system requires very little force to drive the plastic into the mold. The only circumstance that may cause the machine to require more force is if the heat tube is jammed or if the plastic is not entirely molten. The full failure analysis looked at the max application of a 100 lbs. force at the end of the lever arm. At this applied force, the bending stress at the connection point between piston and arm (point C in **Error! Reference source not found.**) is 15,692 psi, which gives a safety factor of 2. The team is satisfied with this result because a max force of 100 lbs. is higher than the requirement needed to operate this device correctly. The consequence of misuse, such as a person hanging their body weight off of the arm, would be tipping or bending stress on the pinned joints. The FEA analysis on the lever arm and stand weldment are shown within the Appendix.

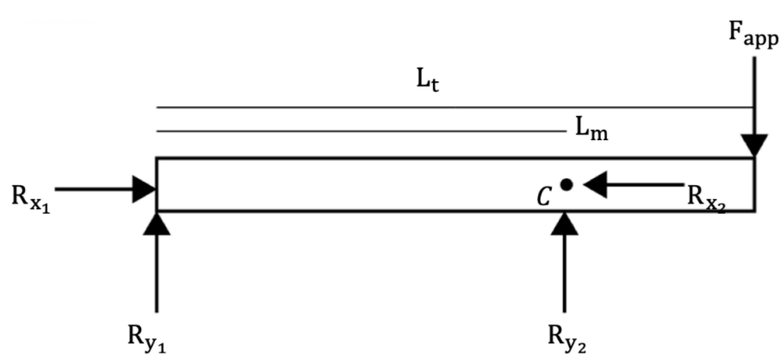



*Figure 6. Free-body diagram of the lever arm.*

### 10.1.7 Relevant Connections to Other Subassemblies

The stand subassembly has two flanges welded to its small arm that will be used to mount the heat chamber. This junction only requires two ¼"-20 partially threaded bolts to secure through the flanges which allows for easy disassembly of the sub-systems. The designed junction provides the support required to withstand the input loads and the weight of the heat chamber assembly.

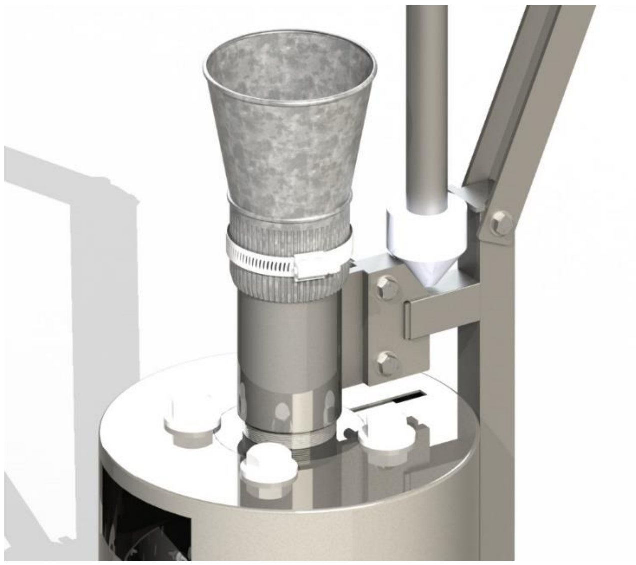


*Figure 7. Heating chamber connection to stand weldment.*

### 10.1.8 Challenges and Opportunities

The primary concern with the design of the lever arm is minimizing the stress within the system when compressing the plastic. If the plastic is molten, the arm will effectively drive out the plastic batch. However, issues may occur should the plastic batch not be entirely molten. If there are portions of the plastic batch that are still in a solid state, during compression of the lever arm, unknown stresses may occur putting resistance into the arm. The lever arm should only be actuated when the plastic reaches a molten state to ensure the bending stress in the arm is minimized. Based on experimental data, the team will determine an optimized heating time that will be used to specify when to actuate compression.

The overall design of Bio-Cube's injection mold has already been validated by other companies and organizations also seeking to clean up the environment by repurposing plastic waste. Bio-Cube's innovation, as previously mentioned, comes from the simplicity of the heating element itself. That said, the stand and four-bar linkage design has already been implemented in similar injection molds, allowing Bio-Cube to focus more on the design of the heating system.

## 10.2 Subassembly Two

### 10.2.1 Description

Plastic waste is fed into the heating funnel. The funnel feeds into the heating tube which serves as a cylinder for the plunger head to slide through and push the molten plastic into the mold. The heating tube conducts heat from the fuel source, then the heat is transferred to the plastic waste. There will be a slip fit tolerance between the outer diameter of the plunger head and the inner diameter of the heating tube.

The tolerance ensures molten plastic will not get stuck between the sides of the plunger head and the wall of the heating tube. The heating tube will be positioned through the center of the heating chamber which consists of two half cylinders. The upper cylinder fits partially over the lower cylinder and is secured with pins on the lower cylinder fitting into slots cut into the upper cylinder. These half cylinders will be connected to form the cylindrical heating chamber. Fuel is added to the system through a window cut into the top cylinder. Vent holes in the lower half of the cylinder and at the top of the upper half of the cylinder will allow air to enter the heating chamber and cause natural convection to occur, improving heat transfer to the heating tube. The lower half of the cylinder has handles attached to allow it to be easily moved and to allow the waste products from the combustion process to be emptied after use of the system.

*Table 5. Subassembly two components*

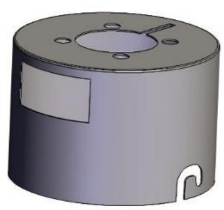
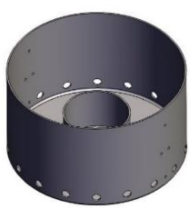
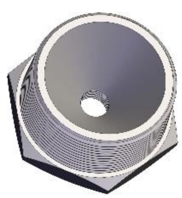
| Part Render | Material | Stock Size | Fabrication Time |
|---|---|---|---|
|  | ASTM 304 Stainless Steel | 9” OD x 10 7/8” depth | 12 hours |
|  | ASTM 304 Stainless Steel | 8”OD x9 ¾” depth | 12 hours |
|  | ASTM Galvanized Steel | 4” female OD x 2-7/8” male OD | 1 hour |
|  | ASTM A36 Steel | 2.5”OD 0.188” wall thickness 1’ length | 1 hour |

*Figure 8. Heating chamber assembly.*

| | | | |
|---|---|---|---|
|  | ASTM 304 Stainless Steel | 6” OD pipe size 2” ID | 3 hours |
|  | ASTM A36 Steel | 2.25” OD 2.01” ID 12” length | 5 hours |
|  | ASTM A36 Steel | 2.5” OD 0.188” wall thickness 1’ length | 3 hours |
|  | ASTM A36 Steel | 6” X 6” Plate, 2” Length 5/8” Head Pin, 12” X 1/2” X 1/2” Bar | 20 hours |
|  | ASTM 304 Stainless Steel | 2 to ¼ pipe size (NPT) | 5 hours |

### 10.2.2 Design Considerations

The team assumes a 10 % waste in the volume of material required for one brick. Therefore, the heating tube needs to have a 10 % larger volume than the minimum required volume of plastic to produce one brick. To produce a 12 $in^3$ brick, the anticipated required volume of plastic waste, accounting for the waste described above is 13.2 $in^3$. The volume of molten plastic is less than the volume of the solid plastic waste due to air between pieces. The team assumes a 40 % reduction in volume between the solid plastic waste input into the heating tube and the final volume of the solid plastic mold. To meet this requirement the volume of the heating cylinder needs to be 18.48 $in^3$. The current heating tube has a volume of 18.85 $in^3$. The team considered the expansion of the heating tube due to thermal expansion. The change in the diameter of the heating tube at is considered negligible. The plastic in the tube needs to be monitored using a simple thermometer to ensure that the center of the heating tube reaches the melting temperature of the plastic. This ensures a constant product from the use of the system. Another concern is the removal of the hot stones or coals from the heating chamber. To ensure safety of the user, the bottom portion of the heating chamber has been manufactured to be removable which, allows the combustion waste product to be discarded after an appropriate amount of cooling time has passed. The cooling time will need to be experimentally determined to ensure safe use of the system.

Due to the slow heating and cooling of the system, as well as the negligible hoop and radial stresses, the team determined that the thermal aspect of the system will not have a significant effect on structural integrity.

### 10.2.3 Motivation

It is critical for the plunger head to slide smoothly up and down the heading tube repetitively without galling. The heating tube must also conduct heat to transfer energy to melt the plastic waste. The upper and lower heating chamber components will house the fuel necessary to melt the plastic.

