Final Report: Prototype Machine for Coating SLMP

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Abstract— A formal structured plan was implemented for the construction of a Stabilized Lithium Metal Power (SLMP) Coating Prototype Machine. The project parameters that were addressed for fabrication specifications and performance; include uniformity layer of the powder onto the anode film, the varying dimensions of the film, coating processes can be speed up to meet the 10 minute finishing process, a semi-automatic process was expected and the dimensions of the prototype itself were designed for the prototype to fit in a small dry room. The following report discusses the project goal (along with the parameters that were to be met), the design concept generation that progressed to the final design selection, background information on SLMP/literature review, final design specifications, design experiment, considerations for environmental, safety & ethics and project management. The methodology used to implement the final design and the specifications addressed throughout the report showcase the process for fabrication and manufacturing of both the mechanical components and electrical components. The final design prototype is shown to vibrate the funnel (on the frame) with an experimental powder to produce flow and dispersion onto the conveyor belt system. The conveyor belt system moves horizontally back and forth to achieve the uniformity required. The electrical components are controlled using an Arduino Mega microcontroller unit. Future recommendations are discussed to address future progress and upgrades that can be implemented for an increase in reliability and performance of prototype machine.

I. Introduction

The objective of this project is to develop a Stabilized Lithium Metal Powder (SLMP) coated anode electrode. A prototype machine that can uniformly coat SLMP on a flat battery electrode is to be developed.

In order to achieve the conditions necessary to result in battery improvement and life longevity, the SLMP should be coated on the anode electrode uniformly. This uniform coating is an optimum ratio, experimentally found, of copper anode to stabilized lithium metal powder. The exact ratio cannot be disclosed due to patent rights, thus the prototype will coat a minimum thickness of $150\mu m$ as to ensure that the ratio will be achievable.

Our approach to the application of SLMP on anodes will be focused on dry dispersion, specifically a surface application method. The advantages of attempting a dry dispersion method are that it will be cost effective, will not require the use of harmful or potentially dangerous liquids/solvents, quicker application time, and no dry time period. One specification that will be met includes, semi-automatically coating a flat battery electrode with the SLMP. The uniformity of the coating should be expected to be better than 20% and the coating area of the electrode is variable from 5-12 cm (width) and 5-250 cm (length). The coating time process is expected to be less than ~10 minutes. The prototype machine has been allotted a budget of $2,000.00 US dollars, which is to be spent on all fabrication and procurement costs.

A. Need Statement

Project Team 16 is sponsored by General Capacitors, which is located in Tallahassee, FL. The sponsor is Harry Chen, the chief technology officer at General Capacitor LLC., however our main liaison and advisor is Dr. Zheng whom is their top research engineer and professor at FSU. The current project calls for Team 16 to develop a coating machine. This machine will apply a uniform layer of stabilized lithium metal powder to the anode electrode of a Li-ion battery and to a Li-ion super-capacitor. This material and process application is newly developed. So group 16 is researching and developing a mechanism that can be scaled up to a production level. There are other coating machines on the marketplace, however none for this specific type of application. Due to the hazardous nature of the lithium metal powder, group 16 will develop a safe and productive way to meet our mechanisms requirements.

"A coating machine for this specific application is non existent"

B. Objective

The goal of this project is to develop an electrode with a uniform coating of stabilized lithium metal powder. To achieve this goal we must be able to reach the following objectives: Uniformity of roughly 20% for a thickness of 150μm, ability to apply a sufficient coat onto the electrode, ability to apply a coat in less than 10 minutes, ability coat electrodes of varying sizes, and a process that is semi-automatic. To execute this process, our intent is to design a prototype machine that will handle the lithium metal powder safely while applying a coat of specified thickness to the surface of a metal sheet that will be later cut into an anode.

C. Project Constraints

A prototype machine for coating copper anodes with stabilized lithium metal powder (SLMP) will be made by May 2015. General Capacitors LLC. is providing the Senior Design Team 16 with a budget of $2,000. The prototype selected has been designed with the project constraints as the parameters of its fabrication.

1. The budget given by General Capacitors is $2,000
2. The lithium powder is to cover the total surface area of the flat battery's anode
    a. The anode dimensions will vary from 5-12 cm (width) and 5-25 cm (length)
3. Lithium coat must have a uniform layer of 150μm with 20% fluctuation in thickness
4. One coating process under 10 minutes
5. The metallic lithium content of the powder needs to be at least 98%
6. Working with the lithium powder must be done in a dry environment
    a. AME dry room is 0.5% humidity
    b. Lithium reacts explosively to H_2O

II. Background Research and Literature Review

A. Background

The Stabilized Lithium metal powder (Li/Li_2CO_3) is a relatively new product created by FMC Lithium Corporation. Stabilized Lithium Metal Powder (SLMP), Li/Li_2CO_3, has been developed for the application in Li-ion batteries. This type of lithium material comes in the elemental dry form, as seen in Figure 1, which enhances the energy carrying properties. In combination, the Li-ion anode yields the most efficient utilization and the fastest diffusion [1]. The SLMP particles are a form of lithium metal based on a core/shell concept[4]. The CO_3 reacts with the lithium metal and forms a shell layer on the surface of unexposed lithium metal[4]. According to the safety data sheet for SLMP, exposure to elevated temperatures above the melting point (180.5°C/357°F)[2] as well as contact with humid air, can result in spontaneous ignition. The main application of this metal powder is to be used in existing lithium ion batteries. By introducing SLMP into Li-ion batteries it creates the opportunity for variation in anode/cathode material, such as Si, Sn based and manganese, vanadium respectively. These variations can lead to double the energy density, more overage tolerant systems, and potentially lower costs in new generation Li-ion batteries using SLMP [6]. The methodology improves the capacity of the Li-ion battery by 5 to 15% [2] as seen in Figure 2. Another application of the SLMP is in Li-ion super-capacitor to improve the energy density by 2-4 times [2].

Figure 1. Optical microscope image of Stabilized Lithium metal powder.

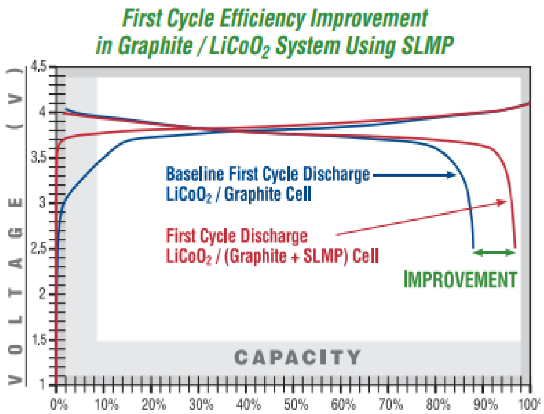


Figure 2. Graphical Analysis of efficiency improvement in anodes coating with SLMP. (Taken from FMC Lithium Corp)

Stabilized Lithium metal powder has been recently developed, thus the experimentation and search for methods of application have only just begun. There are two main types of dispersion methods available with SLMP, dry dispersion or wet dispersion. As of current the only method that has been attempted for coating is the wet dispersion.

Application of SLMP utilizing the wet method has been researched and funded by two companies: FMC Lithium Corporation and Tokyo Electron Limited. FMC Lithium Corporation has created a prototype that employs a standard slurry procedure to lithiate electrodes with stabilized lithium metal powder. This prototype operates a conveyor belt system that uses a long anode sheet as the belting. This belting is rotated through a spraying area, which coats the anode with a slurry mixture, and then the coated anodes are then rolled through a heater in which the solvent is melted off. Tokyo Electron Limited has developed a complex slurry method that employs the use of Argon gas. An anode is placed within a sealed pressurized chamber where it is sprayed with a slurry mixture. Once the spraying is completed, the chamber is flooded with Argon gas, which is heated to melt off the solvent and leave a uniform coating of SLMP upon the anode surface.

B. Literature Review

A key component of our prototype machine is the mesh. The mesh is important because it filters out particles that are too large inside of the funnel, thus keeping agglomerated SLMP from reaching the drop area. The mesh count was determined for a given particle size using the Equation 1. found in Fundamentals of Modern Manufacturing: Materials, Processes, and Systems by Mikell P. Groover. Particle size refers to the dimensions of the granular material that can fit through the open area of the mesh.

$$PS = \frac{1}{MC} - t_w$$

Equation 1.

In the Equation 1: PS= particle size, in; MC = mesh count, openings per linear inch; and tw = wire thickness of screen mesh, in. The particular values for this equation are depicted in Figure 3.

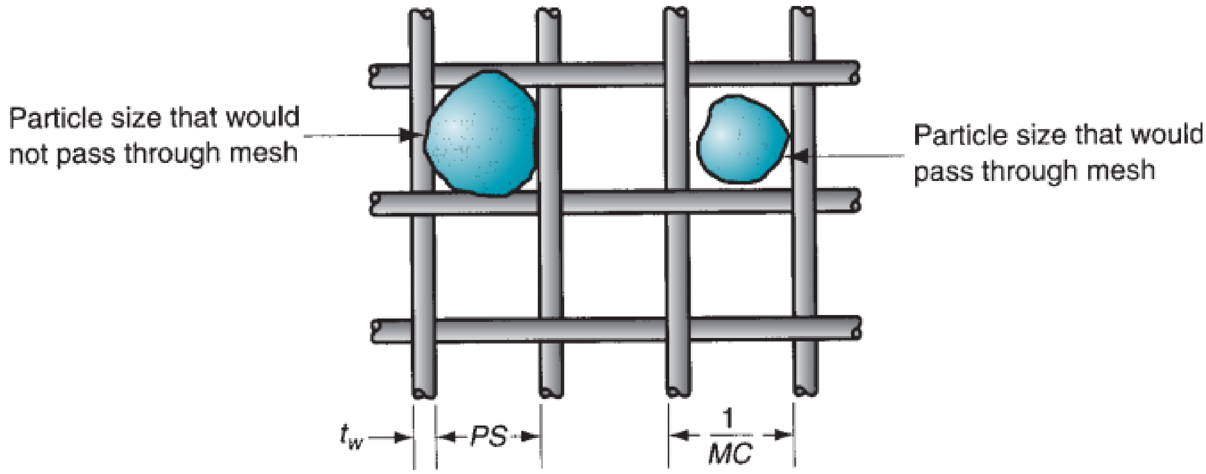


Figure 3. Taken from Fundamentals of Modern Manufacturing: Materials, Processes, and Systems by Mikell P Groover, the image depicts screen mesh for sorting particle sizes.

There are numerous types of metallurgy in existence, which all have differences in their production and application. A common way of classifying metallurgy is by the particle shape and internal structure. As shown in the figure below, found as Figure 4 in Fundamentals of Modern Manufacturing: Materials, Processes, and Systems, there are many metal powder shapes. A simple measure of shape is the aspect ratio- a ratio of the maximum dimension to the minimum dimension of a given particle. The aspect ratio for SLMP, as it is roughly spherical, is around 1.

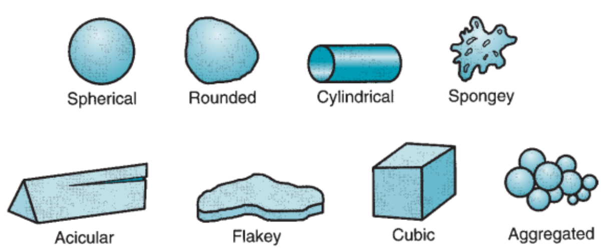


Figure 4. Image depicts the various particle shapes of metal powders, taken from Fundamental of Modern Manufacturing: Materials, Processes, and systems by Mikell P.Groover.

According to chapter 16 of Fundamentals of Modern Manufacturing: Materials, Processes, and Systems by Mikell P. Groover, the most conventional procedure for application of metal powders is a three parts process: blending the powder, compaction, and sintering as seen in Figure 5. The mixing of the material is necessary as it is important to homogenize the metal powder for successful results in compaction and sintering. In compaction, a high pressure is applied to the powders to form them into the desired shape. Our design group will be using the conventional method of compaction – pressing. Finally the pressed powders will be heat treated to bond the metallic particles, increasing strength. Alternative methods of application include isostatic pressing and powder inject molding. More alternative methods are powder rolling, extrusion, and forging. Depicted below is an example of what a production apparatus might look like.

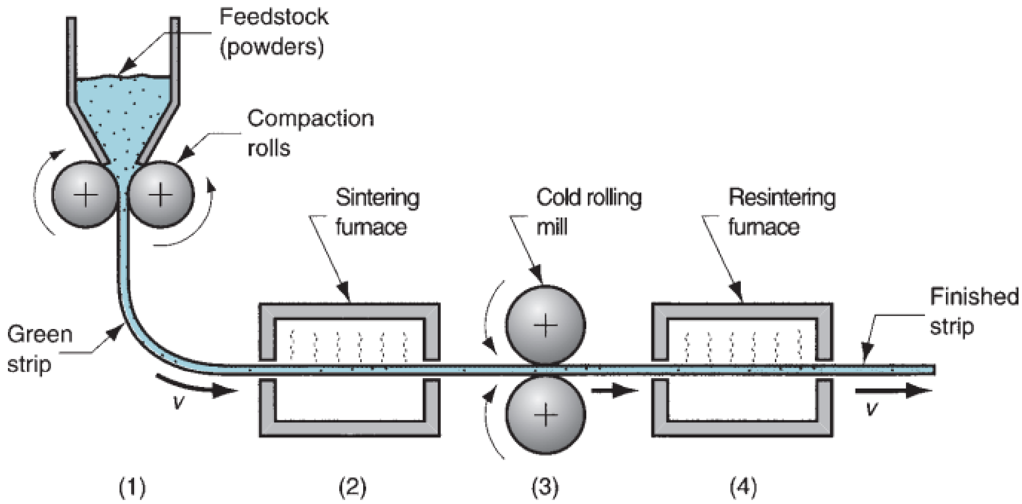


Figure 5. Image depicts the conventional powder metallurgy production sequence: (1) blending, (2) compacting, and (3) sintering. Taken from Fundamentals of Modern Manufacturing: Materials, Processes, and Systems by Mikell P.Groover.

III. Concept Generation

Each conceived design had been implemented with a focus on dry dispersion method, specifically surface application on pre-existing anodes. Each typically dealt with 3 main steps: dispersion, coating, and pressing. The method used for these may vary from concept to concept.

During this section of the paper detailed calculations and all designs conceptualized will be discussed chronologically from the initiation of the project until the final design selection. The initial designs will be discussed briefly while the final design will be discussed in more detail. Each design will also have a CAD drawing that will show a 3D model of the proposed design.

A. Design #1

A copper electrode sheet will be continuously pulled by a conveyor belt. The prototype being created to coat a copper electrode sheet consists of three major parts. The first major part is a funnel dropping the SLMP onto the copper electrode sheet. The SLMP is dropped by shaking the funnel with an actuator. The funnel's nozzle is a controlled cross-section in order to evenly coat the electrode sheet, as seen in figure 6. This funnel uses a series of meshes inside the funnel to help resist the flow rate of the SLMP through the coating process. After the SLMP is sieved through the meshes and the particles dropping downward onto the anode, there is a roller that will lightly press the SLMP onto the electrode sheet to better bond it to the electrode surface. The roller design, found in figure 6 and 7, was chosen because it is typically utilized for the fast and constant pressing of sheets. Speed is the primary attribute of the roller. The use of bearings will ensure that the roller can cover a large amount of area in a given time. The roller will start with a minimum load and if need be will be loaded until the precise loading pressure is determined to ensure the SLMP sticks to the anode rather than the roller. Lastly there will be a punch, as depicted in Figure 6 to cut out the desired shape out of the electrode sheet. The punch's head will be interchangeable to vary in length and width depending on what size of anode is being coated. Excess copper and lithium powder will be collected by the base, which acts both as a container and a support for the whole mechanical system. This base is flat with a couple added features to smooth out the coating process. The most noticeable feature being the holes on the side of the plate. These holes will allow for excess SLMP balls to roll off and not affect the pressing of the SLMP onto the anode. Thus allowing for the coating to be uniform throughout the layer of applied SLMP. The next feature you will notice is the two-rod holders at each end. These will both hold a role of the anode material, most likely copper. This will also supply the force to move the material throughout the process by using a motor on the back cylinder roller, the elevated roller. This will pull the roll of anode material through the coating process.

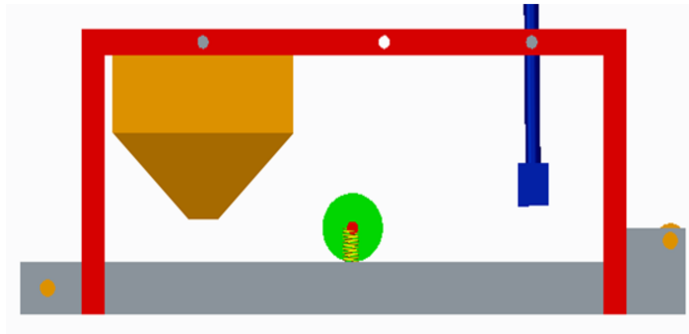


Figure 6. CAD Assembled side view of Design #1.

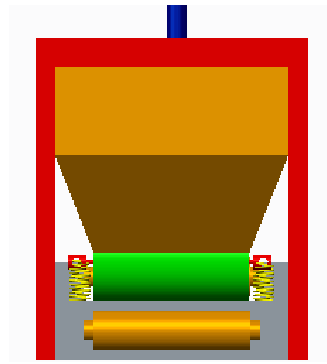


Figure 7. Front view of design #1 as seen in CAD.

This design's advantages are that it will be affordable to construct, that it will be safe for the user to operate, and that it will be simple to operate as well as to repair. Its weakness are that it will consume more power than any of the other designs, that it is not very durable based on the types of components it is made of, and that the roller used to stick the stabilized lithium metal powder onto the electrode wont supply enough pressure to break the carbon coating of the SLMP powder. This roller also has the possibility that it may slip leading to a non-uniform coating.

B. Design #2

This design is a slight variation of the dry method for coating SLMP onto the electrode sheet, as seen in figure 8 and 9. This design still uses the three main components: funnel, roller, and punch. Instead of fixed position components design #2 uses a slider coupled with the components in order to move the components of the system. The electrode sheet would remain stationary and the components themselves would move over the electrode sheet. Only one component would be used at a time. For instance if the funnel was running then the roller and

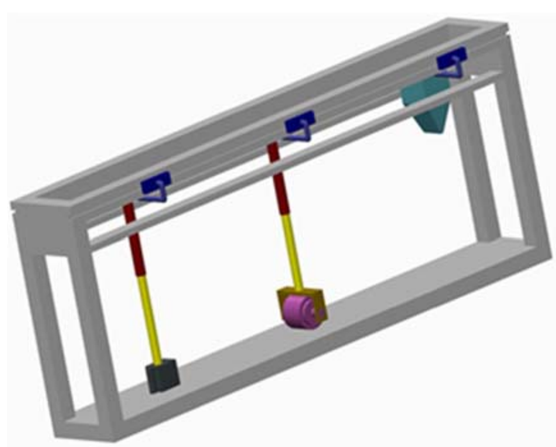


Figure 8. Assembled Pro E rendering view of design #2.

punch would be stationary at the opposite end of the funnel. The track would have gear teeth and the slider would have gears on bearings in order to move. The sliders have small motors powering the gears. The electrode sheet in design #2 is manually moved, no conveyor belt is used.

As in design #1 a long rectangular funnel is used in design #2. Design 2's components move in a 1-D motion. The funnel needs to be wide enough for the maximum width of the electrode sheet, 12cm, thus the width of the funnel is 14cm. The excess of the SLMP not falling onto the electrode sheet is collected and is deposited back to the SLMP reservoir. The speed of the slider mechanism will constrain what the height of the funnel opening needs to be. If the funnel system is not able to move at a certain speed then the opening of the funnel will need to be narrowed and use a variety of meshes to help resist flow. What will also be needed is a mechanism to close the funnel nozzle when SLMP flow is not needed. The funnel volume will be designed for the number of full applications of SLMP desired in a batch. For example, a full funnel may be able to coat 5 electrode sheets before needing to be refilled.

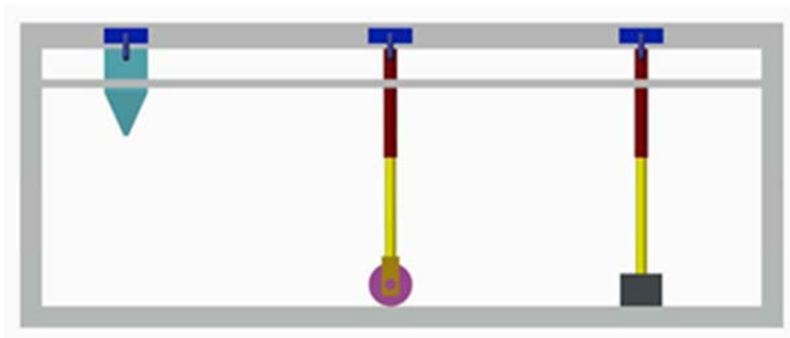


Figure 9. Side view of Design #2 as rendered through ProE.

The roller and punch are both operated by similar coupling mechanisms. They are driven not only by an identical slider mechanism but also an arm coupled with the slider mechanism. This arm is a hydraulic arm and can be extended in order to provide the needed force onto the electrode sheet. The punch will need a more powerful hydraulic arm, making it the only difference.

The roller's job is to break the SLMP beads and create a flat, uniform layer on top of the electrode sheet. The roller's contact with the SLMP means that some of the SLMP could stick onto the roller surface. Accumulation of SLMP on the roller surface causes irregularity of the surface and can then cause uniformity of the SLMP layer to diminish. Lubricant is be dripped on the roller while the roller is running to prevent accumulation of the SLMP. The lubricant comes from a feed through the hydraulic arm.

A sharp metal puncher is used to cut out the desired shape of the electrode as in the process of design#1. The punch is made from steel and is detachable from the hydraulic arm. By using a punch, production of the electrodes is faster and more efficient than cutting by hand.

This design is safe at a distance. Its components are moving constantly and rapidly, until a process is done and a new electrode sheet is introduced. The design is open and exposed; this means a person close to the machine could be covered with SLMP if not careful. Human fingers will need to avoid the roller and especially the punch. Many parts are needed to build design #2, which drastically increases the cost of the system. The more parts also mean more possibilities of a component breaking driving the maintenance cost higher. Repairs will take longer the more parts there are to a system.

The system will be automated and only the movement of the electrode sheet is manual, making design #2 easy to use. Most of the prototype machine will be aluminum and steel. Metal has a high wear coefficient, components will last for many cycles. Power consumption is high for this machine; every component has a small motor. Pumps for the hydraulic arms and lubrication feed all require electrical power. The prototype machine can be easily moved between work sites. Every component can be removed from the system's body for storage or workstation changes. The true drawback is the complexity of using a system that uses a mechanism with three separate moving parts. The cost of this device along with possible repairs makes this design not optimized for our use.

C. Design #3

This design forgoes complexity and is a simple funnel, drop, and roll system. The funnel is similar to the other designs' funnels however this one is fed onto a ramp at a 45-degree angle with the horizontal in order to add to the feeding process as seen in Figure 10. The ramp includes edges along the sides to prevent SLMP from slipping off the side.

