6-13-2019

Pedal 4 Purification

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Santa Clara University

DEPARTMENT OF MECHANICAL ENGINEERING

Date: June 13, 2019

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Cory Yamagata, Coleton Rodd, Jonathan Keyes, Matthew LoGrasso

ENTITLED

Pedal 4 Purification

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF

BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

Dr. Tony Restivo

Dr. Walter Yuen

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ABSTRACT

The lack of access to clean drinking water remains one of the largest issues still facing humanity. The Pedal 4 Purification is a product that addresses this need by utilizing pre-existing bicycle infrastructure and local freshwater sources to allow people to purify their own drinking water on a daily basis. Attachable to any standard bicycle, the Pedal 4 Purification product consists of pump, purification, cart and adjustable kickstand subsystems that allow the operator to pump, purify and transport 40L of potable water. Pedaling at the reasonable rate of 60 rpm will provide the optimal flow rate of 1.54L/min through the filter. At this rate, it would take the operator 26 minutes to provide enough drinking water to satiate 20 people for the day. As a result of the drastic reduction in the time and effort it takes for individuals to obtain drinking water, target communities will have more free time allowing them to focus on other pressing issues. Use of the Pedal 4 Purification product results in a 266% increase in user time savings as well as 54 times the amount of water collected per minute of user exertion compared to traditional methods. The Pedal 4 Purification team travelled to San Andres Itzapa, Guatemala to manufacture the entire device at Maya Pedal, an NGO that creates 'bicimaquinas' to help provide its local community members with basic human resource infrastructure. After the manufacturing process was complete, the team and Maya Pedal workers drove to the highland community of Patzun to implement the design and instruct the local people about how to use it. User feedback was noted after the successful implementation in the developing community of Patzun.

ACKNOWLEDGEMENTS

The authors wish to thank the following individuals for their help throughout the Pedal 4 Purification project thus far. Dr. Tony Restivo, Dr. Walter Yuen, and Dr. Timothy Hight, for their advisement throughout this project. Sincere gratitude goes to Allan Baez and the Frugal Innovation Hub for outreach support. A special thank you to Dave Renfrow, Lupita Lyneal Scooter, and David Odila for their help while working in Guatemala with Maya Pedal to ensure the project was completed as well as Pedro Ramos Hernandez for his generous guidance. Lastly, the authors would like to thank our parents, families, and friends for their dedication and support of our education at Santa Clara University.

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1. Introduction

1.1. Background and Motivation of Subject Matter

The lack of a consistent source of potable water is one of the largest issues facing the developing world today. Over 844 million people lack basic drinking water and it is projected that by 2025 half of the world's population will be living in water-stressed areas [1]. Besides the malnourishment effects that this can have on people, especially children, the lack of clean water kills one child under the age of five every two minutes. Furthermore, 1 in 9 people in the world do not have a clean water source close to their home [2]. This means that even if a village has been provided LifeStraws, or a similar purifying product, that users will still have to travel approximately 3km to obtain drinkable water. In many cases this trip is made easier by cycling, however, it is near impossible to carry a significant amount of water back to the community while riding a bicycle. According to UNICEF, women and girls worldwide spend an estimated 200 million hours daily retrieving water for their families [3]. This is a colossal amount of time that could be spent on other tasks if access to clean water was more easily facilitated.

Conversely, there are a huge number of bicycles present in every continent across the globe. In fact the World Bicycle Relief (WBR), an organization whose main purpose is to mobilize people through the power of bicycles, reports that the world produces over 100 million bicycles every year [4]. Interestingly, automotive car production falls behind that statistic at about 60 million per year. The WBR alone has deployed 427,055 bicycles in rural developing communities all over the globe, more than 200,000 of which were implemented in Africa, South America, and Southeast Asia. In addition, the organization has trained over 1,000 local people to be bicycle maintenance technicians so that they can keep the bicycles running properly. The WBR estimates that compared to walking, riding a bicycle reduces an individual's commute time by a whopping 75 percent [4]. Another major advantage of implementing bicycles in rural developing regions is that individuals can travel up to four times further while using less energy. Clearly, the pre-existing infrastructure of bicycles is ubiquitous throughout the world and is a valuable resource for individuals in developing regions.

The product proposed in this report will help alleviate this drinking water crisis by utilizing pre-existing bicycle infrastructure and local freshwater sources to allow people to purify their own drinking water on a daily basis. It consists of a water purification system that can attach to any bicycle and utilizes power generated by the user to draw water from a fresh-water source, through a filtration system, and into storage tanks. The Pedal 4 Purification would allow a family to obtain their clean water for the day significantly faster than before, lowering the stress involved with obtaining drinkable water in developing communities. As a result of the drastic reduction in the time and effort it takes for individuals to obtain clean drinking water, these communities will become healthier and women and children will have more free time to pursue other pressing issues such as furthering their education or other social justice issues.

1.2. Literature Review of Field

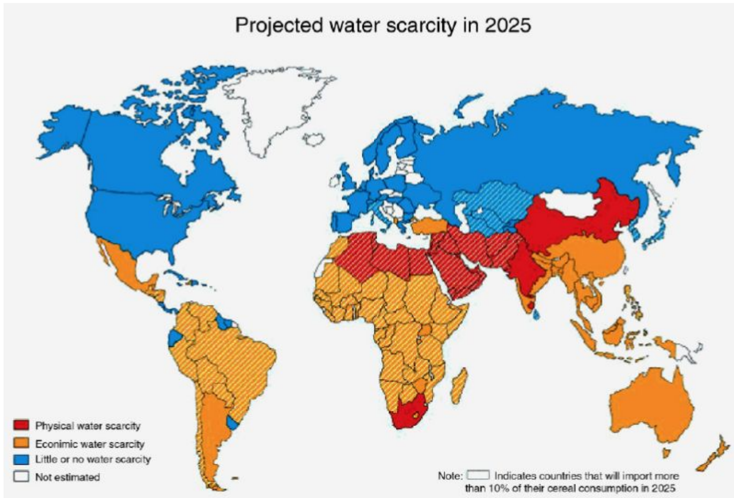

Figure 1. Global Water Scarcity [5, Reproduced without permission]