### 10.2.4 Material Selection

The following components will be made from ASTM 304 stainless steel due to its corrosion resistance at high temperatures: upper chamber (120-003), lower chamber (120-004), interface reducer (120-005), interface tube (120-006), and chamber handles (120-008). The following components will be made from ASTM A36 steel because this material will decrease manufacturing time: heating tube (120-001), mounting flange (120-002), and modified pipe flange (120-007). Additionally, the heating tube needs to be made of a harder material than the plunger head to reduce galling.

### 10.2.5 Manufacturing plan

The heating tube is made from stock tubing purchased from Online Metals, the tube will be cut to length (12”) and a lathe will be used to single-point cut the 2.25”-20 thread into the outside of the tube.

### 10.2.6 Flow Rate

When molten plastic is flowing through the heating cylinder the team assumes a fully developed, steady state flow. The fluid is not accelerating, the effects from gravity are negligible, and the fluid is incompressible. In Equation 8.1 the velocity profile of a pressure driven flow with the above assumptions was derived using the Navier-Stokes equations. The velocity profile is dependent upon the dynamic viscosity of the fluid, the pressure gradient, and the inner radius of the cylinder. In Equation 8.2 the shear force on the wall of the cylinder from the fluid is maximum at the wall of the cylinder. The team assumes the velocity of the molten plastic is zero at the cylinder wall. From Equation 8.2 the shear force from the fluid on the cylinder is not dependent on the dynamic viscosity of the fluid. The shear force depends upon the pressure gradient and the inner radius of the heating cylinder. The force balance on the molten plastic is given in Equation 8.3. The shear force on the cylinder wall is dependent upon the input force from the piston. The physical properties for the fluid flow calculations can be seen in Table 5.

$$\frac{\partial u}{\partial r} = \frac{1}{\mu}\frac{\partial P}{\partial z} r \tag{10.1}$$

$$\tau = \mu \frac{\partial u}{\partial r} = \frac{\partial P}{\partial z} r \quad (10.2)$$

$$P_1 A_c = \tau A_s = 0 \quad (10.3)$$

*Table 6. Fluid flow variables*

| Parameter | Description |
|---|---|
| $\tau$ | max shear stress |
| $\mu$ | dynamic viscosity |
| $\frac{\partial u}{\partial r}$ | velocity gradient in radial direction |
| $\frac{\partial P}{\partial z}$ | pressure gradient in vertical direction |
| r | inner radius of heating cylinder |
| $P_1$ | pressure supplied by piston |
| $A_c$ | cross-sectional area of heating cylinder |
| $A_s$ | inner Surface area of cylinder |

### 10.2.7 Hoop and Radial Stress

For calculating the hoop and radial stresses the thin walled assumption is checked:

$$\frac{r}{t} \geq 10 \quad (10.4)$$

The heating tube has an inner radius of 0.5245 in. and a wall thickness of 0.133 in. which gives a ratio of 3.94 and therefore cannot be treated as a thin walled pressure vessel. The hoop and radial stresses in the cylinder for a thick-walled pressure vessel are then given by:

$$\sigma_r = \frac{r_i^2 P_i - r_i^2 P_o}{r_o^2 - r_i^2} - \frac{(P_i - P_o) r_i^2 r_o^2}{(r_o^2 - r_i^2) r^2} \quad (10.5)$$

$$\sigma_\theta = \frac{r_i^2 P_i - r_i^2 P_o}{r_o^2 - r_i^2} + \frac{(P_i - P_o) r_i^2 r_o^2}{(r_o^2 - r_i^2) r^2} \quad (10.6)$$

Using Equations 8.5 and 8.6, Table 2 was compiled, which shows that the radial and hoop stresses are almost negligible given that the tensile strength of the A36 steel is 36,000 psi minimum, and the stresses are all below 250 psi during the operation of the system.

*Table 7: Radial and hoop stresses*

| Type | Radial | Hoop |
|---|---|---|
| Inner | 174.37 psi | 225.19 psi |

| | | |
|---|---|---|
| Outer | 160.00 psi | 239.56 psi |

### 10.2.8 Combustion Balance

For the overall thermal analysis of the system, a combustion analysis using oak wood is conducted. First a stoichiometric balance is determined using mass percentage data from literature [2]. The combustion process is then analyzed using standard theoretical air ratios with air represented as O+3.76N2. This analysis can be seen below in Table 3. Different wood types can be quickly analyzed if necessary, using the table format.

*Table 8. Energy balance calculations.*

| | C | O | H | N | S | totals | O2 | N2 | | CO2 | H2O | N2 | S | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Atomic W | 12.01 | 15.999 | 1 | 14 | 32 | 75.009 | | | | 44.1 | 18 | 28 | 32 | | |
| weight % | 0.506 | 0.429 | 0.061 | 0.003 | 0.001 | 1.000 | | | | | | | | | |
| # of Moles | 42.132 | 26.814 | 61.000 | 0.214 | 0.031 | 130.191 | | | | | | | | | |
| ST Coeff. | 42.132 | 26.814 | 61.000 | 0.214 | 0.031 | 339.510 | 43.974 | 165.344 | | 42.132 | 30.5 | 165.344 | 0.031 | | 238.0068 |
| h_o | 0 | 0 | 0 | 0 | 0 | | | | | 9364 | 9904 | 8669 | | | |
| h-o2 | 0 | 0 | 0 | 0 | 0 | | | | | 32694 | 28284 | 24027 | | | |
| h_f | 0 | 0 | 0 | 0 | 0 | | | | | -393520 | -241820 | | | | |
| | | | | | | | | | | | | | | Qout per kg of wood | |
| | | | | | | | | | | -1.6E+07 | -6814920 | 2539353 | | 19872.2479 | |
| | Temp | | | | | | | | | | | | | | |
| | 810 K | | | | | | | | | | | | | | |
| | | | | | | g/mol | | | | | | | | | |
| Weight | 6.07706 | 6.863571 | 0.061 | 0.042 | 0.032 | 13.07563 | | | | | | | | | |
| | | | | | | | | Total Weight | | | | | | | |
| | | | | | | | | 1000 | | | | HDPE | LDPE | Delta T | |
| | | | | | | | | | | | cp | 1.9 | 2.1 | 155 | |
| | | | | | | | | | | | | | | | |
| | 506 | 429 | 61 | 3 | 1 | 1000 | | | | | | 20.24338 | 18.31544 | | |
| | | | | | | | | | | | | | | | |
| | 0.506 | 0.429 | 0.061 | 0.003 | 0.001 | | | | | | | | | | |

With the design using heat from the combustion of biomass, the team made the baseline assumption that 30% of the heat released during the combustion of biomass could be directed into the heating tube, this could be much higher depending on the amount of convection that occurs, and a more exact number will be determined from during the testing phase. Using this 30% assumption and the combustion analysis it is determined that 20.2 kg of HDPE or 18.3 kg of LDPE can be melted for every kilogram of wood combusted.

### 10.2.9 Energy Balance

The team assumes the outer heating chamber as a layer of insulation, heat loss to the environment by convection is negligible, and that heat loss due to radiation is negligible. The energy balance quantifying heat transfer from the fuel source to the plastic is given in Equation 8.7. The team assumes a 90 % efficiency of the heat transfer from the fuel source.

$$\dot{Q}_{coals} = \dot{Q}_{plastic} = \frac{mc_p(T_f - T_i)}{\Delta t} \tag{10.7}$$

### 10.2.10 Heat Transfer Equations

A thermal circuit was used to determine the energy requirements based on the physical properties of the heating funnel and plastic. The team assumes the outer wall of the heating cylinder will be uniformly heated to 600 °C, steady state conditions, one dimensional heat transfer, and constant properties. Heat is conducted the through the heating cylinder and through the plastic. The thermal resistance for conduction through the heating cylinder and plastic are given by **Error! Reference source not found.**8.8 and Equation 8.9. The total thermal resistance in the network is shown in Equation 6. The plastic input into the system is recyclable plastic numbers 2 and or 4 which melts at 130 ℃. To determine the energy required to heat a batch of plastic the team considered the mass, the heat capacity, and the change in temperature from solid to molten plastic. The energy required to heat one batch is shown in Equation 8.10. The rate at which energy is transferred from the fuel source to the plastic is shown in Equation 8.11. The rate of heat transfer is dependent upon the total thermal resistance and the temperature difference between the outer wall of the heating cylinder and the center of the molten plastic. To produce one brick the heating cylinder requires approximately 380 W. The thermal properties of the materials used in the previous calculations can be seen in Table 3.