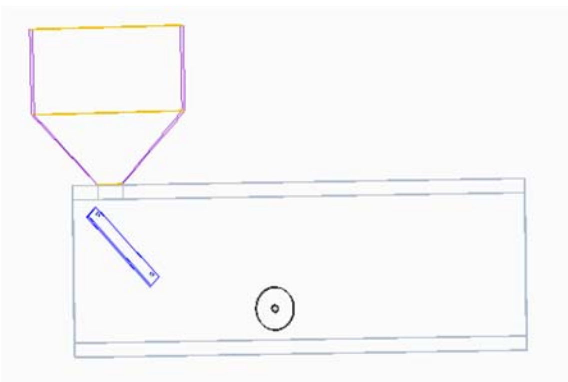


Figure 10. Design #3 depiction using ProE for rendering.

The reasoning behind the ramp is hopefully it could improve the consistency of the drop rate of SLMP while also slowing the flow rate of the funnel. While the SLMP is dropping, a conveyor belt will be moving the electrode at a constant speed into the roller and out the other end as seen in Figure 11. This roller is to be a full roller, ideally with a pressure sensor/actuator to allowing for negligible pressure on the lithium powder to avoid sticking. The internal structure of the machine is held by horizontal rods of quarter inch diameter. Such a simple structural support was chosen due to its simplicity to interchange and replace internal parts. If, for some reason, down the line we decide to remove the ramp, it is a simple matter of pushing out those associated support rods and perhaps lowering the hopper. As one can see, there is no punching device in the back of the case, which is fairly empty. For this design, the user of the machine would have to manually punch the electrode after coating. The reason the case is not consequently shortened is that the extra length provides some balance to aid in the offset mass caused by the funnel and leaves more room for future additions.

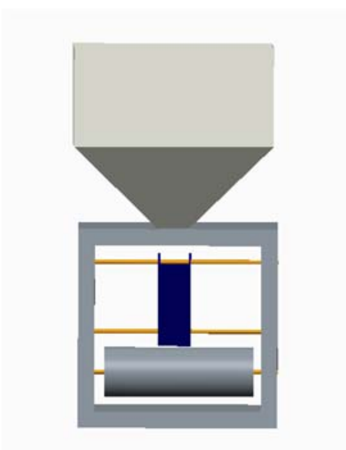


Figure 11.Front view of assembled design #3.

The funnel shape and mesh size are key aspects to this design that will drastically affect the flow rate of the SLMP and, consequently, how evenly the SLMP is coated onto the electrode. For convenience the funnel is shown as a square funnel.

Overall, one can see that this is a very minimalistic or simple approach. There's a lot of room in the case yet, which leaves room for further customization in the future. The advantages of this design are it is inexpensive, easy to make, and further customizable. The disadvantages of this design is that it requires more manual input than the rest of the designs and will likely not be as consistent in the coating process. Another disadvantage is that the whole mechanism is enclosed. While this is beneficial to the safety of the mechanism. It also hinders the accessibility of the components of the mechanism. Hence why this design didn't get off the drawing board.

D. Design #4

Design #4 is just a modification of design #1. It still has the same funnel, conveyor system, rollers, and press as discussed above. However in this design a dispersion device, called a rotary metering roller, is placed below the funnel, as seen in figure 13. This is similar to that of the propulsion of a riverboat. It is placed with a slight offset so it can collect the falling SLMP without rotating the opposite direction. This ideally would allow the SLMP to be dispersed more evenly thus giving a more uniform coating on the copper anode. A similar contraption can be seen in figure 14 below. However this design is similar to that of a spiral staircase or slide. This would be used instead of the one already placed in the assembly in figure 13. This ideally would also disperse the SLMP more evenly on the anode while also resisting the flow rate of the funnel. This design was deemed not functional after collaborating with our advisors. It was determined that it didn't add any benefits over the use meshes. Also the spiral funnel would collect the SLMP in the center, thus not dispersing the material in the manner desired. They suggested simplifying the design and getting rid of any excess parts that could over complicating our design.

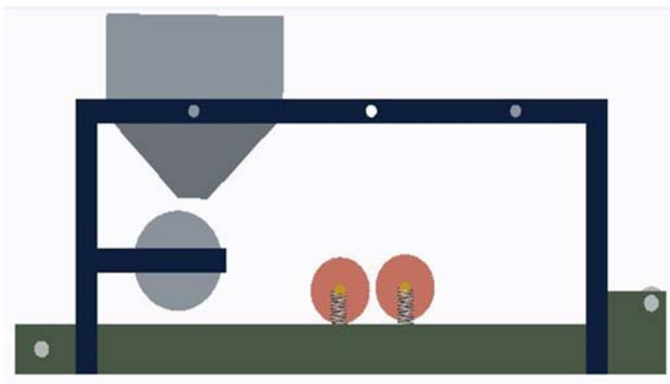


Figure 13.Design #4, rotary metering design, side view of assembled design using ProE.

Figure 12. Angled view of Design #4, showing all components invovled in process as rendered using ProE.

E. Design #5:

Design #5 included several modifications that were implemented after consulting with our advisors it was determined that some of the components had to be redesigned to simplify the mechanism. While also building the mechanism as soon as possible. Doing so will allow ample amount of time to test. This is because the ideal set up and performance of the design won't be known until ample testing is conducted. So as result let's discuss the features of our final design.

The first component that will be discussed is the conveyor belt system. This conveyor belt is a system created by Dorner Manufacturer, shown in figure 14. This selection is precision move conveyor belt. The main reason this particular product was chosen was due its belt material, silicon rubber, and that is reinforced with a polyurethane bed to reduce friction. Silicon rubber is desired due to its nonreactive nature toward the very reactive SLMP powder. This rubber will also prevents slipping thus ideally making a uniform layer of SLMP powder balls before it goes through the press. As seen in figure 15 the roller press and punches have been deleted from the design. This was done because the punches are an afterthought since our main purpose is to coat a uniform layer on the copper anode. The roller we designed also wouldn't exhibit enough pressure to break the carbon coating of the SLMP. Thus our advisor, Dr. Zheng, is supplying a press that was can exert the amount of pressure. This rolling press is the Electric Precision 4" width rolling press with dual micrometers. This press has the ability to exert 500lb/cm^2 of pressure, and is manufactured by MTI Corporation, shown in figure 15.

Figure 144. Photo of Precision move conveyor belt fabricated by Dorner Manufacturing.

Figure 15. Electric Precision 4" width rolling press fabricated by MTI corporation.

As seen in the past designs the same funnel and meshes are used, shown in figure 17. However the optimum design will be determined after the testing process is concluded. This essentially means that a variety of shapes and flow rates of funnel along with different mesh size and shape will be tested intently to find the optimum package for SLMP flow. Another aspect that will be tested will be the location of the meshes. The CAD seen in figure 16 and 17 shows the meshes below the funnel, but the meshes will also be placed inside the funnel and tested. The solutions to the location and sizes of these components will be determined after testing is concluded. Springs are used on the meshes to dampen any vibrations that make effect the frame.

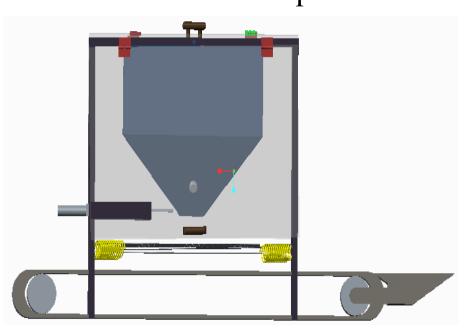


Figure 16. Depicts the assembled view of Design #5 using Pro E.

Due to safety concerns exhibited by the use of SLMP plexiglass will be put on the top, back, and front of the frame. This will help protect the operator due to the combustibility of the powder itself. The glass on the top and front will be able to be opened so an operator can adjust the mechanism.

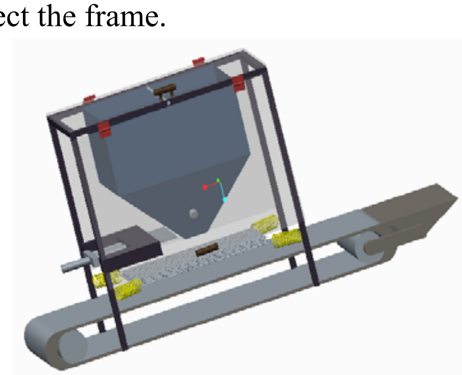


Figure 157. Angled view of Design #5 showing all components rendered using Pro E.

The top will especially be used to load more SLMP into the funnel. Both of these opening will have locking features to aid in the safety of the machine. Another safety feature was added to stop the flow of the SLMP completely. It's a plate that will cover the exit of the funnel by using a small motor and a power screw to place the plate in the correct position.

Another feature that is shown in the figures below is the bridge that will move the anode with SLMP powder into the MTI electric precision 4" rolling press.

F. Design #6

The sixth and final design retained the dry method technique. This design has the key characteristics of design #5, but are modified and perfected. The steel frame encompasses the major mechanical components. The funnel, whole sides are at a 56.3° angle from the normal, is attached to the structure of the frame. Initially, the exit of the funnel to the conveyer belt is 5 inches. From testing, the funnel needed to be lowered. A mending plate, Figure #, is attached on either side of the frame and secured with bolts. The funnel is then secured to the desired extended length of the mending plate. This allows the distance from the funnel exit to the conveyer belt to be adjusted. From testing the lower the less powder is dispelled to the surrounding environment, and only to the anode on the conveyer belt. Meshes are placed within the interior of the funnel. Two layers of meshes have been found to give the optimal powder flow rate. Using only one mesh causes too much buildup of the powder and significantly slows the powder flow rate. More than two meshes, and the flow rate is also decreased. The meshes are made of steel wire cloth with one mesh having a 60μm opening, and the second a 73μm opening. In order for powder to sift through the meshes vibration is needed. Vibration is introduced to the funnel by two vibrating motors. The motors have offset weights at the end of their shaft to cause vibration. This vibration allows the powder in the funnel to flow. Without vibration on the funnel and meshes, the powder is able to sit on top of the mesh with close to no flow. A sliding mechanism is placed under the funnel to ensure the complete stop of powder flow.

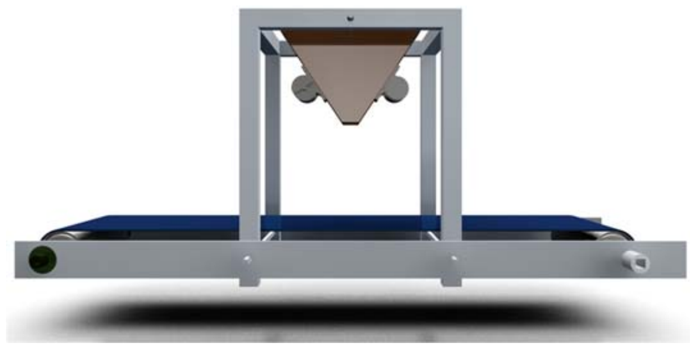


Figure 16. Depicts the assembled view of Design #6, final design selection.

The bottom portion of the coating machine has the conveyer belt system. The conveyer belt system is made possible with the use of 36 inch long flat steel bars. Two identical steel bars are bolted to either side of the funnel, perpendicular to the long side of the funnel. Three 7/16 inch hexagonal sockets and a 3-printed hexagonal to round adapter were used to attach two 1.9 inch aluminum rollers onto the ends of the flat steel bars. Two of the sockets are used to hold the free rolling roller. The third socket is used along with the 3-D printed adapter to hold the driver roller. On the driver roller side, the socket and

Figure 17.Image of mending plate used to lower the funnel to the appropriate height for dispersion.

adapter sit on bearings. The bearings are necessary, because the driver roller is forcibly turned by a stepper motor attached to the adapter. The adapter was needed to be able to transfer the rotation from the round stepper motor shaft to the hexagonal shaft of the driver roller. A thin 1/32 inch rubber belt bounds the two rollers to complete the conveyer belt system.

The rolling press from design #5 is out of commission. A backup flat hydraulic press machine is to be used as the final step of the coating process. After the anode is uniformly coated, the anode is covered in a nonstick plastic wrap and placed on the press machine. If the humidity and SLMP thickness conditions are in order, the black SLMP will turn a shiny metallic grey after the pressing.

G. Evolution of Design

Once the decision between the dry method and wet method of applying SLMP onto the anode was made six dry method concepts were designed. The wet method was ruled out due to the predicted high cost compared to the dry method. The safety hazards, process time, and portability all ranked lower than the dry method. The wet method was also already attempted by General Capacitors. The alternative was attractive enough to make reality.

A system having all the key components needed from start to finish in one machine were attempted to be designed. A successful coating machine system required to have a way to disperse the SLMP onto the anode, a technique to make sure the SLMP sticks to the anode, and a technique to cut the anode. A funnel satisfied the dispersion of SLMP onto the anode. A press machine with enough pressure could cause the SLMP to stick to the anode. A punch, knife, or scissors could cut the processed anode to a desired shape. One of the biggest obstacles to these designs was the press machine. Coating machine designs #1, 3, and 4 had rollers in compression with springs. The amount of force needed to break the outer carbon coating of SLMP was not going to be achieved with a simple spring and roller mechanism. The next option was to build a homemade hydraulic arm to press, as depicted in design #2. This design would utilize two hydraulic arms, one with a roller to press the anode and one to punch a shape in the anode. These hydraulic arms could have been made, but it would have been time consuming and costly. It was only after creating designs #1-4 that it was discovered that the sponsor had a rolling press and a flat press in the Aero-Propulsion Mechatronics and Energy (AME) Center the team could use.

The next obstacle to be overcome was the mesh attachment method. The main difference between design #5 and design #6 is the mesh placements. Design #5 has both interior and exterior meshes. Design #6 only has interior meshes. Both are separate machine systems from the press. The rolling press was the first choice between the roller and flat press. The rolling press can be fed an arbitrarily long anode without stopping, and a therefore faster process time. The flat press constrains the length of the anode to the length and width of the pressing blocks. The flat press was to be used, due to the rolling press being out of commission.

H. Evaluation of Design Concepts

Based on the layout, various components, strengths, and weakness of each design as discussed above in section III.B. the design concepts will be given a score of 1-10(10 being the best) in eight different selection criteria. The score is then multiplied by a weight factor determined by the relevance of the selection criteria defined. The design with the best overall weighted total will then be selected as our optimum design. Below in table 2, are the results of our decision matrix comparing our concepts.

Table 1. Decision Matrix used to make design concept selections. Score is 1-10, 10 being the best. The weighted score will determine the best design.

			Design Concepts					
		Weight	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6
Selection Criteria	Safety	20%	8	6	7	7	9	9
	Affordability	20%	8	6	10	6	8	9
	Ease to use	10%	8	7	6	5	9	9
	Ease of repair	10%	8	5	9	5	9	9
	Durability	10%	6	7	5	6	6	8
	Power consumption	5%	6	5	7	7	6	9
	Portability	5%	7	7	4	8	9	9
	Powder Dispersion	20%	8	8	6	6	8	9
Total			59	51	54	50	67	71
Weighted Total			7.65	6.5	7.15	6.15	8.15	8.88

1. Criteria, Method

The selection criteria used to determine the optimum design is divided into eight categories: safety, affordability, ease to use, ease to repair, durability, power consumption, portability, and powder dispersion. These eight criteria are subdivided further into major and minor categories. Each category highlights a specific need in the system's design that will be crucial to a successful concept.

Safety is one of three major categories. Our project revolves around the use of stabilized lithium metal powder, as mentioned above in section I, lithium is an extremely reactive and flammable element that must be handled with the utmost care and attention. Our designs must ensure that that the lithium will not be exposed to humidity or to anything that may cause it to ignite. Our concept must always guarantee the user's wellbeing. Safety has a weight factor of 20%.

Affordability is another major category. Since each project is allocated a specific budget at the beginning of our team assignments, it is necessary to be realistic with each concept. Some ideas will incorporate unique and intrinsic components that require manual labor and a significant amount of money. Although innovation and original design is important and favored, if the concept is out of reach, the concept remains only an idea. Our budget must be able to cover any expense, such as raw materials, payment for labor for machined components, various meshes, funnels, rollers, wires, and a number of electrical components. Affordability will be a major factor in whether a design can be constructed, this criteria has a weight factor of 20%.

Ease to use is how simple a design is to operate for a user. This criterion has a weight factor of 10%. Although ease to use is not what a design is focused on, it is still an important part to be taken into consideration in the selection process. Although we are currently making a prototype machine if we wish for our mechanism is to be used in a fabrication line, its ease of use is a factor that will be needed and expected.

Ease of repair is the category that ranks a design's maintainability. Whether or not a design uses standard parts that can be purchased in bulk for maintenance or if the part has to special order to be fabricated. The weight factor for ease of repair is 10%.

Durability is directly related to the precedent category ease of repair. This category ranks a concept's cyclic life, thus its weight factor is 10%. Our customer expects a machine that will function for a reasonable period of time before any issues arise. Our concepts must be well thought out to ensure that it will function properly each cycle as well as a certain cycle life.

Power consumption is a necessary criterion to know how much power will be needed to sustain our prototype machine's operations. Each design has different components that will rely on certain electrical devices that will need power to run. This category clearly shows which designs will require more power supplies, thus essentially cost more to operate. This criterion has a weight factor of 5%.

Portability is another minor category. This ranks the design's ability to be moved as well as its relative weight. A design's portability is not crucial in the prototype stage, but if the design is to be mass-produced it can be an issue. Portability has a weight factor of 5% as of current, but in subsequent stages of fabrication this may change.

The last selection criteria is powder dispersion, this is the third major category. Our project is centered on the ability of our mechanism producing a layer of stabilized lithium metal powder onto an anode. The ability of a design to disperse this lithium metal powder is critical to our goal. If a design is unable to disperse an acceptable amount of lithium then the design is essential deemed a failed design. This criterion has a weight factor of 20%.

2. Selection of Optimum

Table 2 This table shows the rank of each design with their weighted totals.

Concept Selection		
Design Concept	Ranking	Weighted Total
Design #1	3nd	7.65
Design #2	5th	6.5
Design #3	4rd	7.15
Design #4	6th	6.15
Design #5	2nd	8.15
Design #6	1st	8.88

Based on the result from the decision matrix in table 3, the optimum selection was determined to be design #6. It was scored a nine in safety; this is based on the fact that this design was sized to be operated within dry room to ensure user safety. Also the frame design in this specific concept captured excess SLMP particles within the plexiglass encasing so that the user would not be under the risk of inhaling or ingesting SLMP. In the criteria of affordability the design received a score of eight. The overall cost of this design has been estimated to be within our general budget thus can be considered as our optimum choice in terms of affordability. For the criterion of ease to use, the design was given a score of nine. It will be directly controlled using the MCU controller, discussed in section III.A.2, that will allow for any input necessary to operate the machine. In terms of ease of repair, the design received a score of nine. Most of parts that are necessary to construct this mechanism are standard parts that can be store bought and are available at a number of locations. This directly correlates to the scored given for durability, eight. Although this mechanism uses standard part it is not indestructible, meshes can be easily broken a motor can burnout after being in operation for such long periods of time. This design was determined to have a score of nine in power consumption due to the number of motors and electrical components that will be necessary to power the machine. For portability this design received a nine. It is sized to be used within a dry room, thus it is relatively compact and will be easy to transport. In the final criterion, powder dispersion, the design scored eight. The total of the design was determined to be 71. Its weighted total was determined to be an 8.88 out of 10.

This design scored highly in the selection criteria of: safety, affordability, ease to use, ease of repair, portability, power consumption, and powder dispersion. Although it did not score as well in durability, we determined that this design concept was the most reasonable selection. It is an economical design that will keep the user safe during the coating process. Although its durability is scored an 8 out of 10, this design is simple to operate and quick to repair which means any repair that may be necessary can be fixed quickly without any major damage to operation timelines. Design #6 was selected as the Final Design.

3. Electrical Components for Final Design Selection

There are many components in our design that will require power and will need to be controlled. Therefore it is important that we begin with an adequately sized power

Table 3. This table shows the power consumption of the system

Component	Nominal Voltage (V)	Maximum Current (A)	Power Consumed (W)
Stepper Motor	12	1.7	20.4
(2) DC Motors	12	0.07	1.68
Cooling Fan	12	0.02	0.24
LCD Display	5	0.1	0.5
		Total Power	22.82

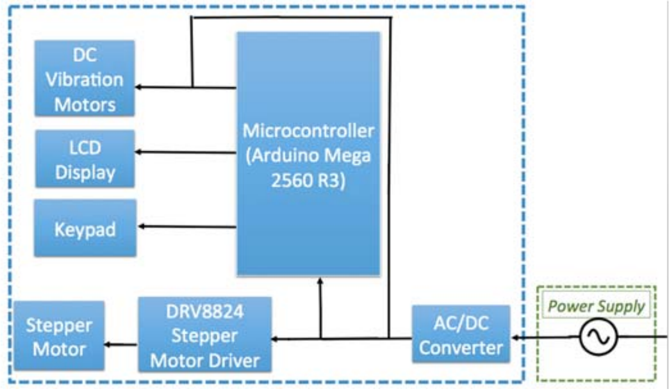


Figure 18. Depicts the block diagram of the electrical system overview.

Figure 19. An image of 12 V, 1.7A, in geared bipolar stepper motor.

supply which has been determined using the nominal voltage of each component and their peak currents as seen in Table 3 the power consumption is around 23 watts. The power supply for this machine is 12V, 5A which will supply up to 60 watts and allow for additional components to be added if needed in the future. A system overview of how all electrical components communicate and how they are powered can be found in figure 20. An Arduino Mega 2560 has been programmed using the Arduino language to control the machine. This MCU has 54 Digital I/O pins which is a major benefit of this MCU since it will need to control a motor driver, LCD, keypad, stepper motor, and 2 DC vibration motors. Essentially the program will begin by accepting an input from the user through the keypad and then will convert this length input into the proper number of steps for the stepper motor to turn. The conveyor belt will then move a fixed distance to the funnel. Once under the funnel the vibration motors will be powered ON while the program begins a loop that will send the electrode back and forward each 5 times. Once the loop has been completed the program will power OFF the DC motors and will move the electrode a set distance until it reaches the end of the funnel. In Appendix I there is a detailed flow chart that can better describe the functionality of the program.

Table 4. Relationship of input to stepper conversion.

Input (mm)	Steps
50	1684
60	2021
70	2357
80	2694
90	3031
100	3368
110	3705
120	4042
130	4379
140	4715
150	5052
160	5389
170	5726
180	6063
190	6400
200	673
210	7073
220	7410
230	7747
240	8084
250	8421

A 12V, 1.7A, 30 Kg*cm stepper motor seen in figure 21 is used to turn the conveyor belt. Some benefits of this stepper motor is that it has a high holding torque and the microstepping function will allow for extreme accuracy with each step resulting in only 0.03mm of linear movement. Table 3 shows the relationship of the amount of steps and the linear motion of the conveyor belt. This motor is controlled by the DRV8825 High Current Stepper Motor Driver, which can provide up to 2.2A when using a heat sink. Since this chip does get hot a metal heat sink has been placed on top of the motor driver. Additionally a 12V DC cooling fan has been mounted inside the electrical box to help ensure that the motor driver does not reach the thermal temperature shut off point. (2) 12V DC motors with offset masses will be used to vibrate the funnel. These are connected to the MCU and the 12V power supply through a BJT with the power supply connected to the collector, MCU connected to the base, and motor on the emitter. There is also a diode placed in parallel to the motors to prevent back currents from harming the circuit.

Some other electronics that our board contains is a 16X2 LCD display and a 4X3 matrix keypad. These will allow for the machine to have user interface. When powered ON the LCD display will ask for the user to "Enter Length" and the user will use the 3X4 numerical keypad to enter their desired length in cm using the '#' symbol to select a value and '*' to re-enter value (See Table 5 for keypad options). If the '*'key is pressed at any time the LCD will display "Re-enter length" and the process will be repeated. Also if the length entered is less than 5 cm or greater than 25 cm the LCD will clear the value displaying "invalid length" and a new length will be needed to be entered. Once a valid length is entered and the '#' key is pressed the coating process will begin. Once the machine is done coating the program will loop around and the same process can be repeated. Both the LCD and keypad will be powered through the 5V output on the Arduino MCU and draw minimal power. A detailed wiring diagram of the LCD and keypad to an Arduino UNO MCU can be seen in Appendix.

Table 5. Table shows the keypad options for the system.

Key Pressed	Result
*	Re-enter Length
#	Select Length
Value < 5 or > 25	Invalid Length: Re-enter Length
Value > 5 and < 25	Begin Coating Process

IV. Final Design

As discussed in the section III.G.b, the final selection was elected to be design #6. This design approaches the coating application by utilizing the dry dispersion method. It is a cost-effective prototype proposal that will be safe to the user, easy to use and repair, transportable, and will produce the highest dispersion capabilities of all designs conceptualized.

This design, although simple, will require the user to have an in-depth knowledge of all its components and safety measures installed. The coating of Stabilized Lithium metal powder (SLMP) is hazardous and the user must read all of the operations manual and the Material Safety Data Sheet before employing the use of the prototype machine.

The operations manual, section IV.A, will give a breakdown of the functional analysis of the system, product specifications, step-by-step

Figure 20. Front view of final design, rendered image using ProE.

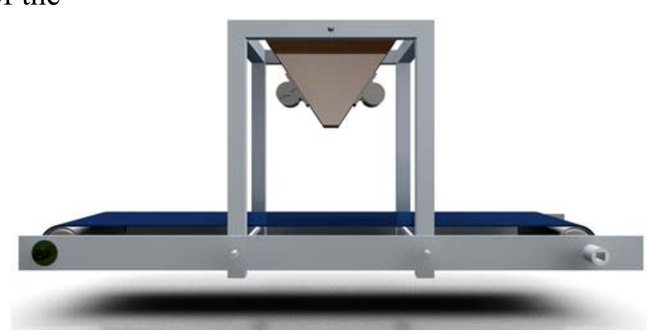


Figure 21. Side view of the Final Design, rendered using ProE.

procedure of any assembly or machining (which can be used along with the technical drawings found in the appendix), and maintenance procedures. The design for manufacturing, reliability, and economics, section IV.B will cover the reasons behind fabrication decisions, the lifespan of certain components that are under use, and the economic feasibility of the design itself as compared to other attempts.

A. Operations Manual

1. Functional Analysis / Functional Diagram

The function of the Stabilized Lithium Metal Powder (SLMP) coating prototype is to apply a uniform layer of stabilized lithium metal powder to the anode electrode of a Li-ion battery. The prototype has the ability to handle varying sized electrodes. This prototype machine implements a dry dispersion method in a semi-automatic process.

The prototype will function in a step-by-step process that will handle the dispersion of the SLMP. First stage, a specific size anode copper sheet is placed at the beginning of the conveyor belt system. The user then inputs the length into the keypad and this data can be observed on the LCD screen, then the start button is pressed. This input data is sent to the MCU, which in turn sends output to start the coating process. The motors run the conveyor belt system to start rotating. As the conveyor belt moves the anode sheet further down the line, and into the funnel housing, the vibration actuators vigorously oscillate the funnel cavity (holding the SLMP). The vibration actuators facilitate the flow of the powder through a series of micro-meshes. These meshes are set in the funnel and mitigate the agglomeration of the SLMP material. SLMP falls though the bottom orifice of the funnel onto the anode copper sheet. The MCU program is set to move the conveyor and anode back and forth five times to ensure a uniform coating layer. Once the anode and program is complete the conveyor moves the anode to the exit of the side prototype and stops prior to reaching the drop-off of the conveyor belt system.

2. Project/Product specification

Arduino Mega 2560

The electrical system is managed by an Arduino Mega 2560 microcontroller (MCU) board. This board runs on an 8-bit Atmel Microcontroller with 16 in-system programmable flash, according to Atmel Corporation. The clock speed is 16 MHz, the flash memory for this board is 256 KB and SRAM is 8 KB. This MCU has six different sleep modes; idle, ADC noise reduction, power save, power-down, standby, and extended standby. It is rated for a temperature range of -40 degrees Celsius to 85 degrees Celsius industrial. The data retention life span is 20-100 years depending on the ambient temperature. This MCU board has 54 digital input/output pins, some of which can be used as PWM outputs. Other specifications include 16 analog inputs, 4 UARTs (hardware serial ports), a 16 oscillator, USB connection, a power jack, and a reset button. The Arduino is powered via the power jack by a 12 V AC–to–DC adapter. The operating voltage is 5 V, input voltage is recommended for a range of 7 – 12 V. The DC current per I/O pin is 40 mA. The Arduino software allows for facilitated communication with a computer, this allows simple textual data to be transmitted to and from the board. The approximate length and width of the circuit board is 4 inches by 2.1 inches and its weight is 37 g. See appendix for Arduino Mega schematics.

Keypad

A membrane 3x4 matrix numeric keypad is used input of the various lengths that will be coated. The keypad is made of a thin, flexible membrane material with an adhesive backing. Only seven microcontroller pins are needed, since the keys are connected into a matrix. The approximate weight of the keypad is 7.5 grams. This keypad includes 85 mm long 7-pin 0.1 inch pitch connector that easily connects to the breadboard. The keypad dimensions are as follows: 70mm x 77mm x 1mm.

Stepper Motor

A 12V geared bipolar stepper motor is implemented into the design to rotate the conveyor belt system. The stepper motor is rated at 1.7 Amps and weighs approximately 503 grams. Other specifications include; mounting plate size is NEMA – 17, wire length 300mm, Shaft diameter 8m. The motor is rated to supply a maximum torque of 77 kg-cm. However, the gearbox is only rated for 30 kg-cm of continuous torque, and 80 kg-cm for brief overloads. It has a step accuracy of 5 percent and step angle of 0.067 degrees. The Shaft maximum axial load is 49.1 N and the shaft maximum radial load is 98.1 N. It is recommended that the gearbox stepper not be loaded beyond the torque rating of the gearbox, as this will shorten the useful life expectancy.

LCD

A 16X2 character LCD is used to communicate with the user. This is a light weight LCD with a blue background which takes a 5V input voltage.

Actuators (DC Vibrators)

Two 12V DC motors with offset masses are used to vibrate the funnel and begin to flow rate. One motor is set at 3000 RPMs and the other is at 4000 RPMs, allowing for different frequencies to shake the funnel preventing backups. Both motors have similar sizes with masses of approximately 59g, total length 39 mm, and are made out of a metallic material.

Conveyor Belt System

The frame of the conveyor belt system consists of A36 Steel flat bars; these bars are attached to the funnel frame and hold the rollers/belt in place. The bars dimensions include; length 35 inches and a height of 2 inches. The rollers are used to support and move the conveyor belt. The dimensions for the rollers are 1.9" in diameter and 12" long. An adapter is used to link the stepper motor to the rollers in order to achieve lateral movement of the conveyor belt. See appendix figure 3 for reference to adapter. This adapter was constructed via a 3D printer with following dimensions; total length of adapter is 2.5 inches and total outer diameter is 0.67 inches, the circular shaft orifice is 1 inch in length and 8mm in diameter, the hexagonal orifice is 1.3 inch in length and 0.44 inches in diameter.

Funnel and Frame

The funnel is supported by the steel frame while hovering over the conveyor belt system. The rectangular angled walls of the funnel are 5.75 inches in width and 7.211 inches in length and the straight walls have a width of 8.90 and 7.211 inches. The funnel top opening dimensions are 5.5 inches in width and 7.40 inches in length, while the bottom opening dimensions are 1 inch in width and 7.40 inches in length. The legs and top square of the frame all have an inside width of 0.75 inches, and an outside width of 1 inch. The cubical legs have a height of 15 inches, while the square top tower has dimensions of 10 x 10 inches.

Meshes

The meshes will control the flow rate of the SLMP as it is loaded into the funnel and then vibrated. Two different meshes will be utilized in the prototype. The meshes are made out of 304 Stainless Steel wire cloth. The first mesh, placed 2.4 inches from the top of the funnel, is a 200x 200 count with an opening diameter of 73.6 μm, while the second mesh, placed 6.3 inches within the funnel from the top, is a 250x 250 count with an opening diameter of 60μm.

3. Product Assembly

The assembly of the prototype machine is to be completed in a series of steps. The components necessary and their corresponding prices can be found in the appendix 1. The first step is the machining process in which certain components will be fabricated to specific desired dimensions. The next step is the joining or bonding of specific machined parts that must be assembled in a certain order to ensure a complete and functioning SLMP coating machine.

a) Machining

A local welding and fabrication workshop, Tallahassee Welding, was commissioned to complete all the machining of this prototype. The final products are described below; technical engineering drawings of each particular component, utilized in the assembly process, can be found in the appendix.

1) Frame/Body

(a) The frame is used to hold the funnel and support the conveyor belt system, this is displayed in the appendix in figure 2. 1" inch A36 Steel square tubing is the material that is used to make the frame. The total dimensions of the frame the 11" by 11" by 12" with the top pieces of frame connected. These top bars have a ⅜" inch hole centered in the middle to allow for a rod to pass through which will hold the funnel. These particular parts will be discussed below. The legs of the frame were each cut to 11" in length and with a ⅜" hole drilled 1¾" from the bottom. These holes are used to connect the frame and give rigidity to the conveyor belt system that will be placed below the funnel. These frame legs are also made of A36 Steel, which is the same material then entire structure is made of. These square tubes are then welded together using steel welding filament. All the welds were then sanded to give a clean finish. See Appendix figure 2 for CAD drawing of frame

2) Motor Adapter

i. A 3-D printed adapter is used to connect the motor to the hexagonal shaft of driving roller, this part is displayed in the appendix in figure 3. The adapter's outside diameter is 25 mm and is 2 ½" long. One end of the adapter has a 7/16" Hex. The other end has an 8mm opening. This 3D printed component is made of ABS plastic as seen in appendix figure 3.

3) Conveyor Bars (2)

i. The conveyor belt bars are bolted into the frame of the funnel and to hold the two rollers, this is displayed in the appendix in figure 5. These bars are cut from a 6' long, 2" wide, ¼" thick A36 steel flat bar. The bar was cut in half to make two 3' flat bars. Then center drilled 4 separate holes. Two holes of diameter ⅜" were drilled, and a ½" and a 1 ¼" were also center drilled into the flat bar. The 1 ¼" hole will hold the bearing connected to the driving roller, while the ½" hole will hold a sprocket attached to the free roller.

(b) A 2" long and 7/16" sprocket (2) and a 25mm outer diameter of a bearing (2) are attached to the conveyor bars. A plastic epoxy is applied to the inside of each of these holes. This is to ensure a tight fit for each inserted part. After the epoxy sets a layer of JB Weld is added to the outside to attach each part to the conveyor bar to add rigidity to the connection.

(c) Two more parts are then attached to the bearings. On one side another 2" long 7/16" sprocket is attached. Due to the fit being so snug only a layer of electrical tape is necessary to make a sufficient tight fit. On the other side of the conveyor is a 3D printed plastic adapter. This is also tightened to the bearing by adding a layer of electric tape to prevent the adapter from slipping out.

4) Funnel

i. The funnel is made of A36 ¼" thick steel plate. This funnel is composed of two identical triangular pieces and two identical rectangular pieces. These four parts are welded with steel filament, this is displayed in the appendix in figure 4. All edges of the funnel were then machined down to give a smooth finish. The particular dimensions of the funnel are included in the appendix of this paper.

(d) The funnel has four 1" threaded steel rods attached to the outside of the funnel. These rods are 2" apart, and hold the bracket attached to the actuators that vibrate the funnel. These rods are super glued to place the rod in position, and then JB Welded to strengthen its positioning.

i. See appendix figure 4 for CAD drawing of funnel

5) Conveyor Belt

Cut the conveyor belt to the desired length of 75". Then attach the two by applying super glue to the side of each to stabilize the two ends connected. To add additional strength two layers of plastic epoxy is applied to the belt.

6) Emergency Stopper

The emergency stopper is a manual slide, made out of 1/8" thick aluminum metal sheet which is cut into an 8" inch by 1" inch strip. The left end of the stopper, 2" inches in length will be bent at a 90 degree angle to allow for facilitation of pulling and pushing of the stopper. This part must then be bent and sanded to make the edges smooth and safe for handling.

7) Cross Bar

The cross bar is made out of 3/8" threaded steel. It was cut to 12 ¾", and the ends were belt sanded to ensure that bolts could easily go on. This bar goes through the holes made at the top of the tower. Connecting the lowering bars to the funnel

8) Electrical Box

The Electrical box will house the Arduino Mega 2560 MCU, the breadboard, and all the wires. This will initially be placed on the ground in a Plexiglas enclosure next to the coating machine. A 16X2 LCD and Keypad will be attached in the Plexiglas enclosure allowing for easy access.

i. *Stepper Motor*

The stepper motor will be connected to a 12 V source and an H-bridge which will give the motor bi-direction capabilities.

(e) *DC Vibrators*

The 2 DC Vibrators which are connected to the outside of the funnel will be wired along the frame and into the electrical box. A BJT will be used to control the motors by connecting the motors to the emitter, the Arduino to the base, and the 12V power supply to the collector. Additionally, a diode is placed in parallel to the motor to prevent back currents.

b) Final Assembly

a) Conveyor Assembly

(a) One conveyor bar is attached to the outside of the tower. This is achieved by using (2) 2" bolts that are attached to a locking nut.

(b) The driving roller and other roller are attached to their respective fastener.

(c) The conveyor belt is slid around both rollers

(d) The other conveyor belt is then attached to the rollers using their appropriate fasteners. When positioned into their appropriate hex's. The conveyor bar is attached to the tower using two 2" long by ⅜" diameter bolts fastened to a locking nut. Locking nuts are used due to the vibration that the coating machine will experience during coating.

9) Funnel Assembly

The funnel attaches to two "ladder" like steel flat bars. These bars have a variety of holes to allow the funnel to be lower or raised to the desired dispersion height. This ladder should assist in dampening the vibrations felt by the tower and conveyor belt. The ladder bars are attached to the funnel by using the cross bar, these are secured by using locking nuts on all ends of the cross bar.

i. *Another cross bar is used on the lower end of the "ladder" to attach the funnel. This again is secured by adding locking bolts to prevent the funnel from movement.*

(e) The slide stopper is inserted in the bottom of the funnel, and is secured due to the integrated positioning of the funnel.

(f) Fasten the meshes along the walls of the funnel. The 1st mesh, 250x250 count, will be adhered to the walls at 6.3 inches as measured from the top of the funnel.

(g) The 2nd mesh, 200x200, will be placed at 2.4 inches from the top of the funnel and fastened.

4. Operation Instruction

When operating the Stabilized Lithium Metal Powder coating machine safety is essential. Proper protective equipment such as gloves, masks, eye protection, lab coats, closed toe shoes, proper fire extinguisher, etc. should be wore and accessible at all times. Once the proper safety measures are taken and the machine is in a dry room the user may begin operation of the machine. The first step is to plug in the AC/DC converter into a 120V wall outlet to power the machine. Next an acceptable amount of SLMP is to be loaded in the hopper (at least 3 cm of SLMP above the highest mesh and no higher than 2 cm below the top of the funnel). Once the SLMP is properly loaded into the machine the user can then remove the stopping piece at the outlet of the funnel to allow for SLMP to flow. Now the machine is ready to be powered up and the switch can be flipped from 'OFF' to 'ON' allowing for power to be provided to the Arduino and motors. Now that the Arduino has power the user will place the electrode at the designated starting line. A 16X2 LCD display will ask for the user to "Enter Length" and the user will use the 3X4 numerical keypad to enter their desired length in cm using the '#' symbol to select a value and '*' to re-enter value (See Table 1 for keypad options). If the '*'key is pressed at any time the LCD will display "Re-enter length" and the process will be repeated. Also if the length entered is less than 5 cm or greater than 25 cm the LCD will clear the value displaying "invalid length" and a new length will be needed to be entered. Once a valid length is entered and the '#' key is pressed the coating process will begin. The conveyor belt will begin to turn and the LCD will display "Coating". During the coating process the conveyor belt will move the anode under the funnel where the DC vibrators will be turned on to start to flow of SLMP. The anode will be moved back and forward 5 times to ensure a uniform coating layer. Once the anode has passed through its 5th time the vibration will stop and the anode will be moved to the end of the conveyor belt and the coating processed is now finished. When finished,

Table 6. Key Pad options that the user will input to control prototype functions.

Key Pressed	Result
*	Re-enter Length
#	Select Length
Value < 5 or > 25	Invalid Length: Re-enter Length
Value > 5 and < 25	Begin Coating Process

the LCD will display “Coat Again?” If the ‘#’ key is pressed the same procedure will occur, if not then the machine will be powered off.

5. Troubleshooting

When dealing with the element, Lithium, safety is essential. Although this is a stabilized version of the Lithium there are still many risks and safety should be of high importance. Some potential problems that can be associated with Lithium are the possibility of combustion or ignition due to either contact with water, humidity, or a static charge. It is important to have an appropriate fire extinguisher nearby at all times such as Copper Powder, Graphite, or Lith-X ® and to never use water or sand when attempting to extinguish a fire caused by the SLMP. It is also important to wear the appropriate PPE (safety glasses, dust masks, gloves, and a laboratory coat) and to only operate the coating machine within a dry room that has humidity less than 0.5%. An ON/OFF switch will be located on the machine that will instantly kill power to the machine if there is ever a safety issue, a piece of equipment breaks, or any other emergency is encountered. See appendix to reference the SLMP materials data sheet.

Furthermore, when loading the SLMP it is important to load an appropriate amount into the hopper. If the funnel is overloaded there is a risk of the SLMP vibrating out of the top of the funnel causing it to spill outside of the conveyor belt. However if not enough SLMP is loaded into the hopper then the desired flow rate may not be accomplished and/or not enough SLMP will be loaded onto the anode. To prevent any problems with spillage and to make our machine as safe as possible the hopper will be placed inside of a Plexiglas border. The Plexiglas will fully enclose and cover the top of the funnel so that the only way to load the funnel is by opening the top of the container by pulling on the handle. Once loaded the top piece of Plexiglas need to be returned to the shut position. Another safety measure installed to ensure that the SLMP will be confined to the funnel is the emergency stopper. The stopper can impede the flow of SLMP by sliding it into a notched crevice at the outlet of the funnel when necessary. This is to prevent the SLMP from falling through the funnel and becoming a hazard when not in use. It is important to remember that at all times when handling SLMP it is always best to proceed in a safe manner and to error on the side of caution.

6. Regular Maintenance

a) Daily Maintenance

1. Check the mesh to see that the opening is not clogged and the SLMP is free to flow. It might be necessary to use an airbrush to blow out any clogged openings.

10) Check the bearing connected rollers to ensure that they are tight. If loose or tape has lost its adhesion it will be necessary to disassemble the conveyor and apply more tape until it deemed a secure fit with the bearing.

11) Check all nuts connected to the funnel to ensure they are still locked and tight

12) Clean out entire funnel, this will get rid of SLMP particles that are too big to fit between the mesh openings to prevent build ups and ensure there is a steady flow rate.

13) Apply grease to the bearing to ensure rotation is still sufficient. Since the machine being used in a dry room the bearings need to be tested regularly.

b) Key Component Replacement

We designed our machine to be as reliable as possible to minimize the chance of components breaking or needing replacement due to component failure. However after a long period of time the following components may need to be replaced.

1. Meshes need to be cleaned regularly and changed whenever there is an issue such as wear, rips, bends, etc.

14) DC motors and stepper motors may need to be replaced after an extended period of use.

15) The Driving motor adapter is likely to wear out of time since it is made out of ABS plastic and connects to metal pieces.

c) Spare Parts

Some Additional parts/pieces that may be needed nearby to ensure that downtime is limited if an error occurs are:

I. Additional Meshes to replace worn meshes
A. Can be purchased through Grainger
II. JB WELD to fix any deterioration in the conveyor
A. Can be purchased through Home Depot
III. Plastic Epoxy to fix any deterioration in the conveyor
A. Can be purchased through Home Depot
IV. DC vibrators in case of a burnt out motor
A. 12V 3000 RPM DC vibrating motors.
V. Driving motor adapter, since made out of ABS plastic deterioration is predicted. Having an additional adapter will prevent any downtime when the machine is needed.
A. Will need to be 3D printed according to the specific dimensions.
VI. Additional driving motor. This will also allow for limited downtime when a motor burns out.
A. 12V, 30N*M stepper motor with 4 wires and 8 mm shaft diameter

B. Design for Manufacturing, Reliability, and Economics

1. Design for Manufacturing

The first step in the manufacturing process of the coating machine for SLMP is to construct the frame and funnel. The frame and funnel were designed using Creo Parametric 2.0. The construction of the frame and funnel were outsourced to Metal Fabrication and sales of Tallahassee. Mechanical drawings from Creo were used to ensure exact dimensioning when machining the frame and funnel. It took Metal Fabrication and sales of Tallahassee a total of 5 business days to finish both components. This manufacturing decision was made due to the time constraints of the project timelines.

Once the frame and funnel were completed the next step of manufacturing was the purchase and mounting of appropriate vibration motors. The actuators, or DC motors with offset weights, purchased have varying amplitudes and voltages to produce significant vibrations within the funnel and meshes. The actuators were attached to the two long sides of the funnel with motor brackets and JB weld epoxy glue. This was done to ensure that the integrity of the funnel, which houses the loaded SLMP. The SLMP must not be obstructed as our goal to produced a uniform and constant flow rate onto the anode. The JB weld was a quick and inexpensive method in which to fasten the vibrators.