$$R_{cylinder} = \frac{\ln\left(\frac{r_{ho}}{r_{hi}}\right)}{2\pi L K_{cylinder}} \tag{10.8}$$

$$R_{plastic} = \frac{r_{hi}}{2\pi r_{hi} L K_{plastic}} \tag{10.9}$$

$$R_{total} = R_{cylinder} + R_{plastic} \tag{10.10}$$

$$Q = mc_p\left(T_f - T_i\right) \tag{10.11}$$

$$\dot{Q} = \frac{T_{outer\ wall\ of\ heating\ cylinder} - T_{center\ of\ molten\ plastic}}{R_{total}} = \frac{\dot{Q}}{\Delta t} \tag{10.12}$$

*Table 9. Physical properties for thermal analysis.*

| Parameter | Description / Value |
|---|---|
| L | length of heating cylinder: 12 in |
| $K_{cylinder}$ | conductivity of heating cylinder: 50 $\frac{W}{mK}$ |
| $K_{plastic}$ | conductivity of plastic: 0.42 $\frac{W}{mK}$ |
| $r_{hi}$ | inner radius of heating cylinder: 0.5 in |
| $r_{ho}$ | outer radius of heating cylinder: 1.125 in |
| M | mass of plastic: 0.60 kg |
| $c_p$ | specific heat of HDPE plastic: 1900 J/kg-K |

| | |
|---|---|
| $T_f$ | final temperature of plastic: 130 C |
| $T_i$ | Initial temperature of plastic: 25 C |
| $T_{outer\ wall\ of\ heating\ cylinder}$ | temperature at the center of hot stone collector: 600 C |
| $T_{center\ of\ molten\ plastic}$ | desired temperature at center of molten plastic: 130 C |
| Q | Heat: 1200 kJ |
| $\dot{Q}$ | Heat rate: 377 W |
| $R_{cylinder}$ | thermal resistance of heating tube: 0.0012 1/K |
| $R_{plastic}$ | thermal resistance of plastic: 1.24 1/K |
| $R_{total}$ | total thermal resistance in network: 1.245 1/K |
| $\Delta t$ | change in time: 5.27 min |

#### 10.2.11 Relevant Connections to Other Subassemblies

The heating tube will be connected to the stand assembly by a custom welded flange, the flange will be welded to a section of threaded pipe that will thread onto the outside of the head chamber itself. This flange will then be secured to the stand by two ¼”x 20 screws secured with nuts and washers. This will provide a secure connection between the stand and the heating tube assembly. A modified pipe flange will be threaded onto the heating tube and the upper heating chamber will be bolted to the flange. The mold subassembly is connected using a threaded section of pipe that will screw onto the lower end of the heating tube, a pipe nipple is then threaded into the lower portion of the pipe section and the mold assembly can be screwed into the pipe nipple.

#### 10.2.12 Challenges and Opportunities

The plastic waste will require preprocessing before being placed into the heating tube. The goal is to reduce the volume of air between plastic pieces. An ideal input size is 1/8” x 1/8” squares of plastic. The team considers this size ideal because it will reduce space between plastic pieces and can be achieved with a plastic shredder. To produce a consistent brick the center of the plastic waste needs to be molten during the heating process. The time required to ensure the plastic is molten in the center will have to be verified experimentally. The team is presented with the challenge that the plastic may stick to the walls of the heating tube and or plunger head. The team will have to ensure the molten plastic has been pushed out when each brick is produced. The force balance on the molten plastic was analyzed assuming the fluid does not accelerate through the heating cylinder into the mold. A greater input force may be required to initially accelerate the molten plastic from rest through the heating tube. The team assumes the force required to initially accelerate the molten plastic does not exceed the input force limit of 100 lbs.

## 10.3 Subassembly Three

### 10.3.1 Description

The mold assembly is the final step in this injection molding process. This assembly is composed of a two-part aluminum mold that creates a stackable block, similar to a Lego piece which, is roughly 13 in3. The two-part mold is 6” x 3.5” x 2” when assembled and weighs less than 3 lbs. without plastic injected into it. Designing a stackable block allows the customer to create multiple blocks and then piece them together to construct various solid structures. This satisfies the goal of repurposing plastic in an effective and safe way.

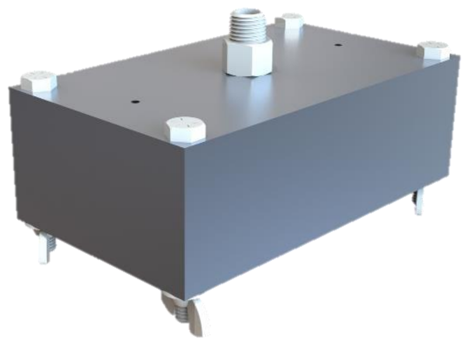
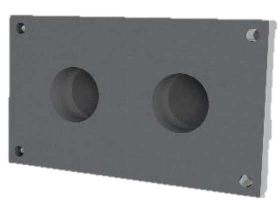


*Figure 10. Full mold assembly*

*Figure 9. Full mold assembly exploded view.*

*Table 10. Subassembly three components.*

| Part Number | Material | Stock Size | Fabrication Time |
|---|---|---|---|
|  | ASTM 6061 Aluminum | 3.5”x6”x1” | 5 hours |
|  | ASTM 6061 Aluminum | 3.5”x6”x2” | 5 hours |
|  | 304 Stainless Steel | ¼” NPT Male Threaded Pipe Fitting | N/A |

Design considerations and Material Selection. The mold assembly is designed as a two-part mold that is compressed together with fasteners. The top and bottom mold are made from 6061 Aluminum Alloy. Using aluminum provides a lightweight, cost-effective and easily manufactural mold. Having a mold that is light weight reduces the downward force being applied to the pipe fitting.

In addition to a Lego-like shape, the mold has two risers which, helps reduce the pressure inside the mold and allows for ventilation. It also helps indicate to the customer that the plastic has filled the mold. The final plastic block looks like a Lego piece with additional plastic from the two risers and the sprue. This additional plastic is then removed so the final product resembles more of a Lego building block.

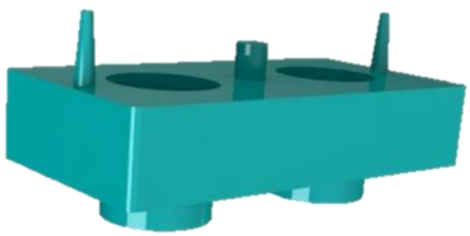


*Figure 12. Plastic brick output with risers.*

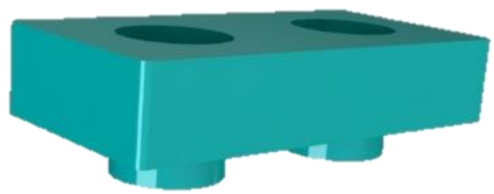


*Figure 11. Plastic brick output with no risers.*

### 10.3.2 Motivation

The mold needs to accurately produce the plastic block piece as intended to ensure the customer can use it for their personal building needs. Therefore, the mold is designed to maximize the amount of plastic the customer can put in to make a completed plastic block.

### 10.3.3 Manufacturing Plan

This assembly consists of two main parts that are manufactured in house, the top and bottom mold. The top mold is manufactured in two phases; Phase One creates the holes for the fasteners and the pipe fitting,

Phase Two creates the mold cavity. The bottom mold is done is a single phase which includes, creating the holes for the fasteners and the mold cavity. General milling techniques are used to create this mold with special attention towards creating the draft angles which, uses a 2° tapered end mill.

Relevant connections to other subassemblies

The mold assembly is connected to the heat chamber with a pipe fitting. The pipe fitting connects to the top mold and then connects to the threaded bushing. This pipe fitting is critical because it supports the weight of the mold and serves as the sprue for the mold.

### 10.3.4 Challenges and Opportunities

The concerns that arise from this mold assembly revolve around the sprue. The sprue must be large enough to fill the cavity with plastic and allow for the plastic to cool evenly. The plastic cooling time is determined during the testing phase. Sink marks and flashes are a natural concern with injection molding however, for this mold, it does not affect the functionality of the plastic block and does not need to be considered.

This mold design is intended to be a template for future molds used with this injection process. The current mold produces a Lego-like block but different molds can easily be attached to the pipe fitting to generate a different plastic piece. This variability provides endless opportunities for the customer.

# 11 Testing Plan

## 11.1 Approach

The test plan is comprised of three experimental phases: determine the time required to heat a batch of plastic, determine the time the brick can be removed from the mold, and determine when the heating chamber has cooled to a temperature at which the contents can be cleaned out. Each component is necessary for safe use and developing intuition as to how long it takes to produce a brick.