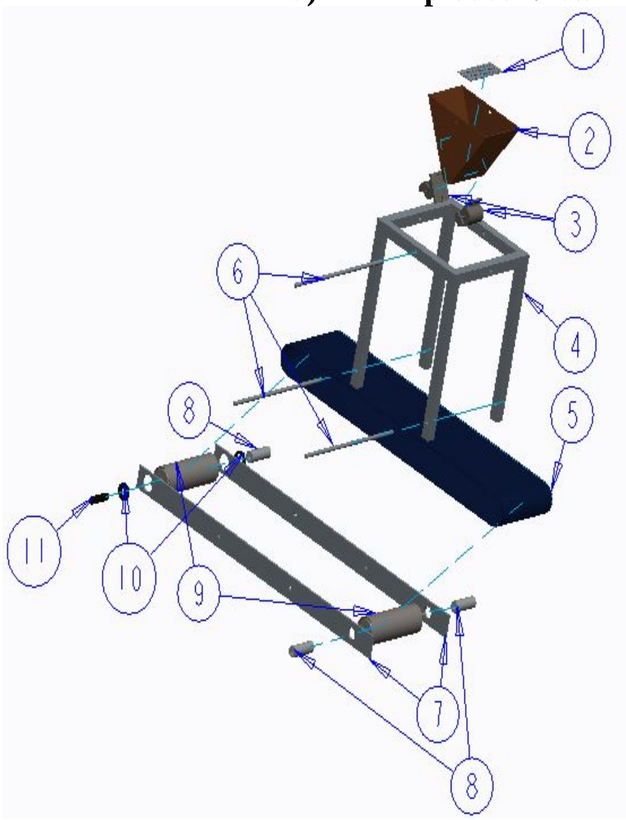
Two flat steel bars were bolted along the bottom of frame's legs on each side. The bolts go into predrilled holes in the frame. To construct the conveyor belt, two rollers were fixed onto the two flat steel bars. One of the rollers is the driver and the other is idle rolling. The driver roller was fitted with radial double shielded bearings to safeguard frictionless and continuous movement. The bed of the conveyor belt was made from a PVC belt that is glued together with epoxy. The PVC belt is in tension with the two rollers. Brackets were used to make the conveyor level. This frame was necessary to guarantee that the conveyor belt would be set at a fixed distance, the belting material would be constantly help in sufficient tension, and to facilitate the movement of the prototype. A hexagonal female to male round adapter was 3-D printed in the machine shop at FAMU-FSU College of Engineering, with the help of Professor Keith Larson. This adapter was essential to the assembly of the prototype to couple the hexagonal shaft of the roller and the shaft of the stepper motor. The stepper motor was fixed onto the shaft of the driver roller via the hex to round adapter and steel flat bar.

The meshes purchased were selected in 3 differing opening diameters in a steel wire cloth material. This material was selected for its durability and rigidity. These meshes will be able to be fastened in tension to increase particle dispersion and have secure fit along the walls of the funnel fold. Epoxy is used on the side of the meshes to further secure them to the sides of the funnel. This was done to shorten the assembly time to be cost efficient. To enclose the frame and components, plexiglass was glued onto the sides of the frame. The plexiglass on the top of the frame was not glued, but hinged so as to allow an opening to add more SLMP into the funnel. The plexiglass is used as a protective barrier for the user, to guarantee that they do not unknowingly come into contact with SLMP. Holes were drilled through the plexiglass to feed wires from the Arduino to the two motors on the funnel. The stepper motor was also connected to the Arduino.

The assembly process took longer than the project team had initially estimated. Due to procurement issues, such as purchasing order delays, items under back-order, and long shipping periods, manufacturing and assembly time was automatically increased and prolonged. The process step that changed the project timeline most drastically was the purchasing process. A note for future teams attempting this type of the prototype would be place procurement orders as soon as possible, preferable before the 2^{nd} period of the project time line. Procurement had to be completed by individual members of the team to shorten the shipping time and product pick up. The assembly process was allocated a month of labor to complete, the process has now been re-evaluated to require a month and half for full completion. Additional days must be added into the time period due to the 24 hour curing time of the epoxy and JB weld used to attach specific parts. The other days added were due to trouble shoot the prototype design. The troubleshooting included how to securely attach the actuators, meshes, and fasteners to the frame and funnel. The total time of the assembly took 14 days, or 75 real time hours. This approximation does not include the curing time of any epoxy or JB weld. One particular step that took longer than expected was attaching the conveyor belt in tension.

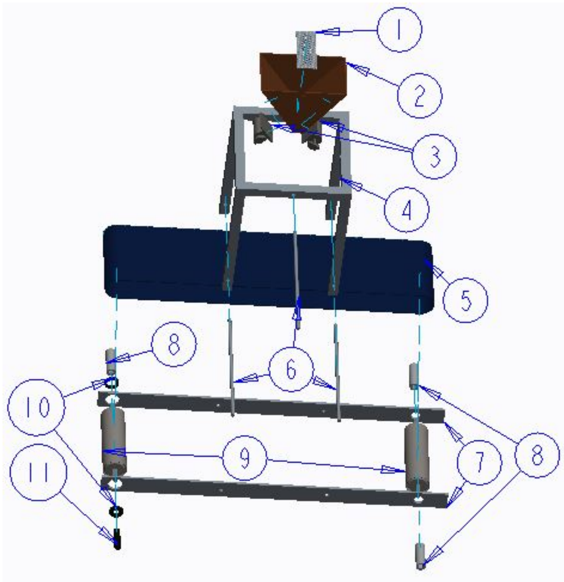
The varying number of components used to assemble the final design prototype are noted to include essential parts that are necessary to produce a high level of quality. This final design was produced with the appropriate quantity of components to ensure that the prototype would have high functionality in the coating process. Some assembly portions did require less invasive structuring than others, for example the vibration actuators were attached to the funnel using metal straps rather than building a encasing to attach to funnel wall. This was done to simplify the design and to create better contact between the funnel wall and the vibration actuators. Other aspects of the final design required more components; this was required in the conveyor system, as it was more complex. The conveyor system needed a high number of components for the structure to work and produce reliable results. Some of the more important parts included; hexagonal socket, bearing, frame flat bars, rollers, conveyor belt and an original adapter to connect the roller to the motor.

a) Exploded View



Bill of Materials		
No.	Part	Quantity
1	Mesh	1
2	Funnel	1
3	Vibrating Motor	2
4	Frame	1
5	Conveyor Belt	1
6	Shaft	3
7	Flat Bar	2
8	Socket	3
9	Roller	2
10	Bearing	2
11	Hex to Round Adapter	1

Figure 22. Shows a detailed exploded of the assembled design in Creo. It is featured alongside the bill of materials.



Bill of Materials		
No.	Part	Quantity
1	Mesh	1
2	Funnel	1
3	Vibrating Motor	2
4	Frame	1
5	Conveyor Belt	1
6	Shaft	3
7	Flat Bar	2
8	Socket	3
9	Roller	2
10	Bearing	2
11	Hex to Round Adapter	1

Figure 23. Exploded view of assembled prototype in Creo, front angle with bill of materials on the side.

2. Design for Reliability

Reliability is a huge aspect of design. Often times, as is the case with this project, time and resources are limited and consequently reliability suffers. The prototype machine is not as reliable as the design group would hope but with the resources allotted, it is reasonably reliable. With that being said, the prototype machine is subject to various modes of failure. In this section all modes of failure will be assessed and discussed, including the design choices made and advice for future work on the design.

The prototype machine performs the task of coating without much strain on the machine. However, with repeated use many of the components fatigue and eventually fail. The component most likely to break is our 3D printed adapter, which was printed with a relatively weak plastic. As shown in the FMEA table found in the appendix in section II, the adapter has the highest risk priority number (RPN) of 240. This part will likely fail within 50 uses of the machine as it has already broken during our troubleshooting of the machine. The failure of this part would mean a cease of operations, as the conveyor system would fail. The hex adapter has since been redesigned as thicker and hopefully more durable. With more resources, this part should be refabricated with a more durable material and through a different fabrication process, such as die-casting.

The second component most likely to fail has been estimated to be the conveyor belt. The belt is held together with an epoxy and is held under tension. As shown in the FMEA table found in the appendix section II, the belt has the second highest RPN of 168. This part will likely fail within 100 uses. The failure of this part would result in a failure of the conveyor system. The belt has been adhered together using a strong epoxy that has an estimated strength of 3,200 psi. In future works, it is recommended that the belt be secured with stronger adhesive or perhaps manufactured as continuous.

The component third most likely to fail is estimated to be the vibrational actuators. Through the coating process these motors are vibrating against the face of the steel funnel and endure considerable strain through repeated use. As shown in the FMEA table found in the appendix in section II, the vibration actuators have the third highest RPN of 144. These eccentric rotating masses are estimated to fail within 125 uses. To reduce the wear on the actuators, electrical tape has been applied to the actuators and it serves to insulate them from the surface of the funnel during use. In future works, it is recommended that the actuators be encased in a protective shell.

Other notable parts likely to fail are the vibration actuator mounts and conveyor belt motor. The motor mounts on the funnel were adhered using J.B. weld. They were secured in this manner due to limited time and resources. This part is likely to fail within 100 uses. As shown in the FMEA table, found in the appendix in section II, the motor mounts have a RPN of 54. The failure of this part would cause a failure of the vibration induction. In future works, it is recommended that the actuators are mounted in a more permanent manner. The conveyor belt motor is a risk as the conveyor system is relatively heavy. Repeated times driving the system, the motor will fatigue and fail. It is likely that this part will fail after 200 uses. Failure of this part would mean a failure of the conveyor system. To combat this risk a high torque motor has been secured to minimize wear on the motor during use. All other risks and potential failures considered are depicted in the FMEA table in section II of the appendix.

FEM analysis was performed using ProE on our preliminary design for our frame with a distributed load to simulate the weight of a loaded funnel. The simulation, depicted in Figure 3 and Figure 4 below, showed that even with loads scaled 2,500 times, the stresses in the structure remained in the negligible region. The results of this simulation are what drove the design team to choose steel for the structure.

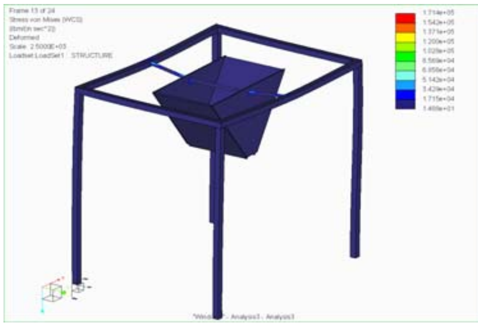


Figure 24.Image of Maximum stress state of the FEM simulation in ProE.

With regular maintenance it's estimated that this machine will last the life of the bearings. The method in which the bearings were secured to the frame, it would deem their replacement difficult. Consequently the life of the prototype is estimated to be equivalent to the life of the bearings. The bearing life was estimated to be 250 million revolutions using Matlab, the script for which can be found in the appendix. The .m script utilized Equation 2 shown below, which yields the life of the bearing in millions of revolutions.

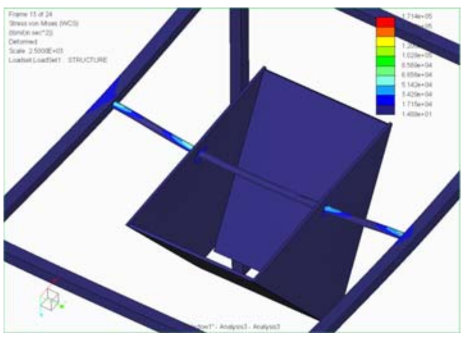


Figure 25. Close up of maximum stress state of FEM simulation.

$$L_{10} = t * rpm * \frac{60min}{hour}$$

Equation 2

3. Design for Economics

The goal of this project is to create a prototype machine that can coat a pre-existing anode with a uniform layer of Stabilized Lithium Metal Powder. From the initial conceptualization, the team's main focus has been on manufacturing a viable and cost-effective prototype machine that will meet our sponsor's needs. Throughout the several design models generated over the course of the project, cost efficiency has continually been one of the major factors in the selection process, along with safety and reliability.

The current technology available for coating SLMP has been recently developed within the last 6 months. This is due to the novelty of Stabilized Lithium Metal Powder as a product as well as being commercially obtainable. Two companies have invested in fabricating prototype machines for coating SLMP: FMC Lithium Corporation and Tokyo Electron Limited.

FMC Lithium Corporation has created a slurry application system, which is estimated to cost around 2 million dollars. It encompasses a conveyor belt system with several rollers that move an anode sheet used as a belt. This belt is sprayed with a mixture of a solvent and SLMP and then heated until the solvent is melted off, leaving on a uniform layer of SLMP on the anode.

Tokyo Electron Limited has invested a significant amount of capital in researching a complex method of application. The basis of the technique is a slurry application, but it employs the use of harmful gases to seal and bond the SLMP to a pre-existing anode. Essentially an anode is placed within a chamber in which it is sprayed with a slurry mixture, and then by utilization of argon gas, the solvent is melted to leave only the SLMP remaining upon the anode surface. The chamber used during the SLMP spraying is a vacuum/depressurized chamber and the nozzle system implemented is very extensive and precise. This prototype machine has been estimated to cost $6 million dollars to manufacture and has a 6-month construction period.

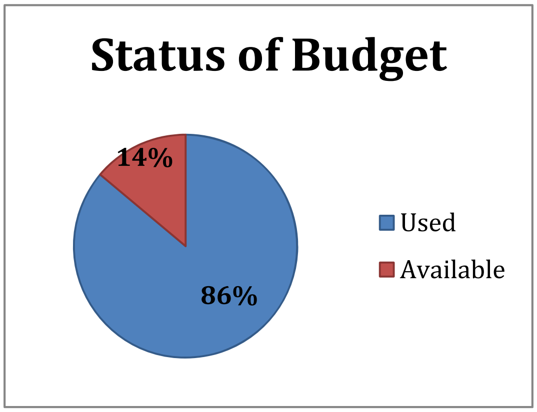


Figure 26. Depicts the budget status of project

The senior design team was given an allotted budget of $2,000 US dollars for the construction of a prototype machine. The selected method of approach, dry powder dispersion, was chosen due to the time constraints of the project, its feasibility, and the elimination of harmful gases and solvents used in the application procedure. The current expenditure of the project has totaled to $1,722.12. The detailed breakdown of the budget can be found in the Appendix, Section III.

Of the $2,000 US dollars, 86% of the budget has been spent, as depicted in Figure 5. The budget apportionment, as seen in Figure 6, was divided into 4 sections: machining, parts for assembly, electrical components, and raw materials. The machining cost accounted for 31% of the spent budget. Although this percentage seems high, it accounts for construction and welding of the part within a 2-day period at a rate of $150 dollars per hour for labor. To reduce the cost of overall prototype, it is recommended to have in-house machining if time permits. The materials for assembly summed to a total of 25% of the budget, $430. 53. The accumulation of electrical components was 40% of the budget depleted, which accounts for $688.84. The remaining 4% of the spent budget was used to purchase raw materials for the construction process.

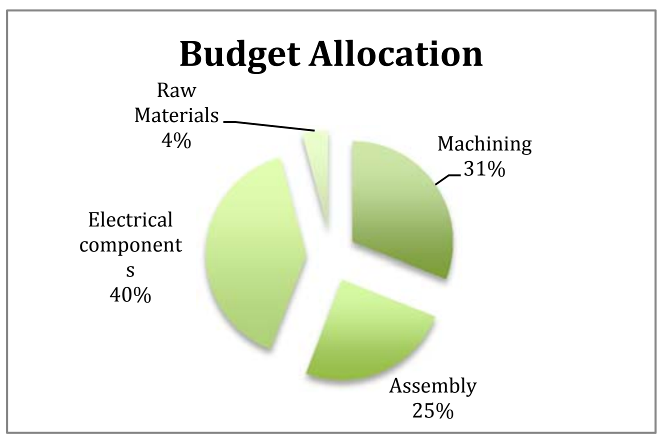


Figure 27. This Graph shows the budget allocation in terms of : Machining, Assembly, Electrical Components, and Raw Materials

Thru the course of the project, numerous design choices were made in order to consolidate time or budgetary limitations. The frame and funnel of the prototype was originally elected to be fabricated in-house at the college of engineering machine shop, however due to the large volume of senior design projects being built, the average wait time for individual part construction was estimated at 2 weeks. The team chose an alternate route in order to speed-up this wait time and commissioned metal fabrication and sales of Tallahassee to construct the frame and funnel. The materials under consideration for this production were A36 Steel and Aluminum. The locale did not have sufficient amounts of the correctly dimensioned Aluminum and the material was under back-order, thus it was decided to create the frame and funnel out of A36 steel. The conveyor belt system was built using individual parts rather than purchasing a cohesive single system due to the cost difference, equating to $5,000 US dollars, which outweighed the calculated labor time the team would be required to perform. In constructing the conveyor belt, the team was able to stay well with-in the designated budget and still progress the overall status of the prototype. The belting and rollers were procured from suppliers that provide replacement parts to pre-existing conveyor systems, thus the shipping time was accelerated. The distribution of the budget used in the construction of each major component or subsystem can be found in Figure 7.

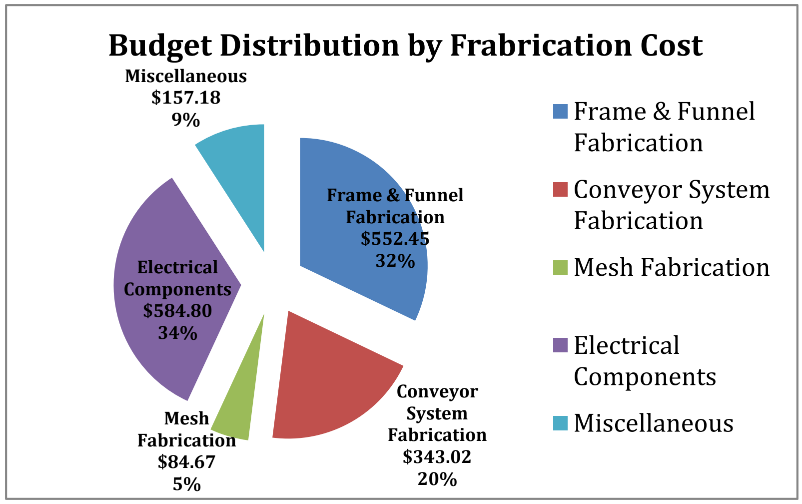


Figure 28.This pie chart shows the budget distribution by each component's fabrication cost.

The current technology commercially available for coating Stabilized Lithium Metal Powder is extremely expensive ranging in the millions of dollars to purchase and produce. The senior design team's competitive design is valued at $ 1,722.12 US Dollars, which is well below price of any other application system. It has been devised in such a manner that it is cost-efficient, safe, and reliable, considering the time constraints under which it was fabricated.

V. Design of Experiment

A. Actuator experimentation

Once the vibration actuators and their circuitry was completed, testing of the effectiveness of the coating machine commenced. Testing methods include observing flowrates for varying amounts of vibration applied to the funnel. Flowrates were observed for a full minute under the following vibration system apparatus variations: two offset mass motor, one offset mass motor, two picovibe motor, one picovibe motor, one offset mass motor with two picovibe motors, and two offset mass motors with two picovibe motors. After several experiments, data was compiled and processed using MatLab; the script may be found in the appendix. The results of the experimentation is depicted below in the graph below, which shows flowrate vs. number of applied offset-mass vibration actuators.

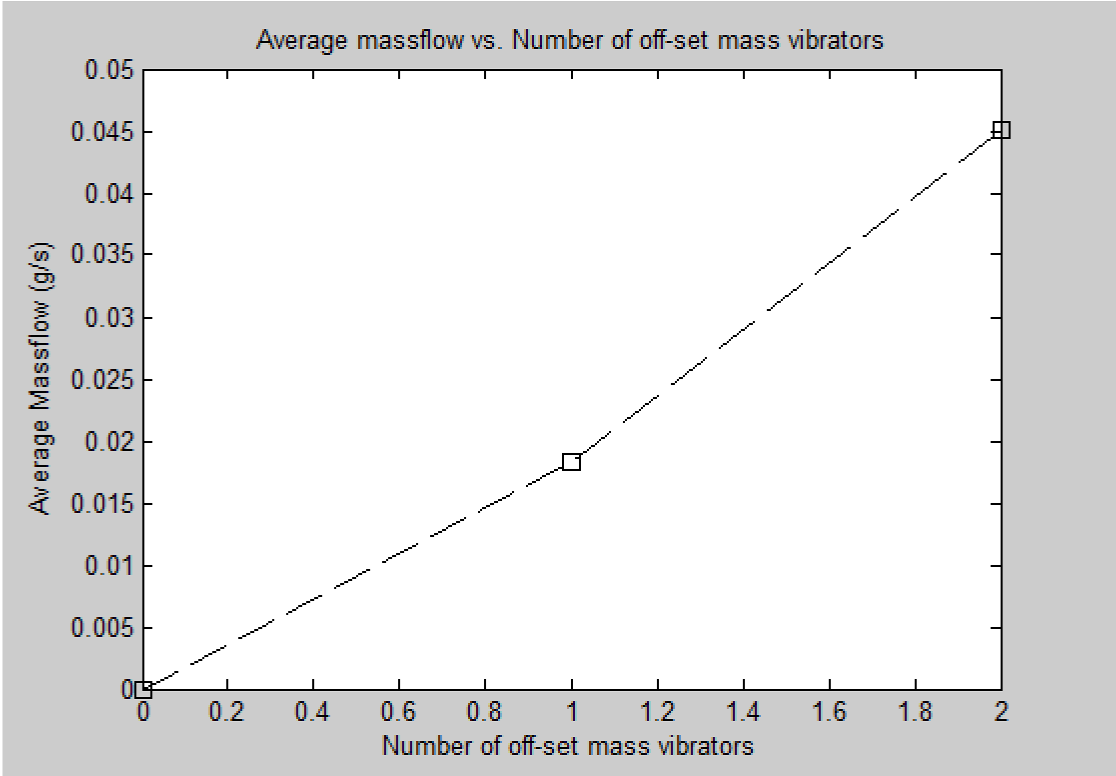


Figure 29. A matlad plot depicting the positive correlation between number of motors and induced mass flow.

B. Mesh Experimentation

Upon completion of the funnel, the design group began testing the flowrates out of the exit orifice of the funnel with varying numbers and size meshes. These experiments were conducted for one minute with two offset mass motors used to induce vibrations in the funnel. At the end of the minute, the vibration actuators are disabled and the granular material that flowed through the meshes during the allotted time was weighed. Each mesh combination was testing a total of three times. From the mass of the material sifted and the duration of the flow, the average mass flow can be approximated. Shown below is a graph depicting the results of our mesh testing that shows the flowrate vs. number of meshes. In addition a visual test is administered after a round of experimentation to determine if the flowrate is reasonably consistent. A table is shown below showing the mesh combinations that induced a consistent flow and which didn't.