## 11.2 Variables Tested

### 11.2.1 Determine Time Required to Heat one Batch

The time required to heat the plastic waste in the heating tube needs to be quantified and verified experimentally. The temperature of the combusting fuel sources is estimated to be 600 °C. The team expects the center of the plastic waste, recyclables two and or four, to reach its melting point of 130 °C in approximately 5.3 min. The temperature in the center of the plastic waste in the heating tube will be recorded using a thermocouple. The melting temperature will be verified. Additionally, the time required to melt the plastic will be recorded and acknowledge for future use.

### 11.2.2 Cooling Rate of Mold

After the mold is filled with molten plastic the time required for the plastic to cool to room temperature will be recorded. The mold can be removed from the heating tube to perform this test. The state of the molten plastic can be observed, and the temperature of the plastic will be recorded using a thermocouple.

### 11.2.3 Cooling Rate of Combustion Chamber

The time at which the chamber cools to room temperature is critical for knowing when the machine has stopped running. The team will monitor the temperature of the heating chamber while keeping track of the time it takes for the temperature to return to a safe level to allow for the removal of remaining fuel source.

## 11.3 Timeline

The testing will begin at the start of week nine. By this time the manufacturing phase is expected to be completed. Each phase of the experimental testing can be completed during the production of a single brick. During the production of a single brick the team will complete each phase as follows: determine the time required to heat a batch of plastic, determine the time the brick can be removed from the mold, and determine when the heating chamber has cooled to a temperature at which the contents can be cleaned out. By the end of week nine the team expects to produce a brick and have collected data regarding the three previously described experiments. Testing is expected to continue through week ten. After week ten the team will assess any problems with the operation of the machine and solutions to these problems.

# 12 Recovery Plan

## 12.1 Failure Analysis

Upon the occurrence of failure the team will begin the analysis of all subassemblies to determine the exact cause of the failure. From this analysis the team will determine whether or not the subassembly is salvageable, if it needs to be re-manufactured, or if a design change is necessary. In the event of a design change or re-manufacturing, the team has left an emergency fund within the full project budget to address the situation with proper financial resources to remedy the situation.

## 12.2 Responsive Action Plan

Upon assessment, the team will break into three groups to assess each subassembly for points of failure or impending failure caused by other events. This in-depth investigation will then be documented with a fully detailed report of all failure analysis done. Based on when the failure occurs during the Phase Two timeline the team will work diligently to develop a time sensitive resolution that targets completion of the project to full scope as outlined in the Design Basis Documentation. The derived failure solutions will be considered and weighted on the following criteria: how much time is left in Phase Two? How much will the solution cost? And how can the system be simplified to prevent the failure occurring in the future?

## 12.3 Mitigation

In order to mitigate failure the team has incorporated thoughtful investigation into safety factors and component interference during the design phase. Safety was considered as one of the leading design factors, and was therefore at the forefront of each subassembly design. It is the team's intent to ensure that all levels of failure are mitigated by having a part that is designed to fail first leading to the least amount of danger to any users in proximity.

# 13 Financial

## 13.1 Summary Overall

One of the driving criteria for this design is cost, to make sure the product is affordable for the target end user. The largest factor for determining the total price of $59,287 is the internal labor. The product is designed so that there isn't a need for external labor which significantly helps keep the price down. The internal labor will be done by the six engineers on this team at a rate of $61.50/hour. This budget summary includes the internal labor for the spring and fall semesters, which comprises of weekly meetings, testing, manufacturing, assembly and documentation, totaling 656 hours. Setting a contingency of 5.0000% and an overhead recovery and profit of 40.0% the total price is $59,287.

*Table 11. Budget Summary*

| Budget Summary | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| Description | Estimated Costs (USD) | | | | |
| | Labor Hours | Internal Labor | Contractor Labor | Materials | Totals |
| **Design and Construction** | | | | | |
| Equipment | 1 | $31 | $0 | $18 | $49 |
| Engineering | 655 | $40,283 | $0 | $0 | $40,283 |
| **Subtotal Design and Construction Costs** | **655.5** | **$40,313** | **$0** | **$18** | **$40,331** |
| **Miscellaneous Costs** | | | | | |
| Contingency | 5.00000% | | | | $2,017 |
| **TOTAL COSTS** | | | | | **$42,348** |
| Overhead Recovery & Profit | 40.0% | | | | $16,939 |
| **TOTAL PRICE** | | | | | **$59,287** |

## 13.2 By Subassembly

The table below breaks down the materials and their associated cost by subassembly. The current budget for this product is $2,000. Although the internal labor is the main factor of the total price, the team has made sure the material cost is minimal. The idea behind these materials is to provide a lightweight product with a long lifespan. Having a product with a significant lifespan assures that our customers do not have to source outside materials for repairs. Since the heating chamber is a critical and high cost component, $716, it is important that the materials specified below are used to ensure it works properly and mitigates any possibility of breaking.