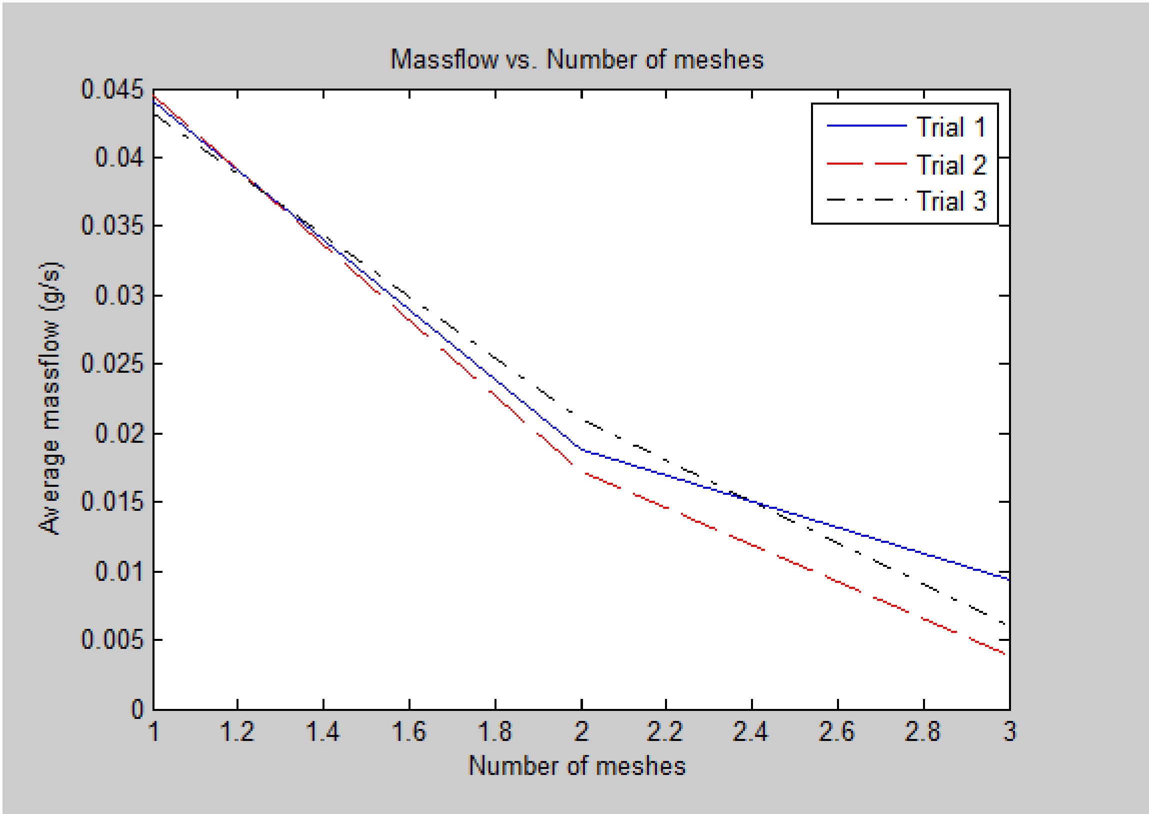


Figure 30. Matlab graph depicting the negative correlation between number of meshes and Induced mass flow for three separate trail runs.

Table 7. This table contains the observed characteristics of the induced mass-flow for the tesing done on three different mesh combinations; using one mesh, two meshes, and finally three mesh layers.

Layers of mesh	Trial Number	Characterization of induced massflow
	1	Consistent
1	2	Consistent
	3	Consistent
	1	Inconsistent
2	2	Consistent
	3	Inconsistent
	1	Inconsistent
3	2	Inconsistent
	3	Inconsistent

C. Conveyor Belt Experimentation

Imminently after construction of the conveyor belt, experimentation began to ensure that the belt translocated the anode reliably without jerking the granular material. The experiments were conducted using an already flour coated anode. Through the experimentation the anode is moved back and forth along the conveyor system with varying sizes of stepper motors. Meanwhile a team of visual inspectors carefully examine the powder on the anode, observing whether the material is dislocated or not. A table below shows which motors at their maximum speed dislocate the powder or not.

Table 8. Shown in this table is the observed dislocation of the dispersed granular material during movement along the conveyor belt for three separate motors.

Motor	Trial Number	Dislocation
1	1	Observed
	2	Observed
	3	Observed
2	1	Not observed
	2	Observed
	3	Observed
3	1	Not observed
	2	Not observed
	3	Not observed

D. Prototype experiment

After the prototype coating machine and all of its components were operational, testing and troubleshooting of the machine's function began. Limited by the time constraint of ten minutes, the machine became subject to trial or mock "anode" coating; in which a piece of aluminum foil was placed on the conveyor belt, taking the place of an anode, and flour was loaded in the funnel as the granular material to be dispersed. Flour has roughly twice the average diameter as stabilized lithium metal powder would have and, consequently, a mesh with openings large enough for the increased particle size is required inside of the funnel. It was observed in the mesh experimentation that, with flour, one layer of mesh inside of the funnel resulted in the greatest and most consistent mass flow. Therefore only one layer of mesh was used during the conduction of the prototype experimentation. After the machine coats the "anode" for ten minutes, the machine is disabled and the mass of the dispersed granular material is measured. From the acquired data the average mass flow rate is then calculated for each run. There were three runs completed before a component, our most powerful off-set mass vibrating actuator, failed. The mass flow calculated for the three runs are compiled in the table below.

Table 9. Tabulation of the mass-flows induced during the three completed prototype trail runs.

Trial Number	Average Massflow (g/s)
1	0.0427
2	0.0398
3	0.0415

VI. Considerations for Environment, Safety, and Ethics

A. Environmental Effects of Lithium

Lithium is an alkali metal that easily reacts with water and does not occur freely in nature. "Lithium is moderately abundant element and it is present in the earth crust in 65 ppm (parts per million)" [13]. Lithium metal has the potential to react with various components in airs, nitrogen, oxygen and water vapor. Lithium can react violently in an exothermal reaction with water to form lithium hydroxide. According to lenntech.com, Lithium in water falls under water hazard class 1. Meaning that lithium in water is not a very big threat to flora and fauna, nor on the mainland but the hydroxide ion may affect the pH of water. Lithium is said to be easily absorbed by plants, some reaching 30 ppm in some plants, acting like a growth stimulant [13]. The range at which normal absorption occurs of lithiated plants is between 0.2 and 30 ppm. A hazardous characteristic of lithium in the environment is demonstrated in its corrosive properties. Corrosive fumes of lithium oxide can be released upon reaction [10].

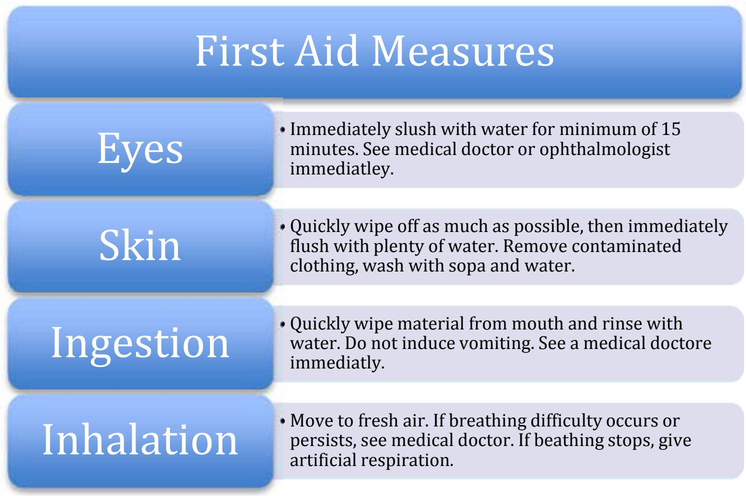


Figure 32. First aid measures to enact in case of bodily exposure.

B. General Safety Issues

Toxicological reports state that lithium is not carcinogenic and not mutagenic/Genotoxic. According to the Globally Harmonized System of Classification and Labelling of Chemicals, Lithium is classified Category 1B skin corrosive and class 4.3 dangerous when wet classification [4]. Meaning, lithium is extremely reactive with body moisture, corrosive to skin, nose, stomach, eyes, highly flammable, and corrosive.

Therefore proper handling of SLMP is necessary to maintain safety. SLMP should only be handled by trained professionals. This means wearing the appropriate personal protective equipment (PPE) like, safety glasses for solid lithium, full flame-resistance face shield and clothing, rubber gloves. Laboratory facilities should be equipped with quick-drench eyewash stations and safety showers. In case of bodily contact with lithium the following guidelines should be followed from figure 20. Proper storage of lithium materials should be followed for safety hazard regulations. SLMP must be stored in a cool, dry location, before opening the shipping container. Once the container is open, it is most suitable to store the material under argon gas, in a dry room or under mineral oil [4]. A water fire-suppression system should not under any circumstances be used in the storage area of lithium. Containers with lithium material should be kept away from water, humid air, acids, heat, sparks, flames and oxidizing materials. Waste containing lithium metal, is required to be properly disposed of. This should be done by contacting a reputable licensed hazardous waste disposal facility. Extinguishers for lithium only should be used, for example, graphite, copper powder, and Lith-X (Ansul) [4].

C. Ethics

Ethics are the standards of conduct set up to describe the appropriate or expected behavior in a field of study. In research, there are several established organizations with sets of ethical rules and regulations for professionals, for example, the IEEE code of ethics or the National Society of Professional Engineers (NSPE) code of ethics. It is stated, in the NSPE code of ethics "engineers are expected to exhibit the highest standards of honesty and integrity" [3]. A person who enters a profession acquires ethical obligations because society trusts them to provide valuable goods and services with specific conduct to certain standards. For example, it would be unethical to improperly dispose of SLMP into the environment. When conducting research, one is responsible on how that research and its entirety might affects society and/or the environment.

The project team has weekly meetings to discuss future plans and the course of actions that will be taken to further the progress of the project. During these meetings, any team member has the opportunity to voice their opinions or concerns regarding the course of the project and any ethical matters that maybe attached to them. To be a good engineer throughout the course of this project we will adhere to the morals and duties expected of an engineer according to the NSPE code of ethics as well as the team's own ethical standards.

D. Material Safety Data Sheet

The material safety data sheet is an important document that archives a specific chemical product, such as stabilized lithium metal powder. "The Federal Occupational Safety and Health Administration (OSHA) Hazard Communication Standard (29 CFR 1910.1200) requires manufacturers or distributors of chemicals to issue Material Safety Data Sheets (MSDSs) with the first shipment of any hazardous chemical product, and the employer is responsible for having them available…."[10]. The information presented for SLMP on its MSDS, references potential hazards and/or how to safely handle the material. It contains information on the use, proper storage of SLMP. The nature of SLMP, including physical/chemical properties, and environmental hazards, are presented in its MSDS document. The materials safety data sheet for stabilized lithium metal powder is provided and can be referenced in the appendix.

VII. Project Management

The design process and construction of the prototype machine has required a vast amount of research, manufacturing, construction, testing, and analysis. This overall process demanded a significant amount of time and as such needed to be broken down into tasks and milestones. Our schedule breakdown can be found below in section VII.A along with figures, tables, and further explanation.

Another portion of our project that must be considered and scheduled is the programming of certain components and user interfaces. The prototype machine has a programmable logic controller that will be utilized to allow a user to input the desired values.

A. Schedule

To properly develop a prototype machine that will uniformly coat an electrode with stabilized lithium metal powder a strict schedule must be adhered to. Below in figure 22 is a breakdown of all of the tasks and milestones required to fulfill the objective. Many of the tasks will be dependent on precedent work; while others can be handled independently will grow upon one another from this point forward. Typically major tasks will be given a 7-day period for completion. For Milestones the time period can range from a 14-day to 30-day period. The time limit assigned is based on the amount of research, analysis, and labor that we as a team have deemed necessary for each task.

	Task Name	Duration	Start	Finish
1	Research SLMP	14 days	Mon 9/8/14	Thu 9/25/14
2	Research Coating Techniques	14 days	Fri 9/26/14	Wed 10/15/14
3	Desinging of 3 Initial Designs	21 days	Wed 10/15/14	Wed 11/12/14
4	Selection of Optimum Design	2 days	Mon 11/17/14	Tue 11/18/14
5	Optimize Choosen Design #4 Design	10 days	Tue 11/18/14	Mon 12/1/14
6	Conduct FEM Analysis on Design #4	5 days	Tue 12/2/14	Mon 12/8/14
7	Winter Break	17 days	Fri 12/12/14	Mon 1/5/15
8	Revize Design #4	5 days	Mon 1/5/15	Fri 1/9/15
9	Optimize New Design - Design #5	7 days	Fri 1/9/15	Mon 1/19/15
10	Finalize Design #5	5 days	Mon 1/19/15	Fri 1/23/15
11	Make Bill of Materials	3 days	Wed 1/21/15	Fri 1/23/15
12	Ordering Parts from Grainger and Time to Receive(TOR)	21 days	Fri 1/23/15	Fri 2/20/15
13	Construction of Wooden Test Frame	2 days	Fri 1/23/15	Mon 1/26/15
14	Perform FEM Analysis on Parts of Design #5	3 days	Sat 1/24/15	Tue 1/27/15
15	Testing of Meshes on Wood Frame	5 days	Mon 1/26/15	Fri 1/30/15
16	Manufactoring of Tower and Funnel and TOR	5 days	Sat 1/31/15	Thu 2/5/15
17	Ordering of Home Depot Parts Through AME and TOR	15 days	Tue 2/3/15	Mon 2/23/15
18	Ordering of Electronic Parts Through AME and TOR	10 days	Wed 2/4/15	Tue 2/17/15
19	Manufactoring of Conveyor Belt Adapter and TOR	5 days	Sun 2/8/15	Thu 2/12/15
20	Manufactoring of Conveyor Bars and TOR	3 days	Mon 2/9/15	Wed 2/11/15
21	Program Arduino Board With Motor	10 days	Tue 2/17/15	Mon 3/2/15
22	Assemble Meshes to Mesh Framing at Varying Sizes	3 days	Wed 2/25/15	Fri 2/27/15
23	Attach Funnel to Tower	2 days	Tue 3/3/15	Wed 3/4/15
24	Attach Actuators to Funnel	2 days	Wed 3/4/15	Thu 3/5/15
25	Spring Break	5 days	Mon 3/9/15	Fri 3/13/15
26	Test Meshes Inside Funnel with Actuator Assist	7 days	Mon 3/16/15	Tue 3/24/15
27	Order More Powerful Actuators and TOR	5 days	Tue 3/24/15	Mon 3/30/15
28	Construct Conveyor Belt	5 days	Wed 3/25/15	Tue 3/31/15
29	Manufactor New Modified Coveyor Belt Adapter and TOR	3 days	Fri 3/27/15	Tue 3/31/15
30	Order New Motor and Conveyor Belt and TOR	5 days	Thu 3/26/15	Wed 4/1/15
31	Test Meshes Inside Funnel with Actuator Assist P2	7 days	Thu 4/2/15	Fri 4/10/15
32	Reconstuct Conveyor Belt	3 days	Thu 4/2/15	Mon 4/6/15
33	Finalize Bill of Materials Included in Construction	2 days	Sat 4/4/15	Mon 4/6/15
34	Test Completed Prototye	9 days	Mon 4/6/15	Thu 4/16/15
35	Analysis of Coating	5 days	Sat 4/11/15	Thu 4/16/15

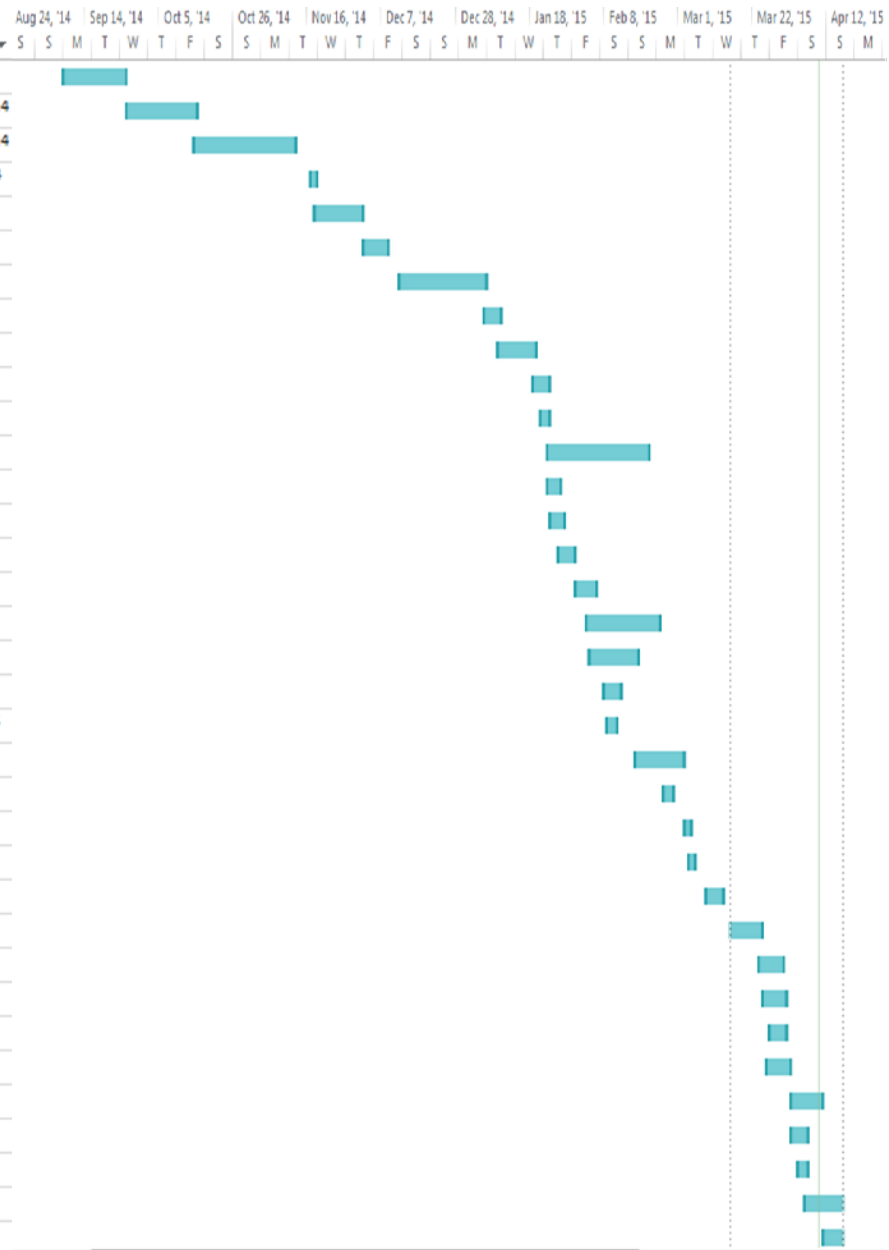


Figure 33.Detailed Gantt chart of the project timeline.

B. Resources

Resource Allocation has been divided amongst the team equally. Each member will be required to put in a minimum of 800 hours work into this project. These hours are divided throughout the year as to minimize the burden on the team. Each team member will have time to rest in-between assigned tasks to be fair and to ensure efficiency and productivity. The detailed division of labor can be found below in Table 10.

Table 10. Tabulation of resource allocation depicting each member's tasks/milestone and hours worked.

		Team Members					
Task/ Milestone	Hours/Days Need to Complete	Marcos Leon	John Magner	Vannesa Palomo	Maria Sanchez	John Shaw	Benjamin Tinsley
Design Compilation	16 Days	X	X	X	X	X	X
Review of Design with Advisor and sponsor	1 day			X		X	
Project Plans and Product Specs	9 days	X	X	X	X	X	X
Midterm Presentation	8 days	X			X	X	
Web Page Design	21 days						X
Midterm Report	13 days	X	X	X	X	X	X
Midterm Presentation 2	7 days		X	X			X
Design Analysis-Electrical Components	3 days		X		X		
Design Analysis-Mechanical Components	3 days					X	X
Material Selection of components	3 days	X		X			
Comparison and Analysis of Material Selection	4 days		X		X		
Place order for Specialized components	3 days	X				X	
Check of Manufactured Components	2.875 days			X	X		
Purchase of all Needed Components	8.5 days	X					
Initiation of Construction	10 days	X	X	X	X	X	X
Mechanism check	4 days		X			X	
Initial testing	5 days			X	X		
Analysis of initial testing	7 days		X				X
Revisions on mechanism	4 days	X				X	

	Test round 2	4 days				X		X
	Analysis of round 2	4 days		X	X			
	Revision round 2	4 days	X				X	
	Final Stage Testing with SLMP	7 days			X	X		
	Report of 1st Final Stage test	7 days	X	X	X	X	X	X
	Final revisions	4 days	X	X				
	Final Test	9 days			X			X
	Presentation to Sponsor	7 days	X	X	X	X	X	X
	Walk-through and Demo	2 days	X	X	X	X	X	X
	Peer evaluation	1 day	X	X	X	X	X	X
	Final Web Page Design	7 days						X
	Final Design Presentations	7 days	X	X	X	X	X	X
	Final Report	5 days	X	X	X	X	X	X
Number of tasks to Complete			17	17	18	17	17	17
Total Amount Time Spent on Task/Milestone			850Hours	850Hours	900Hours	800 Hours	850 Hours	800 Hours

C. Procurement

The procurement process for the proposed project prototype was implemented using several stages prior to acquisition of any component/piece of equipment, as show in figure 36. A needs analysis was conducted of the piece of equipment/component, whether the component was an optimal solution and if it would meet the needs of the project. The next stage of procurement involved an analysis of the budget, whether the component cost would fit into the project budget. The project procurement plan was established as a strategy to review the market for the specific components and their availability through suppliers. This was achieved through research online of suppliers and/or in-person supplier review. Once a supplier was found with the item in stock, a purchase order was placed. Purchase orders were implemented either individually or through the procurement personnel at the Aeropropulsion Mechatronics and Energy Center. The final stage of the procurement process involved the acquisition or arrival of the item and the review of the item to ensure correctness.

Figure 34. Procurement process

Budget allocation was determined by cost parameters of the various fabrication components and electrical components. The distribution of funds were adjusted to meet out budget, the overall US $2,000.00 limit was taken into account prior to procurement of any item. A detailed list of the final budget for all components acquired can be referenced in the appendix. As shown in figure 28 the overall budget used for the final prototype design was $1722.12, an 86 percent of our overall budget. The two highest costing fabrication systems were the frame (US $552.45) & funnel (US $584.80) and the electrical system, taking up 66 percent of the budget as shown in figure 30. A bill of materials can be referenced in the appendix for the final design conceptualization parts acquisitioned.

D. Communication

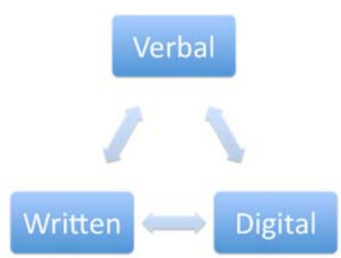


Figure 35. Foundation for an effective communication system with a team.

By setting up a clear communication system within the team protocol, an effective working inner dynamic and process has been established for the project. It is necessary to develop interpersonal skills in coping with project problem solving. Verbal communication is of key importance to create a clear path of the end goal of the team project, as seen in Figure 37. This sets the stage for an effective team with the following skills: group effort of all members, clear goals, focus on learning, mutual trust and support, open communication and a democratic process. Verbal communication defines the tasks/objectives to be achieved in a work plan. Every member has a role to play for each individual part of project deliverables, as tasks are identified and assigned to group members. The next line of effective communication: written documentation on paper, Word docs, PowerPoint, Excel, etc. This portion takes effect in developing technical knowledge that can include: doing calculations, drawing graphs/tables, preparing designs, and analyzing data. This helps with preparation and organization of idea and goals. Plans are drawn out to progress with the project deliverables, by creating timelines and schedules, and communicated to each individual member. The nest step to close the triangle of effective communication within a team dynamic is to set up digital communication systems. For example, but not limited to: email, text messaging, and online programs. Email is used to effectively communicate with group members and sponsors, advisers and mentors. Wiggio.com is an online toolkit that facilitates working in groups. This website allows for keeping a shared calendar, sending mass group emails, and uploading/ relevant documents files. The group can set up meeting polls to plan events, meeting, and deliverable due dates. Google Docs is a web-based word processor allows team members to simultaneously work and access documents anywhere and at any time.

VIII. Conclusion

In conclusion, the purpose of our project is to coat a Stabilized Lithium Metal Powder on the electrodes of batteries to increase the energy density 2 to 4 times as well as increase the batteries total capacity by 5 to 15 percent. The prototype machine we have designed will coat a uniform layer of this SLMP on varying lengths of anodes within 10 minutes. We have used $1722.12 of the $2000 budget we were given. Our design has a stepper motor controlling the conveyor belt that will move an electrode under a funnel filled with SLMP. This anode will be specifically placed so it will be coated entirely, this is achieved by inputting the length of the anode into the keypad. Once the electrode is under the funnel the conveyor belt will move the electrode back and forward 5 times based on the length inputted into the keypad. When the electrode is underneath the funnel, DC vibration motors will be turned ON to start the flow. These DC motors are directly attached to the funnel. These vibrations will allow for the SLMP to flow through a series of meshes attached inside of the funnel and fall onto the electrode with a minimal drop distance.

Our final design was chosen over many other possibilities based on a decision matrix, Table1. This matrix used a variety of characteristics to determine the best selection: affordability, ease to use, ease of repair, durability, power consumption, portability, and powder dispersion. Each characteristic was weighted due to its importance to the project. The losing designs scored from 6.15 to 8.15 on a scale of 1-10, while the final selected design scored an 8.88. We decided due to the simplicity and functionality of design #6 it was the optimum design.

The flow through the funnel is controlled by the use of meshes within the funnel. The optimum flow rate occurred with the use of one mesh while using two vibration motors. This setup had a flow rate of 0.045g/s. Two meshes with two vibrations motors was tested and produced a flow rate of 0.021g/s. The use of two meshes was more controlled and produced less agglomerations, however it produced a limited flow rate. Due to initial testing it was determined that the optimum flow set up in the funnel is with one mesh while being vibrated by two offset mass motors on the side of the funnel. However we still seek the use of two meshes due to its ability to control the flow and resist agglomeration. So in future testing we will use meshes with larger opening to give the desired flow rate to accomplish the coating of the anode within 10 minutes time limit.

A. Future Recommendations

Although the team has made great strides in the prototype design for a Stabilized Lithium Metal Powder coating machine there are still areas that can be improved or modified. One improvement that can be made to this project is to allow for the machine to coat both a variable length and width, differing from the method currently employed that limits the machine to just varying length. Some possible ways of doing this are to make a ramp with adjustable walls that will essentially funnel the SLMP into varying widths or by changing the width of the outlet of the funnel with a mechanical stopper. Some other changes that can be implemented to further improve the current design is to fabricate a solid stable base plate that will support the entire machine and strengthen the design even further.

Experimentation with different materials, funnel sizes, mesh sizes, vibration amplitudes, and other variable components would also be recommended in order to compare data and ensure that the optimal design and components have been selected for the prototype machine. Many components are interchangeable and by changing the specs even slightly the process can be optimized. Exploration of linear vibrational methods rather than vertical displacements is also recommended.

Suggestions to any team implementing this prototype are: to be open minded when in the designs phase and follow a strict schedule throughout the entire project. When fabricating a prototype machine, there are many possible designs that could be successful. It is important to be diligent when deciding on the design and consider all possible choices. Each phase of the prototype, concept generation through Assembly and testing must adhere to a strict a schedule, to ensure completion and sufficient time for troubleshooting. Communicating between the team and the advisors is a great source of aid when reaching an impasse. Throughout the entire process there will be many unforeseen obstacles and without a good team and extra time in the schedule it can be very easy to get overwhelmed when obstacles arise. The team must remember that resilience and perseverance will attain solutions, given the time any problem can be solved.

IX. References

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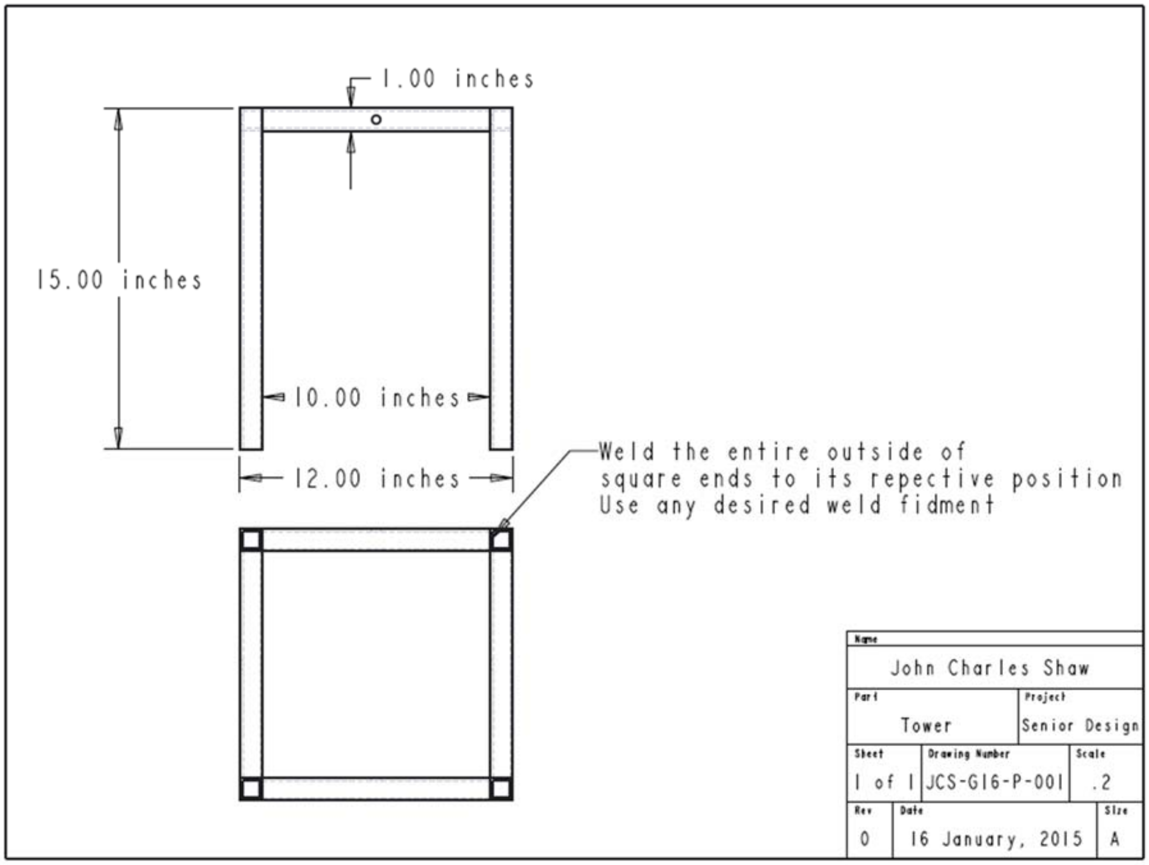
X. Appendix

1. Appendix: Product Assembly

Table 11: Bill of Materials

Component	Quantity
Steel Meshes	2
A36 SteelFrame & Funnel	1
1.9" diameter, 12" long Rollers	2
Conveyor belt (price per foot)	6.5 feet
12V, 3000RPM DC Vibration motors	2
12V, 30.2 N*m Stepper Motor	1
12" X 12" Plexiglass	2
Arduino Mega 2560 Microprocessor	1
4X3 Numeric Keypad	1
2.1 mm Barrel On/Off switch	1
12V 5A, Power supply	1
Metal Hinges	2
Steel frame for conveyor	1
Hex nut- 5/16	4
Hex nut- 5/8	8
Lock nuts- 5/16	2
Lock nuts- 5/8	2
Lock nuts-3/8	4
3/4" Metal EMT Strap	2
Threaded Rod Zinc 3/8" X 12"	1
Female DC Power Adapter	1
2-Way 2.1 mm Barrel Jack Splitter	1
Jumper Wire Kit	1
Stepper Motor Mount	1
Radial Bearings	2
Epoxy-Locite	1
Epoxy- Gorilla	4
JB Weld	4
Electrical tape	1
8" Zinc mending plate	2
1/4" drive 7/16" 6pt deep	4
48"-1/2"x 1/4" Steel plain flat bar	2
1'x1' plain aluminum sheet	1
Steel plain flat bar	1
Silicon glue	1
Threaded Rod Zinc 5/16x 24"	1


1.00 inches
15.00 inches
10.00 inches
12.00 inches
Weld the entire outside of
square ends to its repective position
Use any desired weld fidment
Name
John Charles Shaw
Part
Tower
Project
Senior Design
Sheet
1 of 1
Drawing Number
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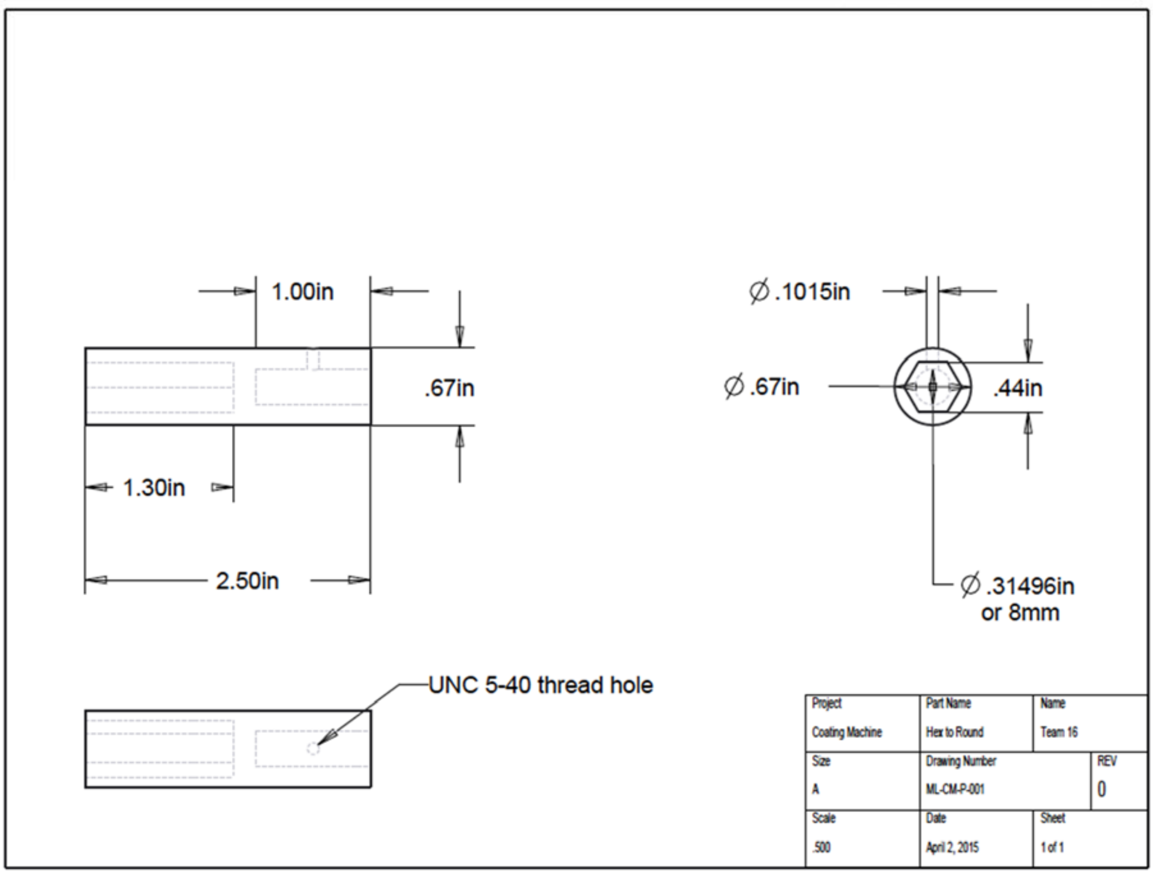
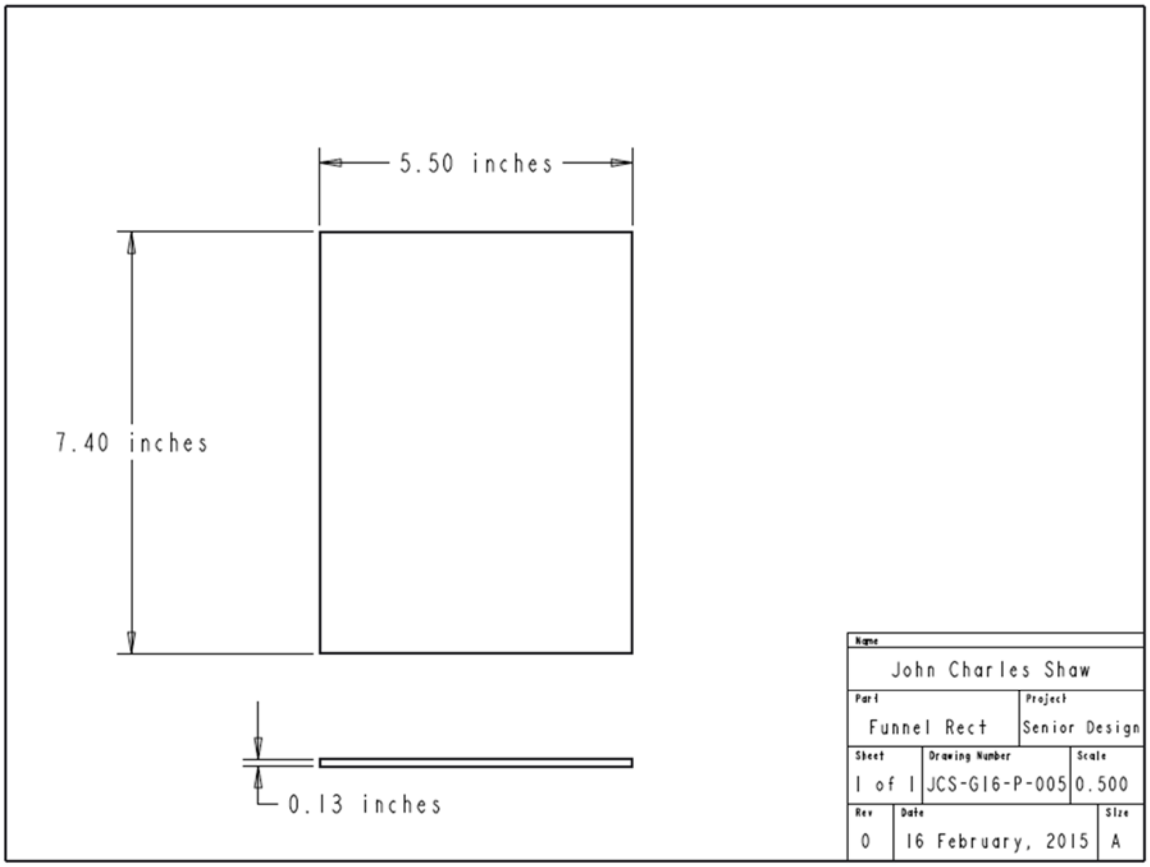
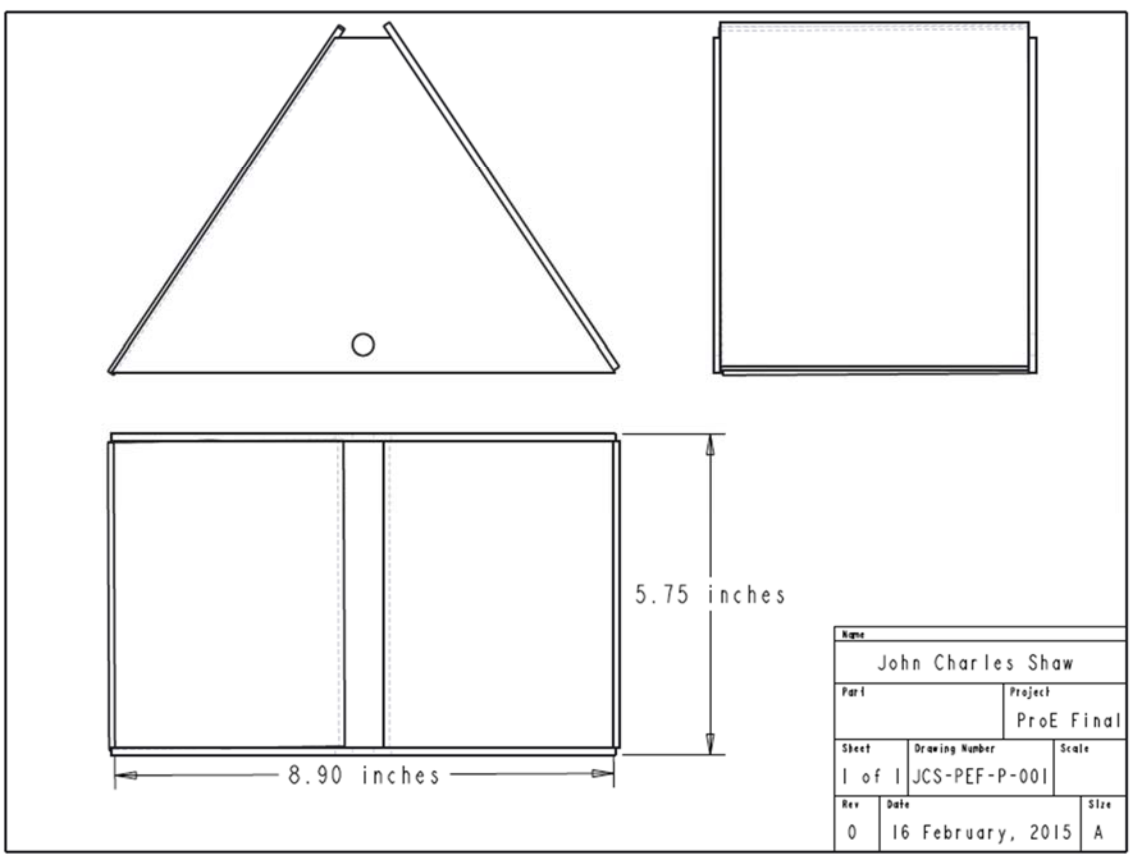
Scale
.2
Rev
0
Date
16 January, 2015
Size
A


1.00in
.67in
1.30in
2.50in
Ø.1015in
Ø.67in
.44in
Ø.31496in
or 8mm
UNC 5-40 thread hole
Project
Coating Machine
Part Name
Hex to Round
Name
Team 16
Size
A
Drawing Number
ML-CM-P-001
REV
0
Scale
.500
Date
April 2, 2015
Sheet
1 of 1


5.50 inches
7.40 inches
0.13 inches
Name
John Charles Shaw
Part
Funnel Rect
Project
Senior Design
Sheet
1 of 1
Drawing Number
JCS-G16-P-005
Scale
0.500
Rev
0
Date
16 February, 2015
Size
A


5.75 inches
8.90 inches
Name
John Charles Shaw
Part
Project
ProE Final
Sheet
1 of 1
Drawing Number
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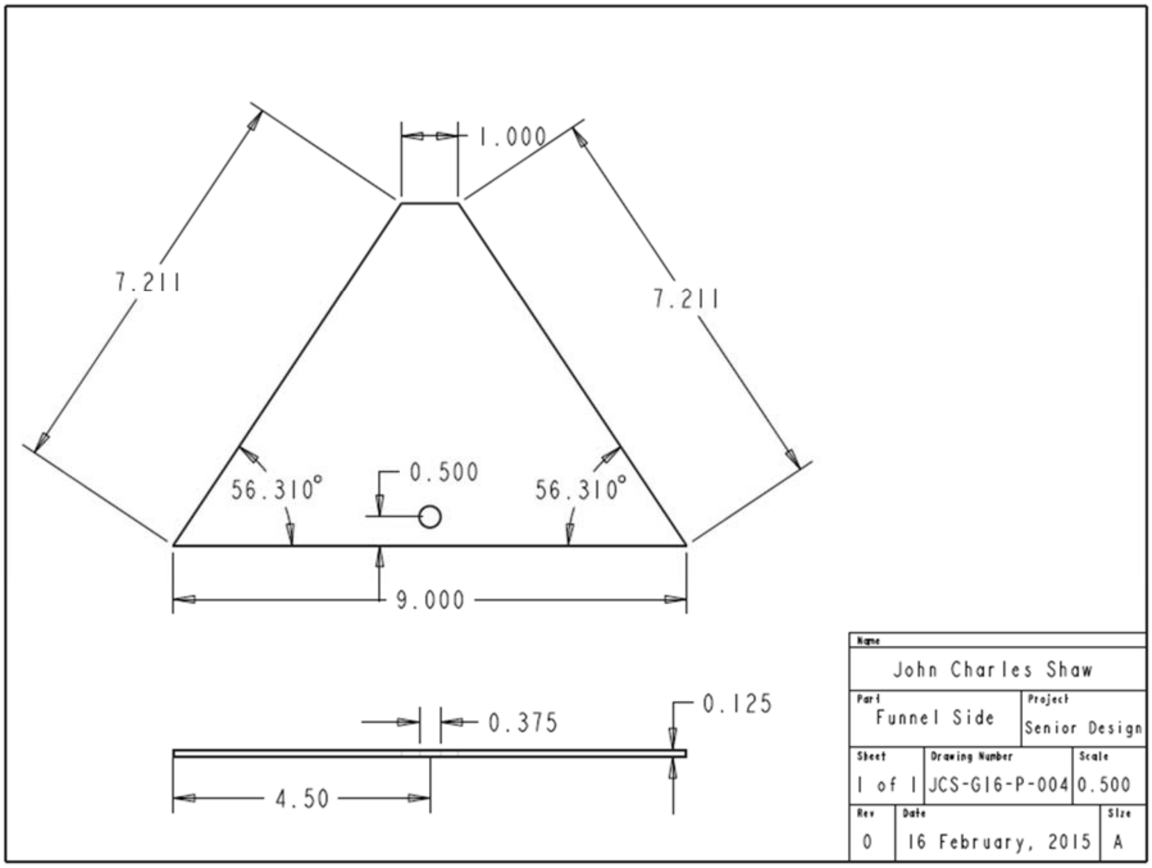
Scale
Rev
0
Date
16 February, 2015
Size
A