*Table 12. Subassembly budget breakdown.*

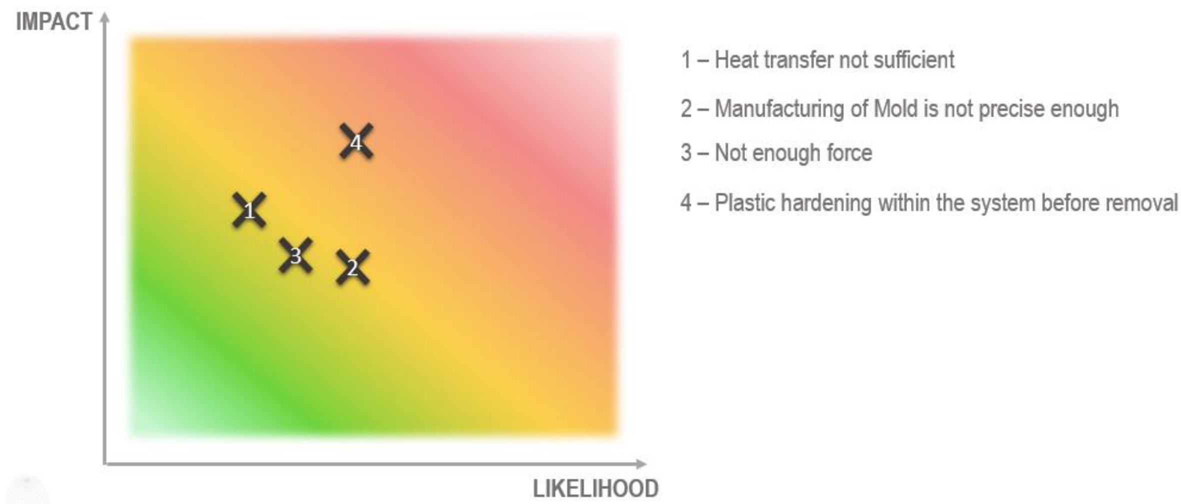
| Material Budget | | | | | | |
|---|---|---|---|---|---|---|
| **WP1 - Heating Chamber Assembly** | | | | | | |
| **Expense** | **Vender** | **Part No.** | **Quantity** | **Price Per Unit** | **Shipping (20%)** | **Net Price** |
| 1/4" Thick A36 Steel Plate (6" x 6") | McMaster-Carr | 6544K22 | 1 | $19.81 | $3.96 | $23.77 |
| 1/2" x 1/2" A36 Steel Bar (1ft) | McMaster-Carr | 9143K17 | 1 | $5.43 | $1.09 | $6.52 |
| 6" OD x 2.5" Thick 304 SS | McMaster-Carr | 44685K225 | 1 | $67.80 | $13.56 | $81.36 |
| 2.5" OD Tube (6") | McMaster-Carr | 89955K701 | 1 | $44.96 | $8.99 | $53.95 |
| 2" -1/4" 304 SS Bushing | McMaster-Carr | 4464K191 | 1 | $25.13 | $5.03 | $30.16 |
| 9" OD - 1/4" SS Bain Marie Pot (9.75) | Grainger | 78820 | 1 | $47.40 | $9.48 | $56.88 |
| 3" OD 2.87 ID Round Tube (2") | McMaster-Carr | 7767T331 | 1 | $9.15 | $1.83 | $10.98 |
| 8.8" OD - 1/4" SS Bain Marie Pot (9.084) | Grainger | 78780 | 1 | $37.70 | $7.54 | $45.24 |
| 2.25" OD 2.01" ID A36 Steel (12") | McMaster-Carr | 7767T84 | 1 | $41.28 | $8.26 | $49.54 |
| | | | | | **Subtotal** | **$358.39** |
| **WP2 - Injector Assembly** | | | | | | |
| **Expense** | **Vender** | **Part No.** | **Quantity** | **Price Per Unit** | **Shipping (20%)** | **Net Price** |
| A36 Steel Bar - Wd 1", 1/8" Thick (6ft) | McMaster-Carr | 6511K471 | 1 | $13.52 | $2.70 | $16.22 |
| A36 Steel Rod - Dia 1" (3ft) | McMaster-Carr | 8920K231 | 1 | $32.22 | $6.44 | $38.66 |
| 1", 0.083" Wall Thickness Square Tube (6ft) | McMaster-Carr | 6527K264 | 2 | $21.72 | $4.34 | $47.78 |
| 0.25" x 1.75" x 6" A36 Steel Plate | McMaster-Carr | 8910K555 | 2 | $5.04 | $1.01 | $11.09 |
| 0.125" x 1.205" A36 Steel Plate (1ft) | McMaster-Carr | 8910K397 | 2 | $3.26 | $0.65 | $7.17 |
| 2" Diam. X 3" 6061 Aluminum Tempered | McMaster-Carr | 1610T15 | 1 | $13.17 | $2.63 | $15.80 |
| 3/8"-16 High-Strength Steel Threaded Rod | McMaster-Carr | 90322A111 | 1 | $3.23 | $0.65 | $3.88 |
| 0.83 x 0.83 Square Tube Caps | McMaster-Carr | 9092K38 | 1 | $12.34 | $2.47 | $14.81 |
| 4" x 2-7/8 Galvanized Steel | McMaster-Carr | 2013K38 | 1 | $8.43 | $1.69 | $10.12 |
| | | | | | **Subtotal** | **$165.54** |
| **WP3 - Mold Assembly** | | | | | | |
| **Expense** | **Vender** | **Part No.** | **Quantity** | **Price Per Unit** | **Shipping (20%)** | **Net Price** |
| 6061 Aluminum Bar - Wd 3.5", 1" Thick (1/2ft) | McMaster-Carr | 8975K627 | 1 | $18.77 | $3.75 | $22.52 |
| 6061 Aluminum Bar - Wd 3.5", 2" Thick (1/2ft) | McMaster-Carr | 8975K629 | 1 | $34.94 | $6.99 | $41.93 |
| 1/4 NPT Male Threaded Pipe Fitting | McMaster-Carr | 4464K721 | 1 | $4.60 | $0.92 | $5.52 |
| | | | | | **Subtotal** | **$69.97** |
| **WP4 - Fasteners** | | | | | | |
| **Expense** | **Vender** | **Part No.** | **Quantity** | **Price Per Unit** | **Shipping (20%)** | **Net Price** |
| 0.125" ID Cadmium-Plated Steel Flat Washer (100) | McMaster-Carr | 98032A421 | 1 | $ 2.10 | $ 0.42 | $ 2.52 |
| 5/8"-11 Grade 5 Steel Hex Nut (10) | McMaster-Carr | 95479A125 | 1 | $ 7.25 | $ 1.45 | $ 8.70 |
| 4-48 x 1/2" Button Head Socket Cap Screw (10) | McMaster-Carr | 92949A329 | 1 | $ 7.56 | $ 1.51 | $ 9.07 |
| 5/8"-11 x 1-3/4" SS Hex Head Cap Screw (1) | McMaster-Carr | 92245A807 | 4 | $ 7.61 | $ 1.52 | $ 31.96 |
| 3-48 18-8 SS Hex Nut (100) | McMaster-Carr | 91841A004 | 1 | $ 3.07 | $ 0.61 | $ 3.68 |
| 0.656 ID (5/8" Screw Size) SS Flat Washer (5) | McMaster-Carr | 91525A366 | 2 | $ 7.86 | $ 1.57 | $ 17.29 |
| 1/2" Wide Band Worm Drive Clamps (10) | McMaster-Carr | 5415K22 | 1 | $ 9.60 | $ 1.92 | $ 11.52 |
| 0.281" (1/4" Screw Size) SS Washers (100) | McMaster-Carr | 90107A029 | 1 | $ 8.25 | $ 1.65 | $ 9.90 |
| 1/4-20 x 2.5" Partially Threaded Bolt (50) | McMaster-Carr | 91257A552 | 1 | $ 12.11 | $ 2.42 | $ 14.53 |
| 1/4"-20 Threaded Wing Nuts (100) | McMaster-Carr | 90866A029 | 1 | $ 10.94 | $ 2.19 | $ 13.13 |
| | | | | | **Subtotal** | **$122.31** |

| | |
|---|---|
| **Total Cost** | **$716** |
| Budget | $2,000 |
| Unalocated | $1,284 |

# 14 Risk Assessment

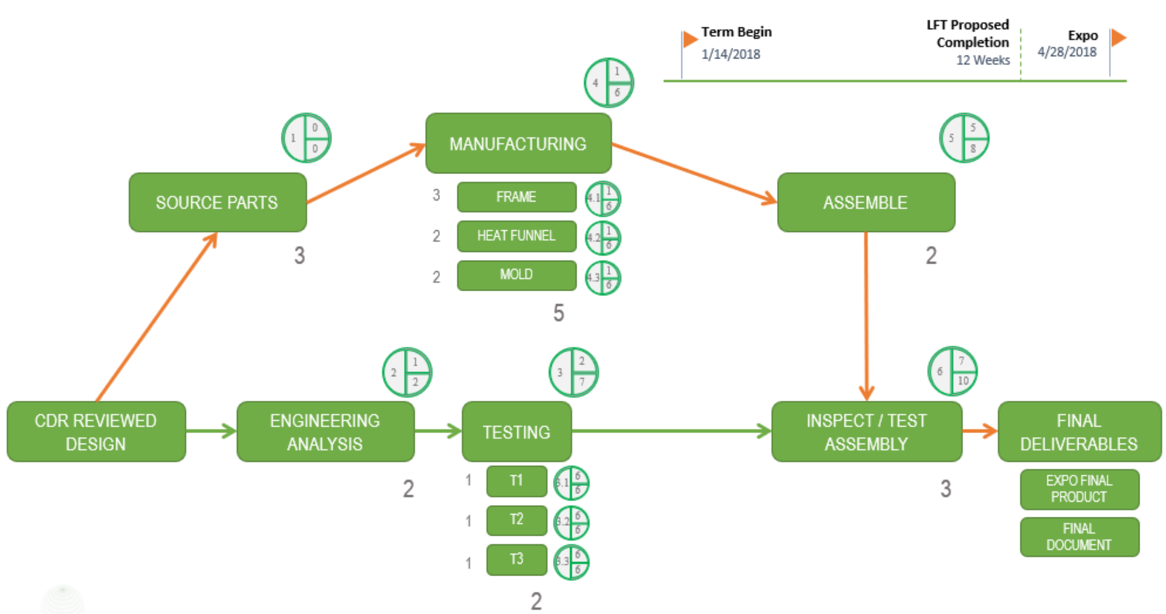
Bio-Cube has analyzed the critical components of the design and outlined them below in the risk assessment matrix. The design was constructed around theoretical assumptions and calculations, and therefore it is crucial that those aspects are realized when the product is operational.