1.000
7.211
7.211
56.310°
0.500
56.310°
9.000
0.375
0.125
4.50
Name
John Charles Shaw
Part
Funnel Side
Project
Senior Design
Sheet
1 of 1
Drawing Number
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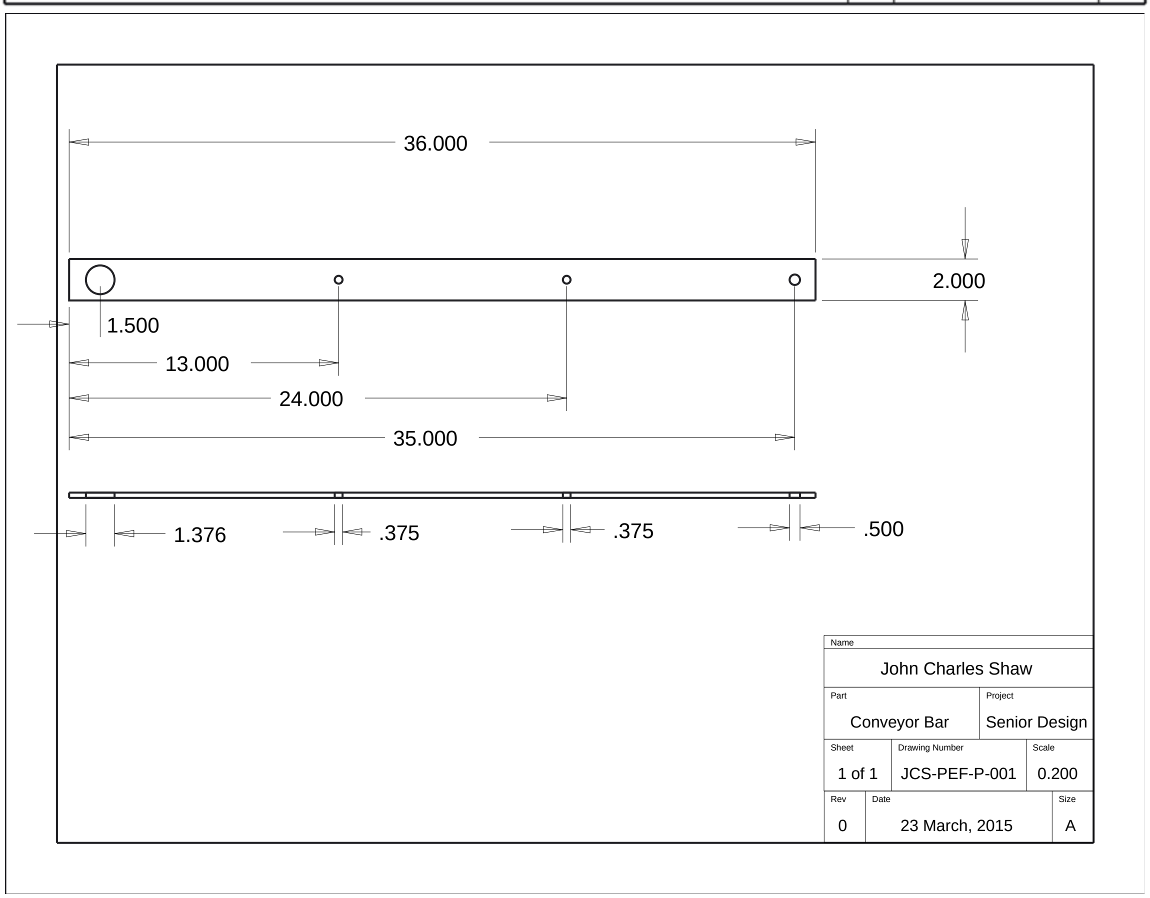
Scale
0.500
Rev
0
Date
16 February, 2015
Size
A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1.500
13.000
24.000
35.000
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.375
.500
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Conveyor Bar
Project
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2. Appendix: Electrical Schematics

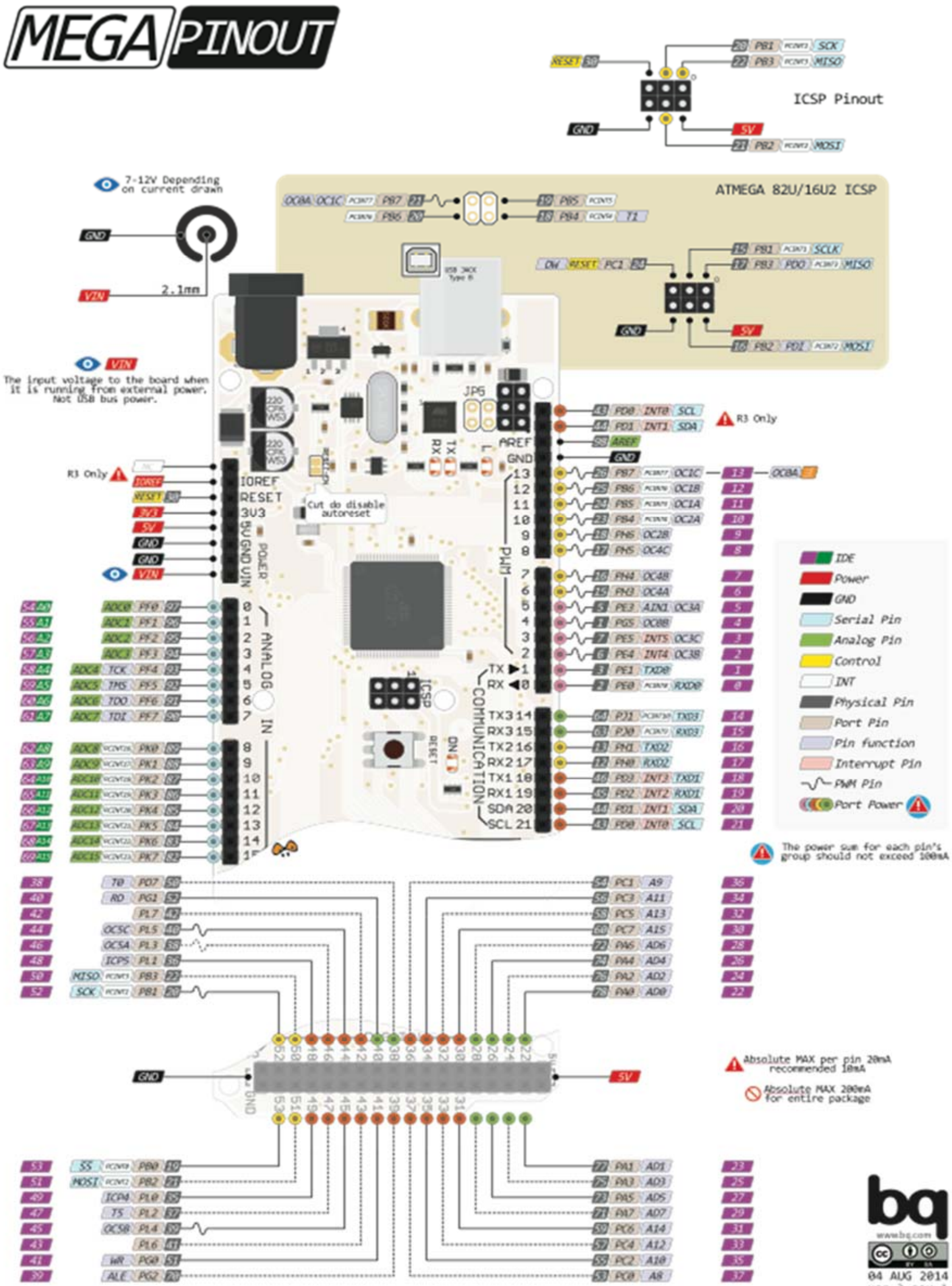


Figure 36: Arduino

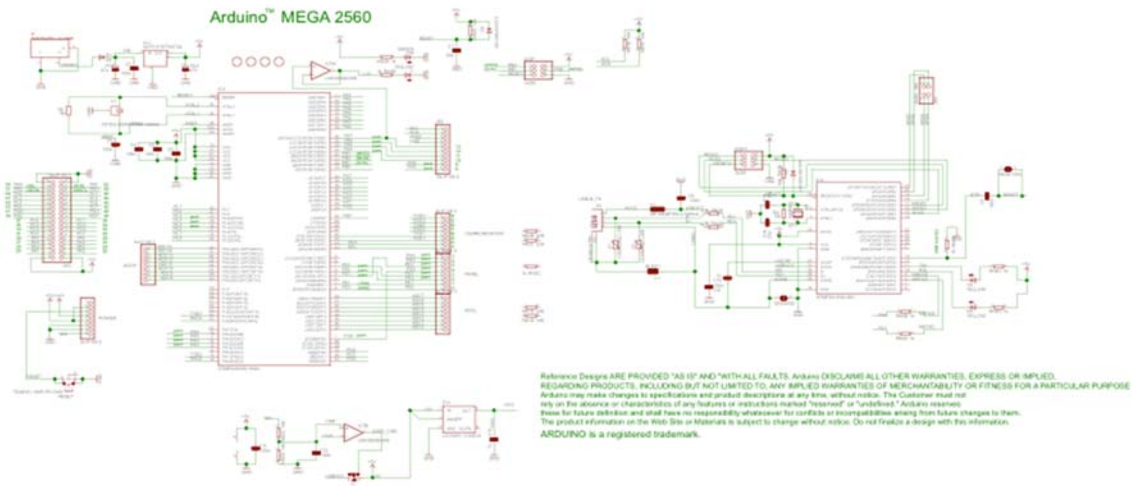
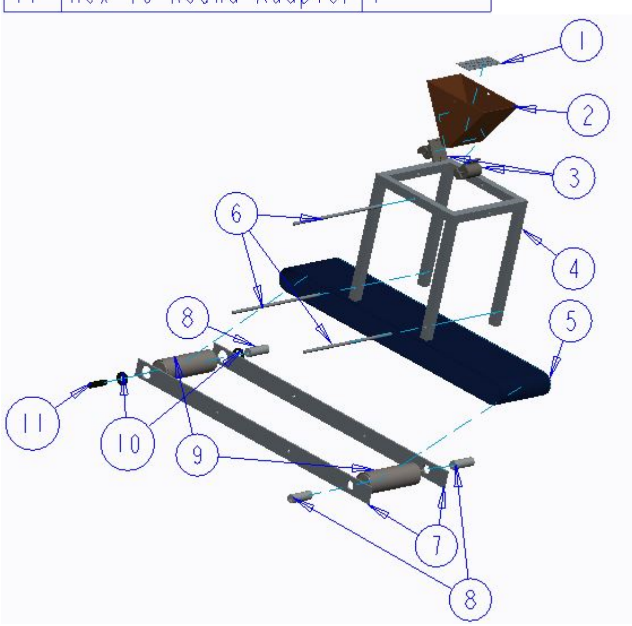


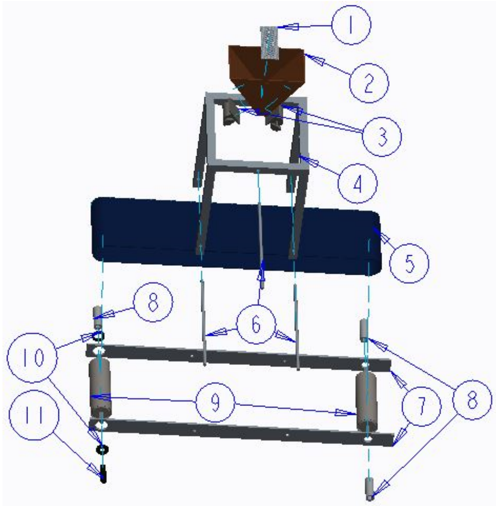
Figure 37: Arduino Mega Schematic

3. Section I: Design of Manufacturing

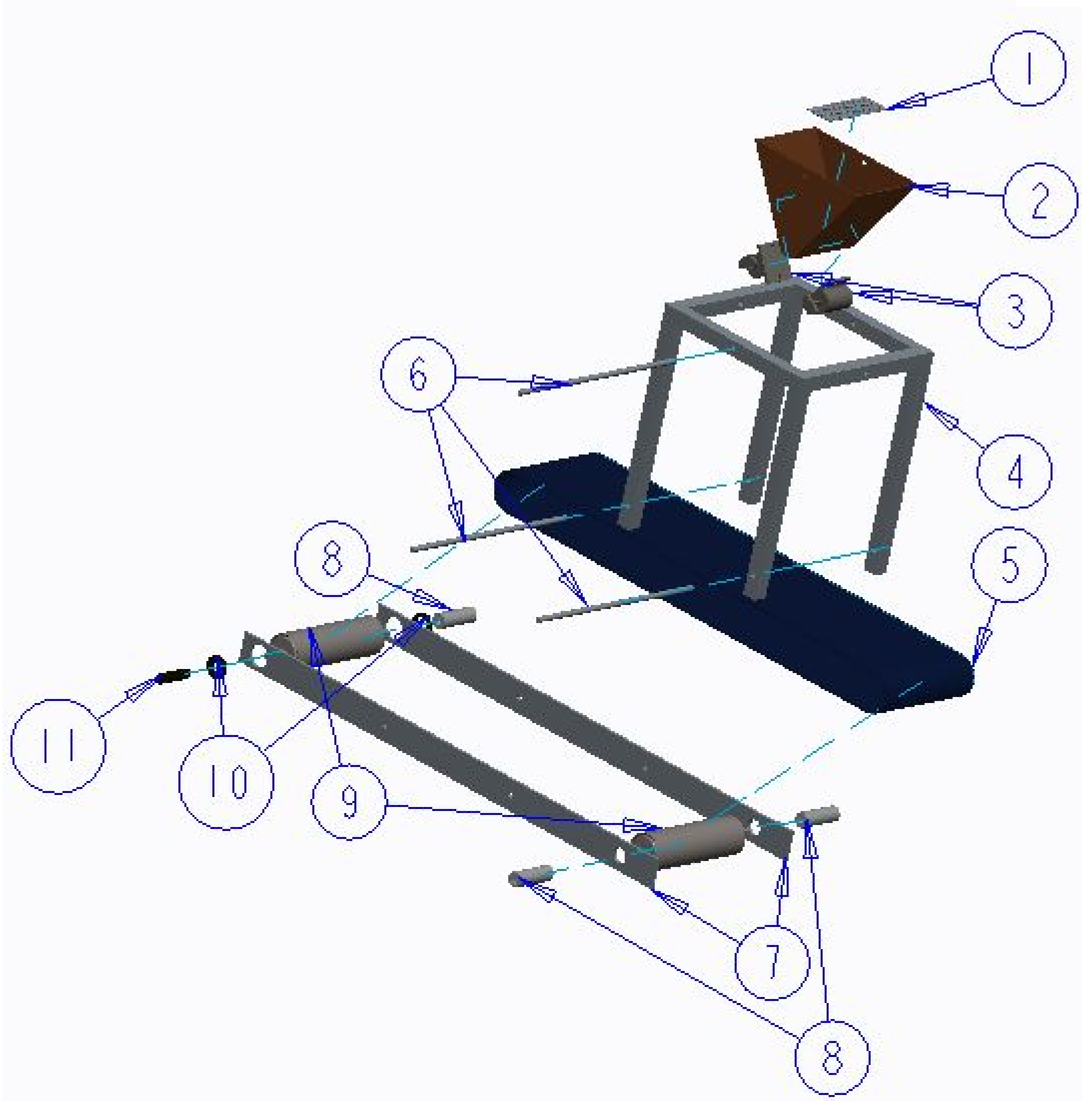
Bill of Materials		
No.	Part	Quantity
1	Mesh	1
2	Funnel	1
3	Vibrating Motor	2
4	Frame	1
5	Conveyor Belt	1
6	Shaft	3
7	Flat Bar	2
8	Socket	3
9	Roller	2
10	Bearing	2
11	Hex to Round Adapter	1



Bill of Materials		
No.	Part	Quantity
1	Mesh	1
2	Funnel	1
3	Vibrating Motor	2
4	Frame	1
5	Conveyor Belt	1
6	Shaft	3
7	Flat Bar	2
8	Socket	3
9	Roller	2
10	Bearing	2
11	Hex to Round Adapter	1



Bill of Materials		
No.	Part	Quantity
1	Mesh	1
2	Funnel	1
3	Vibrating Motor	2
4	Frame	1
5	Conveyor Belt	1
6	Shaft	3
7	Flat Bar	2
8	Socket	3
9	Roller	2
10	Bearing	2
11	Hex to Round Adapter	1



4. Section II : Design for Reliability

Failure Modes Effects Analysis

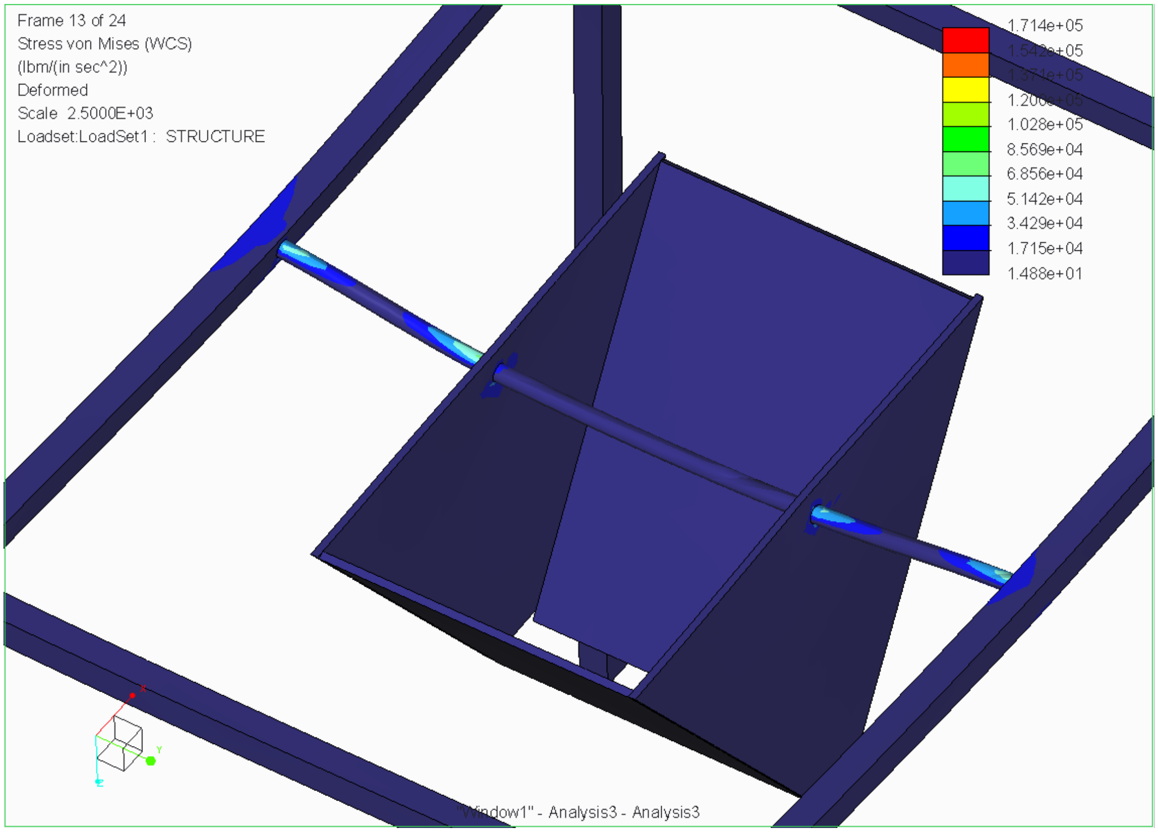
Team #:	16
Project Title	Prototype Coating Maching for SLMP

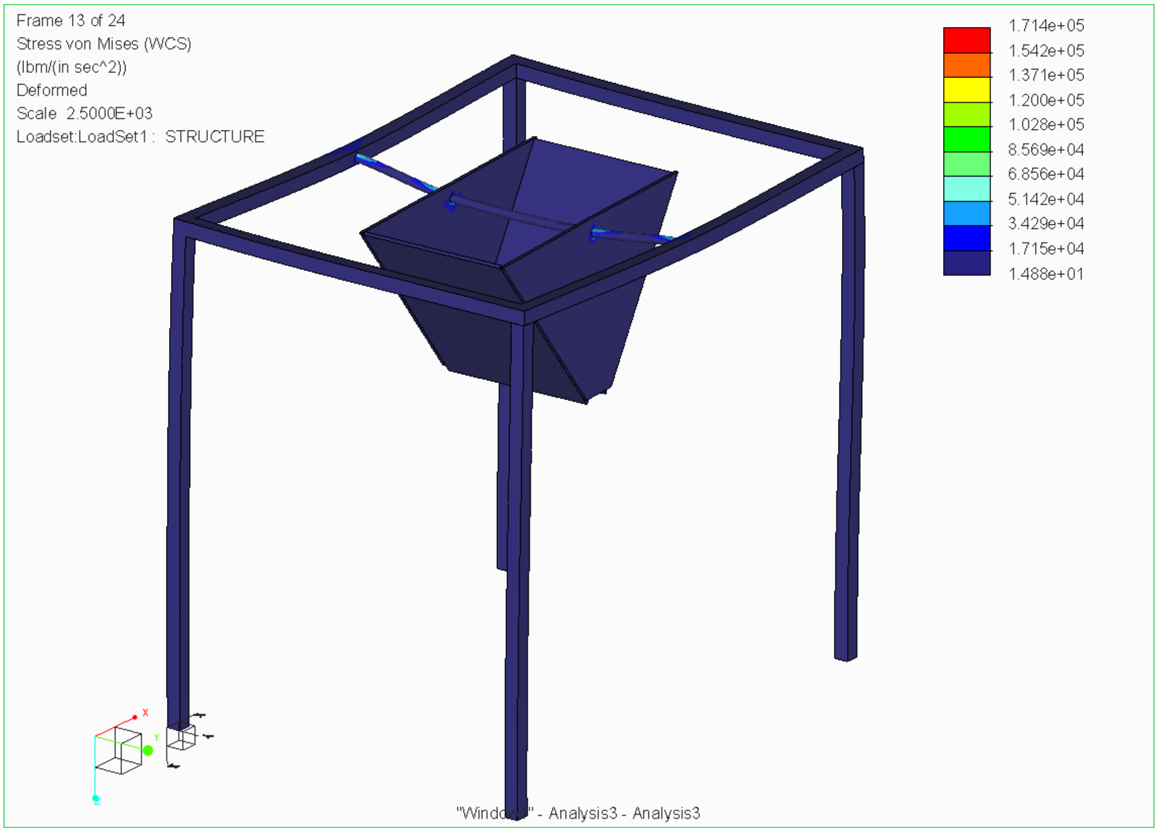
Key Process Step or Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken	SEV	OCC	DET	RPN
What is the Process Step or Input?	In what ways can the Process Step or Input fail?	What is the impact on the Key Output Variables once it fails (customer or internal requirements)?	How **Severe** is the effect to the customer?	What causes the Key Input to go wrong?	How **often** does cause or FM **occur**?	What are the existing **controls** and procedures that prevent either the Cause or the Failure Mode?	How well can you **detect** the Cause or the Failure Mode?		What are the actions for reducing the occurrence of the cause, or improving detection?	Who is Responsible for the recommended action?	Note the actions taken. Include dates of completion.				
Hex Adapter for driving roller	Deformation of the adapter	Ceases operations until part is replaced	4	Weak material. Excessive force easily causes failure	6	Ensure motor is grounded and not hanging on adapter. Visual Inspection.	10	240	Refrabricate part with stronger material		Redesign for thickness and durability	4	6	10	240
Motor mounts on funnel face	Deformation of bolt adhesion	Causes failure to induce vibration	3	Excessive torque applied to bolt; wear from vibration.	2	Hand tighten nuts to secure motor mount.	9	54	Secure bolts in a more permanent manner; bore hole through funnel and run bolt through.		Secured with J.B. weld	3	2	9	54
Conveyor belt motor	Insufficient torque to drive system	Failure of conveyor system	6	Heavy belt, fricition with frame, low voltage applied to motor	2	Avoid belt contact with frame; minimize weight of belt.	9	108	Trim belt to minize friction; use lighter belt; use high torque motor	Design group	Belt trimmed. Motor with high torque ordered.	6	2	9	108
Conveyor belt	Deformation of belt adhesion	Failure of conveyor system	7	Excessive tension applied to belt.	3	Avoid high tension; secure belt with epoxy.	8	168	Refashion belt; use stronger adhesion.	Design group	Epoxy applied to reinforce joint; searched for alternative lighter belts	7	3	8	168
Funnel Suspension	Funnel movement	Inconsistent flow onto anode	3	External forces acting upon structure	1	Keep structure in controlled environmnet; avoid external forces	4	12	Still funnel before activating the machine	User	Funnel secured with nuts	3	1	4	12
Electrical System	Electrical component failure	Failure of input system, vibration system, and conveyor system	9	Excessive voltage applied to component	1	Ensure proper voltage is applied across all electrical components	6	54	Moderate voltages and inspect system often.	Design group	Redesign of circuitry to ensure proper voltages are applied	9	1	6	54
Internal Mesh	Displaced mesh	Failure to moderate flow	1	Mesh moved such that exit orifice is not completely covered	2	Check internal mesh before loading the funnel	3	6	Develop a way to fix a mesh to walls of funnel	Design group	Fit large opening mesh to funnel	1	2	3	6
Roller Bearings	Deformation of bearing	Failure of conveyor system	5	Fatigue after hundreds of uses	1	Visual inspection	6	30	Keep bearings lubricated. Replace when part exceeds bearing life	User		5	1	6	30
Vibration Actuators	Failure of actuation	Failure of vibration system	6	Fatigue after hundreds of uses	3	Visual inspection	8	144	Secure vibrating motors tight against funnel	User	Secured vibrating motors	6	3	8	144

```
>> t = 1/6;%duration of coating process in hours
rpm = 25;%rev/min
L_bearing = t*rpm*60%life calculation in millons of revolutions

L_bearing =

  250.0000
```