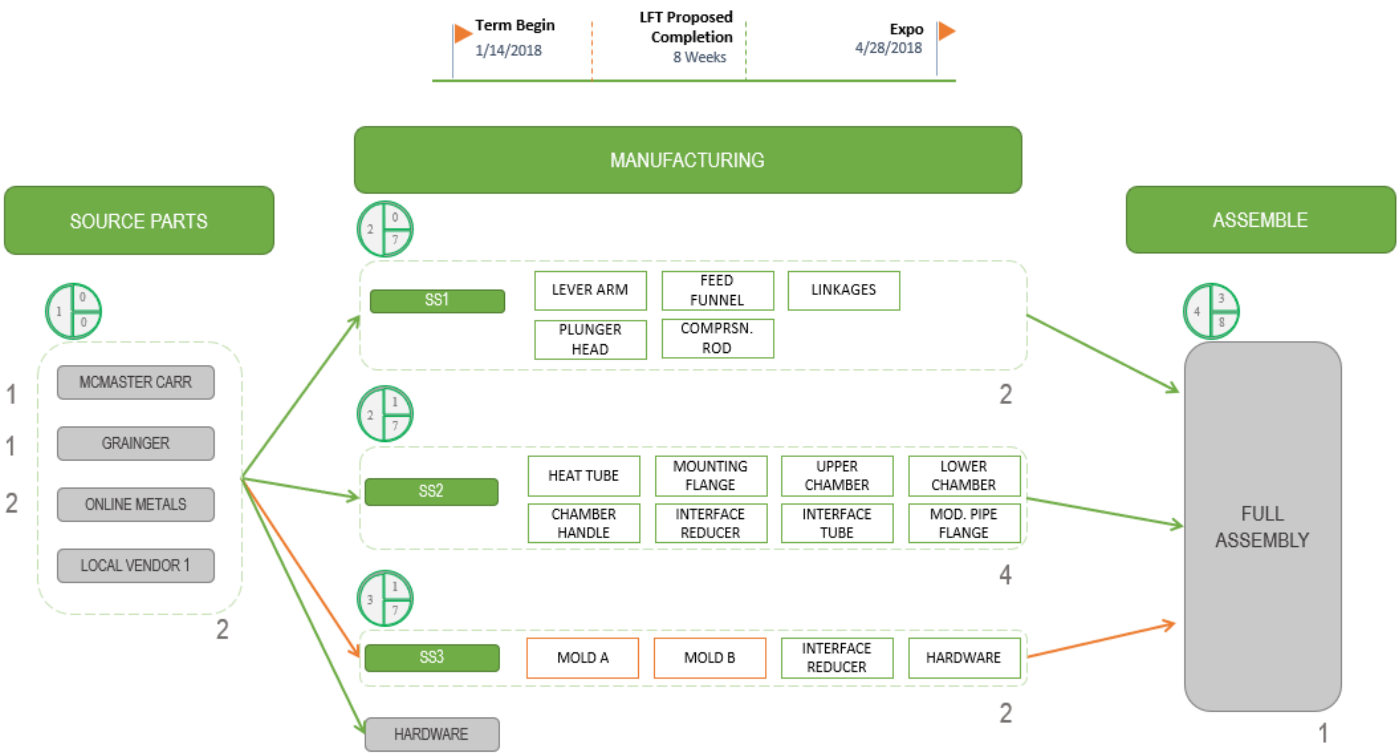
## 14.1 Risk matrix




## 14.2 Critical Path Analysis

The following Critical Path analysis was conducted to better direction the team as Bio-Cube is heading into Phase Two. It was essential to understand which components would provide the largest concern should they deviate from the idealized timeline. The following analysis shows that the manufacturing activities will be the most critical; with the mold assembly being the most demanding of attention.



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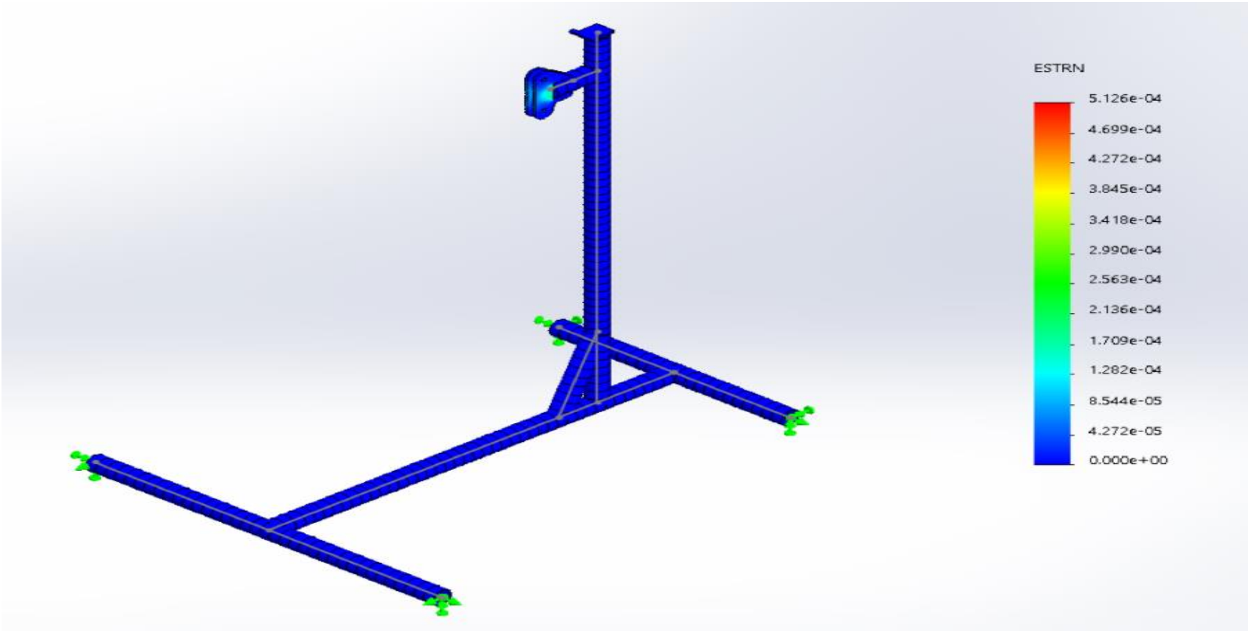
*[1] P. Hartlieb, M. Toifl, F. Kuchar, R. Meisels, T. Antretter, Thermo-physical properties of selected hard rocks and their relation to microwave-assisted comminution, Miner. Eng. 91 (2016) 34–41.*

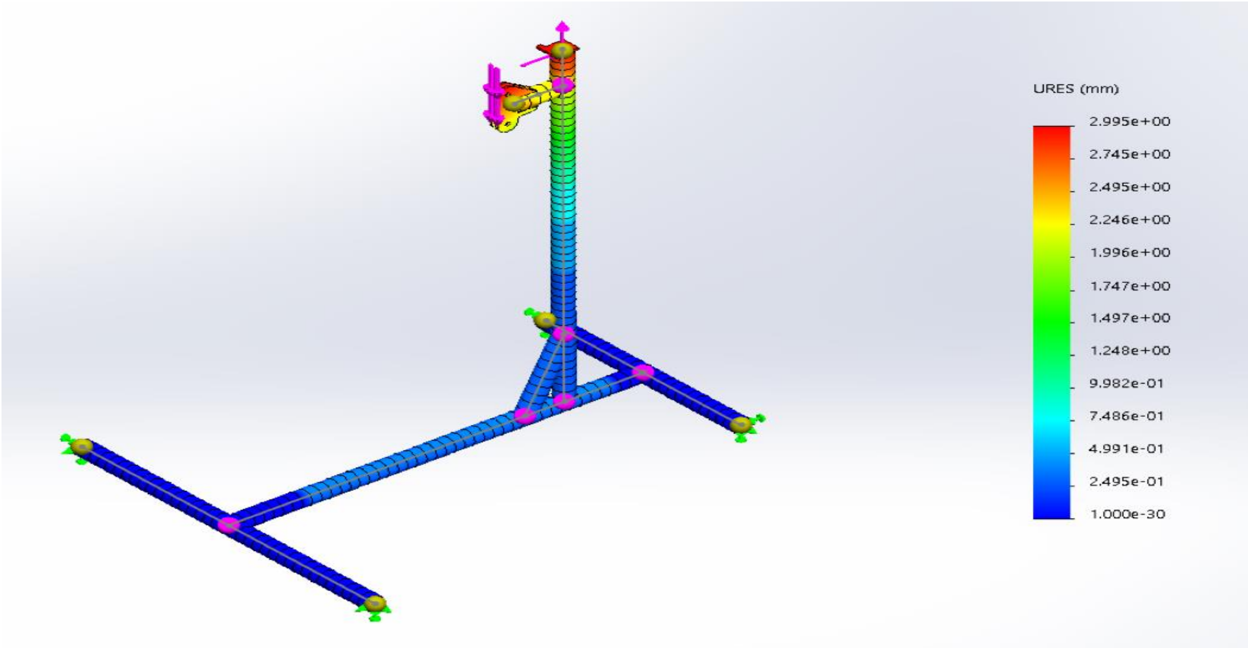
*[2] An overview of the chemical composition of biomass, Stanislav V. Vassilev, David Baxter b , Lars K. Andersen b , Christina G. Vassileva, Central Laboratory of Mineralogy and Crystallography, Bulgarian Academy of Sciences, Acad. G. Bonchev Street, Block 107, Sofia 1113, Bulgaria b Institute for Energy, Joint Research Centre, European Commission, P.O. Box 2, NL-1755 ZG Petten, The Netherlands*

*[3] Sheth, Khushboo. "Countries Putting The Most Plastic Waste Into The Oceans." World Atlas, Worldatlas, 5 July 2016, www.worldatlas.com/articles/countries-putting-the-most-plastic-waste-into-the-oceans.html.*