Frame 13 of 24
Stress von Mises (WCS)
(lbm/(in sec^2))
Deformed
Scale 2.5000E+03
Loadset:LoadSet1 : STRUCTURE
1.714e+05
1.542e+05
1.371e+05
1.200e+05
1.028e+05
8.569e+04
6.856e+04
5.142e+04
3.429e+04
1.715e+04
1.488e+01
- Analysis3 - Analysis3

5. Section III : Design for Economics

Component	Distributor/Manufacturer	Price per Unit	Quantity	Total
Meshes	Grainger Industrial Supplier	$21.79	3	$65.38
Frame & Funnel	Metal Fabrication and Sales of Tallahassee	$360.80	1	$360.80
Rollers	Grainger Industrial Supplier	$24.30	2	$48.60
Conveyor belt	Grainger Industrial Supplier	$5.78	9	$52.00
DC Vibration motors	Amazon	$6.05	2	$12.09
Plexiglas	Home Depot	$7.99	2	$15.98
Microprocessor	Arduino	$44.99	1	$44.99
Stepper motor	Adafruit	$14.00	1	$14.00
DC motor	Phigidt	$107.49	1	$107.49
LCD display	Sparkfun	$4.99	1	$4.99
Keypad	Sparkfun	$8.99	1	$8.99
On/off switch	Sparkfun	$1.99	1	$1.99
Power supply	Adafruit	$24.95	1	$24.95
Hinges	Home Depot	$3.39	1	$3.39
Motor shield	Amazon	$34.95	1	$34.95
Frame for conveyor	Metal Fabrication and Sales of Tallahassee	$166.82	1	$166.82
Clamps	Home Depot	$0.97	4	$3.88
Miscellaneous Electrical Components	Adafruit/Radioshack	$130.99	1	$130.99
Miscellaneous Hardware	Home Depot	$35.00	1	$35.00
Hex nut- 5/16	Home Depot	$0.35	6	$2.10
Hex nut- 5/8	Home Depot	$0.11	8	$0.88

Lock nuts- 5/16	Home Depot	$1.97	1	$1.97
Lock nuts-3/8	Home Depot	$1.70	1	$1.70
Female DC Power Adapter	Adafruit	$2.00	1	$2.00
2-Way 2.1 mm Barrel Jack Splitter	Adafruit	$2.95	1	$2.95
Jumper Wires	Adafruit	$3.95	1	$3.95
Stepper Motor Mount	Adafruit	$2.24	4	$8.95
Adafruit Shipping	Adafruit	$11.51	1	$11.51
Radial Bearings	Grainger Industrial Supplier	$14.66	2	$29.32
Plastic line level	Home Depot	$2.97	1	$2.97
Plexiglass	Home Depot	$9.78	2	$19.56
Epoxy-Loctite	Home Depot	$4.97	1	$4.97
Epoxy- Gorilla	Home Depot	$5.47	4	$21.88
JB Weld	Home Depot	$5.67	4	$22.68
Contour 600-Watt Single-Pole Preset Dimmer - White	Home Depot	$17.97	1	$17.97
Plastic corner guard 3/4" x 3/4" x 4'	Home Depot	$2.48	2	$4.96
Electrical tape	Home Depot	$0.79	1	$0.79
8" Zinc mending plate	Home Depot	$2.28	2	$4.56
1/4" drive 7/16" 6pt deep	Home Depot	$1.98	4	$7.92
48"-1/2"x 1/4" Steel plain flat bar	Home Depot	$11.68	1	$11.68
1'x1' plain	Home Depot	$7.47	1	$7.47

aluminum sheet				
Sheet metal aluminum Gauge 21 6x8	Home Depot	$8.97	1	$8.97
7" wire stripper	Home Depot	$7.93	1	$7.93
Threaded Rod Zinc 5/16x 24"	Home Depot	$1.76	1	$1.76
GE ergonic plastic sheet cutter	Home Depot	$4.97	1	$4.97
Plastic drop cloth	Home Depot	$1.98	1	$1.98
Steel plain flat bar	Home Depot	$13.99	1	$13.99
Tread mill belting	Amazon	$48.60	1	$48.60
Microprocessor	Arduino	$25.60	1	$25.60
Microprocessor	Arduino	$41.73	1	$41.73
Silicon glue	Home Depot	$3.89	1	$3.89
			Total	$1489.44

Breakdown by Major Components	Total Cost
Mesh Construction	$84.67
Funnel Construction	$215.89
Conveyor System Construction	$343.02
Frame construction	$336.56
Electrical components	$401.68
Used in all of prototype	$107.62

Budget Allocation

Process	Cost
Machining	$527.62

Assembly	$416.67
Electrical	$496.72
Raw materials	$48.43
Total	$1,489.44

Budget	$2000
Used	$1489.44
Available	$510.56

6. Material Safety Data Sheet

SECTION 5 — FIRE FIGHTING MEASURES

1. Extinguishing Media

   Do not use water, sand or carbon dioxide. Use graphite, copper powder, Lith-X (Ansul). If not available, dry sodium chloride, dry (anhydrous) calcium oxide can be used.

2. Special Hazards arising from the substance or mixture

a. Hazardous Combustion Products	Lithium oxide, lithium hydroxide.
b. General Hazard	Flammable solid. Water reactive. Combustible dust. Dust explosion hazard.
c. Properties contributing to Flammability	Water reactivity of solid and flammable hydrogen gas given off on reaction with moisture. Explosible dust- May form combustible dust concentration in air.
d. Flashpoint	Not Applicable
e. Flammable limits in air	Not a flammable liquid. However, contains a combustible dust. Concentration for dust is 30-40 g/m^3
f. Auto ignition temperature	Minimum ignition temperature for dust layer is 160 degrees Celsius.
g. Sensitivity to Static Discharge	Yes. Avoid generating dust; fine dust dispersed in air in sufficient concentration, and in the presence of an ignition source, is a potential dust explosion hazard. SLMP is sensitive to static ignition.
h. Sensitivity to static impact	Yes

3. Advice for fire-fighters

   Wear full protective clothing and self-contained breathing apparatus (SCBA) approved for fire fighting. This is necessary to protect against the hazardous heat, products of combustion and oxygen deficiency. Do not breath smoke, gases or vapors generated.

   Lithium fires can throw off molten lithium metal particles. Burning lithium releases corrosive lithium oxide dust and fumes. Lithium metal can reignite after fire is initially extinguished. Never leave remaining residue and be prepared to re-extinguish should reaction occur. Carefully place residue in steel drum, using a long-handled, non- sparking shovel, and cover with extinguishing media.

   Explosive hazard: Avoid generating dust; fine dust dispersed in air in sufficient concentrations, and in the presence of an ignition source is a potential dust explosion hazard.

   For additional fire fighting information, see National Fire Protection Ass. Standard NFPA 485.

SECTION 6 — ACCIDENTAL RELEASE MEASURES

1. Personal precautions, protective equipment and emergency procedures
   Before cleanup measures begin, review the entire SDS with particular attention to Section 2, Hazards Identification; and Section 8, Exposure Controls/Personal Protection.

2. Environmental precautions
   Do not wash into drains. Dispose of at a qualified waste disposal facility

3. Methods and material for containment and cleaning
   Remove all sources of ignition. To prevent ignition, cover with mineral oil (or kerosene), soaking thoroughly, and place in oiled steel drums, which are approved for transport. Keep water and moisture away from spilled material. Avoid generating dust; fine dust dispersed in air in sufficient concentrations, and in the presence of an ignition source is a potential dust explosion hazard. Dispose of waste according to local and federal laws and regulations.

4. References to Other sections
   Before cleanup measures begin, review the entire SDS with particular attention to Section 2, Hazards Identification; and Section 8, Exposure Controls/Personal Protection.

SECTION 7 — HANDLING AND STORAGE

1. Precautions for Safe Handling
   For bulk containers, wear goggles or safety glasses and face shield in vented area with fume/dust abatement, or a full face respirator. Wear fire-retardant clothing. Wear dry, gauntlet style rubber gloves. Use proper anti-static precautions including grounding of all containers, equipment, tools, and operators. Dust abatement system should allow for safe disposal of any accumulated dust (e.g., filter disposal). Proper fire suppression systems should be in place. Transfer of bulk quantities should be performed under a dry argon atmosphere with proper mitigation of dust. Store sealed containers in climate-controlled area, away from excessive moisture and humidity, with fire suppression system in place.

   For small amounts (< 0.1 kg) wear safety glasses and some additional face protection (may include goggles (in place of glasses), face shield, or fume hood sash in proper position. An appropriate dust mask should be used. Alternatively, an argon glove box can be used. Some dust abatement should be in place (e.g., fume hood). Dust abatement system should allow for safe disposal of any accumulated dust (e.g., filter disposal). Use chemical resistant gloves such as nitrile (also can be anti-static). Wear fire-retardant clothing. Use proper anti-static precautions including grounding of all containers, equipment, tools, and operators where possible. Proper fire suppression should be in place. Transfers should be made under argon when possible, although handling briefly under a dry air atmosphere (relative humidity < 1%) is acceptable when applying the material for use.

2. Conditions for safe Storage, including any incompatibilities
   Store sealed containers in dry climate controlled location with fire suppression system. Keep away from water, humid air, acids, oxidizing materials, and flammable material. Keep away from heat, sparks, and flame. Ground bulk containers.

3. Specific end use(s)
   Not available. Chemical safety assessment has not been completed for this product.

SECTION 8 — EXPOSURE CONTROL / PERSONAL PROTECTION

1. **Control Parameter**
   Lithium Metal
   DNEL
   Long-term exposure, systemic, inhalation 4.2 mg/m3
   Long-term exposure, systemic, dermal 12 mg/kg/day
   PNEC
   PNEC aqua (freshwater) 0.165 mg/l
   PNEC aqua (freshwater, intermittent) 1.65 mg/l
   PNEC STP 23 mg/l
   Exposure Limits

Chemical Name	EU TWA STEL	EH40 (UK WEL) TWA STEL	USA (ACGIH) TWA STEL/Ceiling	USA (OSHA) PEL STEL/Ceiling
lithium	none*	none*	none*	none*

2. **Exposure Controls**
   Engineering controls:
   Use local exhaust ventilation to keep airborne concentrations below exposure limits.

SAFETY DATA SHEET

SECTION 1 — CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

Product Identifier Stabilized Lithium Metal Power			SDS Ref. No: QS-SDS-175
Product Use Additive for preparations and articles for industrial and consumer use; Component in lithium batteries; Do not use for private purposes (household)			
Manufacturer's Name FMC			
Street Address Seven LakePoint Plaza 2801 Yorkmont Rd., Suite 300			
City Charlotte	Sate Florida	Email lithium.info@fmc.com	Web: www.fmclithium.com
Postal Code 28208	Telephone 1.704.868.5300	FAX 1.704.868.5370	1.888.lithium
Emergency Telephone Number	CHEMTREC 1.800.424.9300	Plant 1.704.629.5361	Medical 1.303.595.9048
Date MSDS Prepared April 3, 2015	MSDS Prepared By FAMU-FSU College of Engineering Group # 16		

SECTION 2 — COMPOSITION/INFORMATION ON INGREDIENTS

1. GHS Classification [EC: Regulation No 1272/2008; US: OSHA regulations]

Chemical Name	CAS Number	EC No	EC Index No	REACH Reg No	Wt %	Classification, Hazard Statement Code	
Lithium metal	7439-93-2	231-102-5	003-001-00-4	01-2119966143-38-0000	97.0-99.9	Water-reactive1 Skin Corr. 1B	H260 H314 EUH
Lithium carbonate	554-13-2	209-062	none	01-21119516034-53-0005	0.1-2.5	Acute Tox. 4 Skin Irrit. 3	H302 H319
Lithium Oleate	7384-22-7	230-960-8	none	Not available	0.01-2.5	Acute Tox. 4 Skin Irrit. 3	H302 H319

SECTION 3 — HAZARDS IDENTIFICATION

Classification of the Substance or Mixture:

1. GHS Classification
   a. Water-reactive, Category 1
   b. Corrosive to Skin, Category 1B
   c. Self-heating Solid, Category 1

2. EC: Classification
   a. F, R14/15
   b. C, R34

Label Elements:

1. Hazard Pictograms:


2. Signal Word Hazard Statements: Danger
   a. In contact with water releases flammable gases which may ignite spontaneously H260

b. Causes severe skin burns and eye damage	H314
c. Self-heating, may catch fire	H251

SECTION 4 — FIRST AID MEASURES

1. Description of First Aid Measures
   a. EYES:
      Immediately flush with water for at least 15 minutes, while simultaneously lifting the upper and lower eyelids intermittently. See a medical doctor or ophthalmologist immediately.
   b. SKIN:
      Quickly wipe off as much as possible, then immediately flush with plenty of water while removing contaminated clothing and/or shoes. Thoroughly wash with soap and water. Obtain immediate medical attention. Contact a medical doctor if necessary.
   c. INGESTION:
      Quickly wipe material from the mouth and rinse mouth with water. Do not induce vomiting. See a medical doctor immediately.
   d. INHALATION:
      Move to fresh air immediately. If breathing difficulty or discomfort occurs and persists, see a medical doctor. If breathing has stopped, give artificial respiration and see a medical doctor immediately.
2. Most Important Symptoms and Effects, both acute and delayed
3. Indication of any immediate medial attention and special treatment needed.
   This product is corrosive and reacts violently with water. Treatment should first remove much of the material as possible as quickly as possible, then slush with very large quantities of water. Ingestion may produce esophageal damage and/or aspiration damage; dilution with water and other water-containing materials may produce a reaction that exacerbates corrosive activity.

Hazardous decomposition products	Lithium is an element and does not decompose. However, it is highly reactive in contact with many other substances, releasing large quantities of heat and/or hazardous products. It can react violently with water, the humidity in air, and the moisture in other substances, releasing hydrogen gas, which may catch fire explosively. Corrosive fumes of lithium oxide and/or lithium hydroxide are also released.

SECTION 11 — TOXICOLOGICAL INFORMATION

1. Information on toxicological effects
   I. Lithium:

a. Acute toxicity	Based on the available data, the classification criteria are not met.
b. Skin corrosion/irritation	Classified as corrosive to skin on the basis of lithium.
c. Serious eye damage/irritation	Classified as corrosive to eyes on the basis of lithium.
d. Respiratory/skin sensitization	Classed as not sensitizing to the skin on the basis of lithium.
e. Germ cell mutagenicity	Classified as not mutagenic based on lithium.
f. Carcinogenicity	Classified as not carcinogenic based on lithium.
g. Reproductive toxicity	Classified as not a reproductive toxin based on lithium.
h. STOT-single exposure	Classified as not causing organ damage based on lithium.
i. STOT-repeated exposure	Classified as not causing organ damage on repeat exposure based on lithium.
j. Aspiration hazard	Lithium, a solid, does not present an aspiration hazard.

II. Acute Effects from Overexposure:
This product is extremely reactive with body moisture and is corrosive to skin, nose, throat, stomach and eyes (may cause blindness)

III. Chronic Effects From Overexposure:
No data available for product.

IV. Carcinogenicity Listing
EH40: Not listed
IARC: Not Listed
NTP: Not Listed
OSHA: Not considered a carcinogen under OSHA
ACGIH: Not Listed

SECTION 12 — ECOLOGICAL INFORMATION

1. Toxicity : No Classification

Lithium
- Fish, short-term, freshwater: LC50 = 18 mg/L
- Fish, long-term, freshwater: NOEC = 2.87 mg/L
- Daphnia magna, short-term, freshwater: EC50 = 10 mg/L with pH-adjustment
- Daphnia magna, long-term, freshwater: NOEC = 1.7 mg/L
- Algae (Pseudokirchneriella subcapitata), long-term, freshwater: ErC50 = 25.6 mg/L

2. Persistence and Degradability
   Material reacts slowly with air in the environment to form lithium hydroxide, lithium carbonate and nitrides.
3. Bioaccumulative potential
   Not Accumulative
4. Mobility in soil
   No data available for product
5. Results of PBT and VPvB assessment
   Not Applicable for lithium metal
6. Other adverse Effects
   Lithium metal reacts violently with water. The hydrolysis products consist of hydrogen gas and lithium hydroxide. The hydroxide ion may affect the pH of the water.

SECTION 13 — DISPOSAL CONSIDERATIONS

Waste treatment methods

Waste containing lithium metal is considered a reactive waste. Disposal facilities specializing in the handling of reactive waste are recommended. Dispose of waste according to local and Federal laws and regulations.

SECTION 14 — TRANSPORT INFORMATION

UN Number	UN3209
UN proper shipping name (IMDG, ICAO, ADR, DOT)	METALLIC SUBSTANCE, WATER-REACTIVE, SELF-HEATING (STABILIZED LITHIUM METAL POWDER)
Transport hazard class(es) (IMDG, ICAO, ADR, DOT)	4.3, Dangerous when wet, (4.2 Self heating solid)
Packing group (IMDG, ICAO, ADR, DOT)	I
Environmental hazards	Based on available data, the classification criteria are not met.
Special precautions for user	None
Transport in bulk according to Annex II of MARPOL73/78 and the IBC Code	Based on available data, the classification criteria are not met.

SECTION 15 — REGULATORY INFORMATION

1. Safety, health, and environmental regulations, legislations specific for the substance [or mixture]

a. European Union

German water hazard class

Lithium	2
Lithium Carbonate	1
Lithium Oleate	not listed

b. United States

Section 311 Hazard Category (40 CFR 370):	Reactive, fire hazard, immediate (acute) health hazard.
Section 313 Reportable Ingredients (40 CFR 372):	This product does not contain a toxic chemical subject to the reporting requirements of Section 313 of Emergency Planning and Community Right-To-Know Act of 1986.
Section 302 Extremely Hazardous Substances (40 CFR 355):	Not listed
CERCLA Hazardous Substance (40 CFR 302.4):	Not listed
TSCA Sec 12b Export Notification:	This product is not subject to TSCA 12 (b) Export Notification Requirements.

NFPA Rating: **Health: 3** **Flammability: 3** **Reactivity: 2** **Special:** W

XI. Biography

Team Members:

Vannesa Palomo: Team Leader

Vannesa Palomo is a senior of Mechanical Engineering at FSU/FAMU College of Engineering. She is the team leader of the prototype machine for coating stabilized lithium metal powder project. Vannesa has minors in mathematics, physics, and hospitality management. She is fluent in four languages: English, Portuguese, Spanish, and Italian.

John Shaw: Co-Team Leader

John Shaw is a senior in the Mechanical Engineering Student at the FSU/FAMU College of Engineering. He is co-Leader of Group #16 and the lead CAD designer. He has interned for a chemical insurance agency, conducting loss control surveys. He has also interned at FI-DE machine, as a intern working under a professional machinist.

Marcos Leon: Treasurer

Marcos Leon is a Senior Mechanical Engineering student at Florida State University with a focus on Mechanics and Materials. Marcos serves as the treasurer of Group 16. He holds membership in the Society of Hispanic Professional Engineers (SHPE), allowing opportunities for networking. His plans are to graduate in May 2015 with my BS and then work in product development.

John Magner: Presentation Leader

John Magner is a senior Electrical Engineering student at Florida State University with minors in Physics and Mathematics. Over previous summers, he has worked as an Electrical Apprentice for Intercostal Electric Inc. in Lake Worth, Florida. In 2014, he interned with Duke Energy in Winter Garden, Florida, in the Power Quality, Reliability, and Integrity department.

Maria Sanchez: Electrical Engineering Liaison

Maria is a Senior in the Electrical Engineering department at the FSU/FAMU College of Engineering. Her title for this project is Electrical Engineering liaison for group #16. She has previously worked in academic research and published a journal article. She has had an internship in the power distribution and management for URS Corporation, contracted at Kennedy Space Center.

Benjamin Tinsley: Webmaster

Benjamin Tinsley is a senior Mechanical Engineering student at FSU. His specialization track is magnet science, however his main interests lie in thermal fluid studies. In 2011, he participated in a pre-engineering internship with the USF's biomedical engineering department where he developed and tested controls for a sailboat designed to enable a paraplegic to command the sailboat individually.