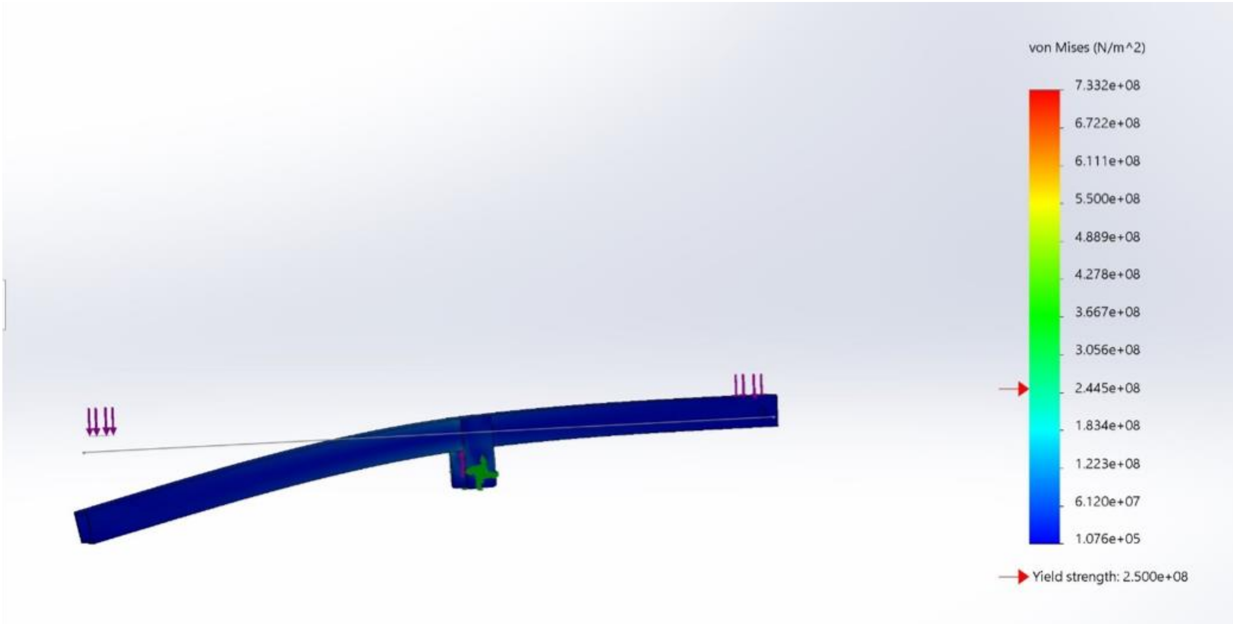
# 16 Appendix A: FEA Analysis

## 16.1 FEA Analysis on Stand Weldment

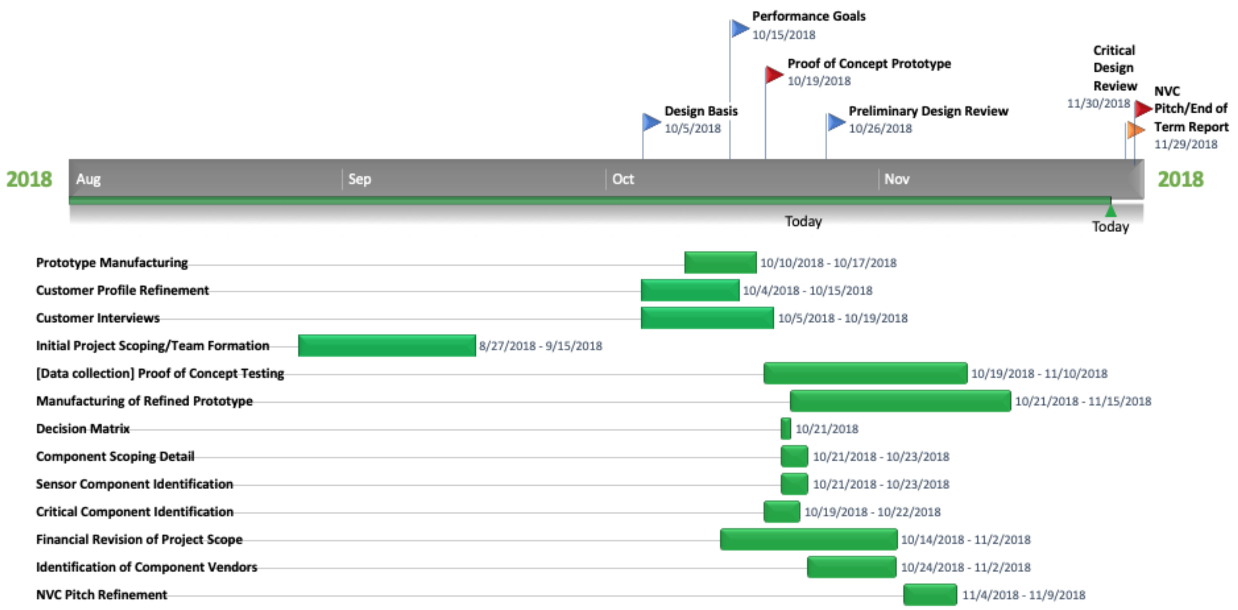


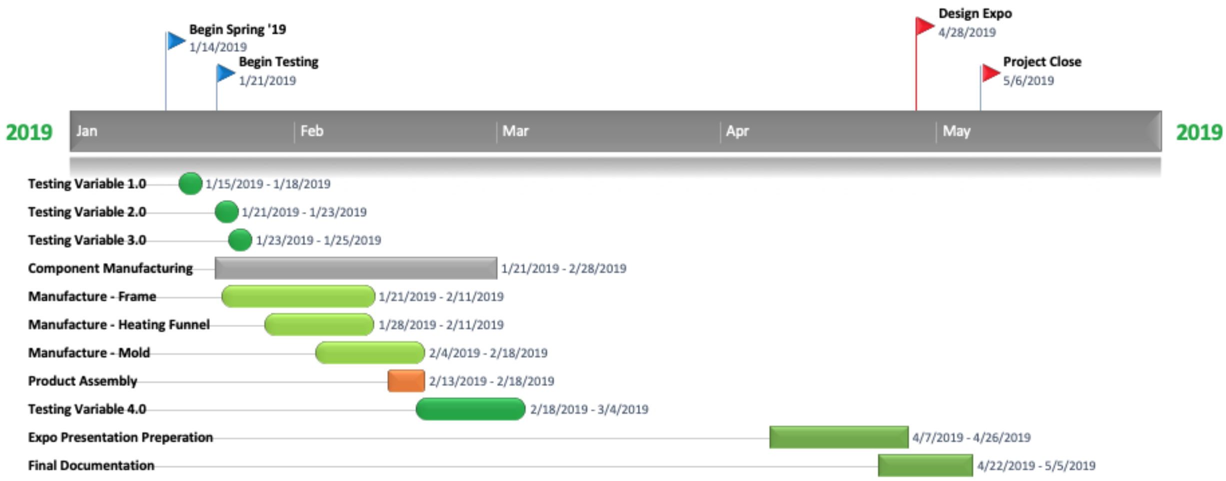



## 16.2 FEA Analysis on Lever Arm



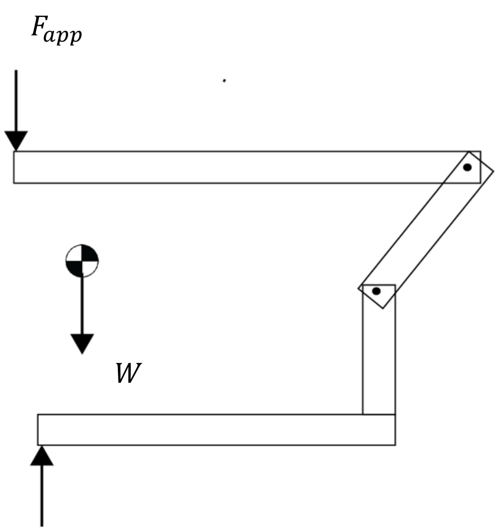

# 17 Appendix B: Gantt Charts

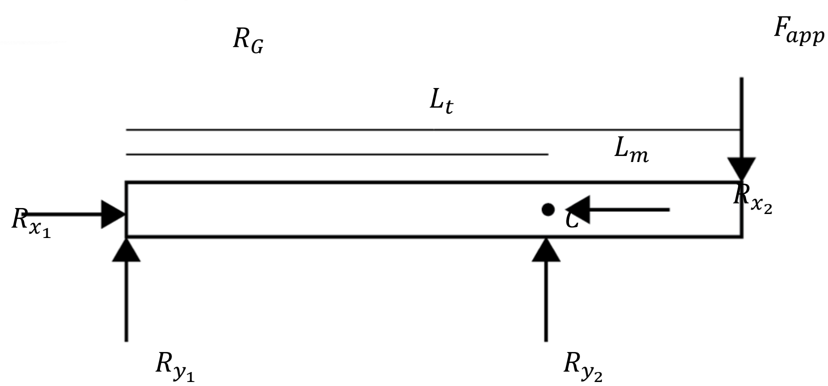





# 18 Appendix C: Analysis Calculations

## 1.1 Structural Analysis Calculations



### 1.1.1 Parameters:

$F_{app} = 100\ lbf$ $\qquad$ $L_b = 14\ in$

$L_{arm} = 24\ in$ $\qquad$ $\theta = 66°$ (Angle at which max bending will occur)

$L_t = 23.5\ in$ $\qquad$ $W = 26\ lb$

$L_m = 10\ in$ $\qquad$ $CG = [0\ 1.42\ 0.745]\ ft$

### 1.1.2 Total System Calculations:

$$R_{y_4} = F_{app} + W = 126\ \ lbf \qquad (A.1)$$

$$L_{bottom} = \left(\frac{F_{app} * L_{arm} + W * CG_z}{R_{y_4}}\right) * 12 = 20.89\ in \qquad (A.2)$$

This is the length required of the bottom plate to ensure stability of the whole system (no tipping).

### 1.1.3 Internal Reaction Forces at Pinned Joints:

$R_{y_1} = 235\ lbf$ $\qquad$ $R_{x_1} = \ 60.11\ lbf$

$R_{y_2} = 135\ lbf$ $\qquad$ $R_{x_2} = 60.11\ lbf$

$R_{y_3} = 135\ lbf$ $\qquad$ $R_{x_3} = 60.11\ lbf$

### 1.1.4 Bending Stress on Lever Arm

$$M_{max} = \frac{FL_m(L_t - L_m)}{L_t} = 1350\ psi \qquad (A.3)$$

$$\sigma_{bending} = \frac{M_{max} * c}{I} = 15{,}692\ \ psi \qquad (A.4)$$

$$\sigma_{yield} = 32{,}000\ psi \qquad (A.5)$$

(For mild steel 1” OD tubing)

$$SF = \frac{\sigma_{yield}}{\sigma_{bending}} = 2.0 \qquad (A.6)$$

### 1.1.5 Tear-out of Lever Arm and Pinned Joint

Parameters:

$$w = 1\ in \quad D_H = .26\ in \quad D_p = .25\ in \quad L_{sp} = .37\ in \quad t = .125\ in \quad S_{su} = 36{,}000\ psi \quad S_{tu} = 58{,}000\ psi$$

Shear Failure

$$A_s = 2L_{sp}t = 0.925\ in^2 \tag{A.7}$$

$$P_{su} = S_{su} * A_s = 3330\ lbf \tag{A.8}$$

$$FS_{tu} = \frac{P_{su}}{F_{app}} = 33.3 \tag{A.9}$$

Bearing Failure

$$A_{br} = D_p t = .0312\ in^2 \tag{A.10}$$

$$P_{bru} = S_{bru} A_{br} = 2714.4\ lbf \tag{A.11}$$

$$S_{bru} = 1.5 S_{tu} = 87000\ psi \tag{A.12}$$

$$FS_{bru} = \frac{P_{bru}}{F_{app}} = 27 \tag{A.13}$$

# 19 Appendix D: Matlab Code

## 19.1 Lever Arm Calculations

```
% low carbon steel
% A36 steel sigma = 32 kpsi
clc, clear
%%Lever arm [TOP]
sigma_yield = 32000; % psi
c = 0.5; % distance from axis to extreme fiber
wall_thick = 0.083; % in
a = 1; % square tubing outer length
b = 1 - 2*wall_thick; %  square tubing inner length
L_t = 23.5; % in
L_m = 10; % in
```

```
I = (a^4 - b^4)/12; % mass moment of inertia for square tube
x = L_m;%in
% F = 100;%lbf
% R_By=-F.*(L_t-L_m)./L_m;
% R_Cy=(L_m.*F+F.*(L_t-L_m))./L_m;
% M_c=-R_By.*x-F.*(x-L_t)+R_Cy.*(x-L_m);

% reaction forces
R_y1 = 235; % lbf
R_y2 = 135; % lbf

% lever arm measurements
L1 = L_m; % in
L2 = L_t - L_m; % in

% max bending moment
M_max = R_y1*L1*L2/L_t; % psi

% max bending stress at R_y1
sigma_bend = (M_max*c)./I % psi

% bending safety factor
sf_bend = sigma_yield/sigma_bend

% shear stress
V_max = 270; % lbf
Ac = a*a - b*b; % in^2 x-sectional area
sigma_shear = V_max/Ac % psi

% shear safety factor
sf_shear = sigma_yield/sigma_shear
```

## 19.2 Reaction Forces

```
clc,clear

% params
F = 100; % lbf
theta = 66; % deg
Lt = 23.5/12; % ft
Lm = 10/12; % ft
Lb = 14/12; % ft
Larm = 24/12; % ft
W = 26; % lb
CG = [0 17.01 8.94]/12; % ft X Y Z,  Y up Z left x out of page

A = [0 0 0 1 1 0;
     -1 1 0 0 0 0;
     0 0 0 Lm 0 0;
```

```
     0 0 0 0 -1 1;
     0 -1 1 0 0 0;
     0 Lb*sind(theta) 0 0 Lb*cosd(theta) 0];

b = [F 0 F*Lt 0 0 0].';

% Internal Reaction Forces
x = A\b % lb
% External Reaction Force at base
Ry4 = F + W  % lb

% Sum momemts about CG
Lbot = (F*Larm + W*CG(3))/Ry4 * 12  % in

% length of platform infront of tower
% lbase = Lbot*12 - 5.42 % in
```

## 19.3 Thermal Network Calculations

```
clc,clear

% High-density and low-density polyethylenes -- HDPE and LDPE
% or recyclables 2 and 4 -- melt at 130 degrees Celsius (266 degrees Fahrenheit)

% params
% now using biomass
% Kcoal = 0.3; % W/m*K
https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/96JB01884
Ksteel = 50; % W/m*K
Kplastic = 0.42; % W/m*K https://www.engineeringtoolbox.com/thermal-conductivity-
plastics-d_1786.html
l = 12*0.0254; % m; % m lengh of tube
ro = 970; % kg/m^3 HDPE
% V = 0.000196645; % m^3 for final brick
% m = ro*V; % kg

% plastic cp for HDPE = 1900 J/kg*K http://www.goodfellow.com/E/Polyethylene-High-
density.html
cp = 1900; % J/kg*K

% LPDE melting temp 95-115C
http://www.matweb.com/search/DataSheet.aspx?MatGUID=557b96c10e0843dbb1e830ceedeb35b0&c
kck=1
% HDPE melting temp ~ 130C
Tf = 130; % C
Ti = 25; % C room temp
Tfire_init = 600; % C  at outer wall of heating cylinder

% heating pipe params
```

```
rhi = 2/2; % in
rho = 2.25/2 % in
rhi = rhi*0.0254; % m
rho = rho*0.0254; % m

V = pi*rhi^2*l;
m = ro*V;

% coal conatiner pipe
% rci = 5.25/2; % in
% rci = rci*0.0254; % m

% thermal network
% d = (rci - rho)/2 + rho; % m

% Rcoal = log(d/rho)/(2*pi*l*Kcoal);
Rtube = log(rho/rhi)/(2*pi*l*Ksteel);
Rplastic = rhi/(2*pi*rhi*l*Kplastic);

% Rt = Rcoal + Rtube + Rplastic;
Rt = Rtube + Rplastic;


% energy
% Q = m*cp*(Tf - Ti)
% Q_dot = (T4 - T1)/dt

Qdot = (Tfire_init - Tf)/Rt % W
Q = m*cp*(Tf - Ti) % J
delta_t = (Q/Qdot)*1/60 % min
```

## 19.4 Thermal Strain Calculations

```
clc, clear

% temps
tf = 600; % C
ti = 25; % C

% linear thermal expansion
% 304 ss
a = 16.8*10^-6; % m/m-K

% volumetric thermal expansion
% av = 69*10^-6; % m/m-K

rhi = 2/2; % in
rho = 2.25/2; % in
% l = 12; % in
```

```
rhi = rhi*0.0254; % m
rho = rho*0.0254; % m
```

## 19.5 Tube Dimensioning

```
clc,clear

% params
% init dim in for test condition
di = 2.75;
hi = 3;
% final dim in for test condition
df = 2.75;
hf = .25;
% desired dim in
l = 3;
h = 2;
w = 2;
vbrick = l*w*h*1.1 % assume 10% waste material

% volume
Vcyl = @(h,d) pi/4*d^2*h; % in^3
Vi = Vcyl(hi,di);
Vf = Vcyl(hf,df);

% size factor from test
vsf = Vf/Vi


% required size of cylinder
vcyl = (1.4)*vbrick

% test dim of cylinder
d = 2;
h = 6;
vcyl_test = Vcyl(h,d)
```