A geographic region is considered water scarce when a large population lacks access to safe and affordable water needed for drinking or cleaning for an extended period of time. Access to clean drinking water remains a global concern with water borne illnesses causing the estimated death of 20 million people every year [5]. Children are the most impacted group with 5,000-6,000 kids dying every day from water-borne disease. Access to clean water plays an important role not only in avoiding debilitating disease, but also in supporting economic and social development of a population.

Only 0.3% of the world's water is freshwater. With 98.5% of Earth's freshwater located underground in aquifers, getting access to clean drinking water presents quite a challenge [6]. Groundwater tends to require less purification, but above ground fresh water is more readily available. Water pollutants take many forms, from man made chemicals that leak into our water supply via agricultural run off, to naturally occuring heavy metals that contaminate drinking water via metal piping. Both man-made chemicals and heavy metals are detrimental to human health with build up of heavy metals in human tissue over time leading to harmful physiological effects. Microorganisms such as bacteria, viruses, protozoans and parasites also pose health risks to humans and are often a product of our own waste.

Eradicating the different forms of pollutant from collected water proves quite a task. Fortunately, finding clean drinking water has been our number one priority since our inception and as a species we have evolved various techniques to cope with mankind's longest standing trial. The conventional, established methods for cleaning drinking water include coagulation, flocculation, sedimentation, filtration and chlorine disinfection. Interestingly, while the use of chlorine to purify drinking water effectively deters microbial pollutants, it also creates purification byproducts that could potentially harm humans. Enough chlorine is added to drinking water to remain at 1 part per million to avoid regrowth of algae or microorganisms in the water supply [5].

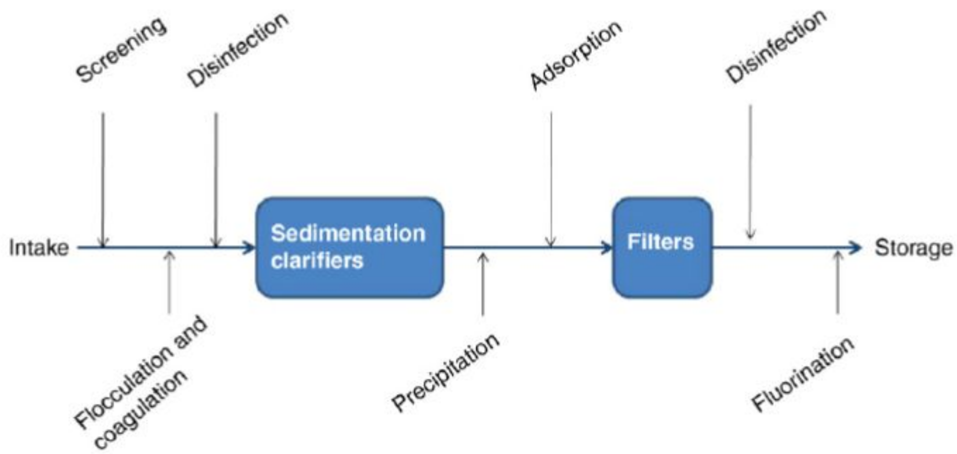

Figure 2. Basic Water Purification Process [5, Reproduced without permission]

The following method outlines the general idea behind current water purification processes. Another step in the purification process involves the addition of aluminum sulfate to drinking water to cause charged colloids, tiny impurities in the water, to floc together and settle so that they are easier to remove than the initially charged, less dense particles. Removal of impurities such as clay, silt and the newly formed flocculates occurs through the filtration of the water through a bed of sand and gravel. As water passes through the sand, the remaining particles are trapped in the sand bed.

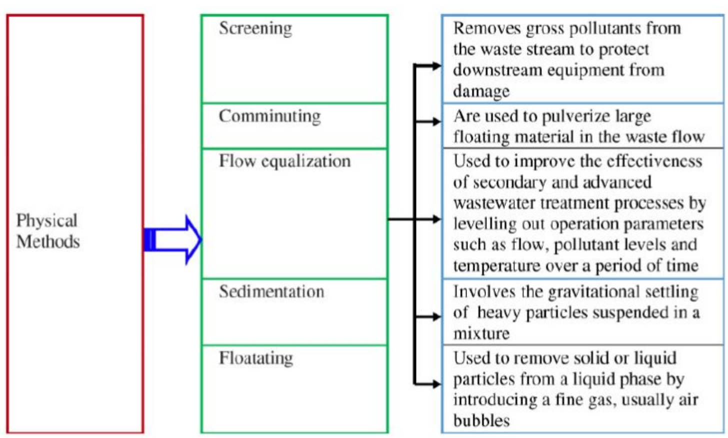

Figure 3. Physical Purification Methods [5, Reproduced without permission]

The use of membranes in filtration systems provides a physical barrier that traps pollutants still freely flowing in the water supply. Most membranes are made of synthetic organic polymers. An important consideration to keep in mind is the effect of a membrane on fluid flow and performance. When choosing a water purification method there exists a constant battle between the permeability and selectivity of the membrane, the winner selected for its design/function parameters. Metal nanoparticles offer an interesting option for water purification. Silver compounds are successfully used as antimicrobial compounds for coliform compounds in wastewater treatment. While zinc oxide nanoparticles were successfully used to remove arsenic from water.

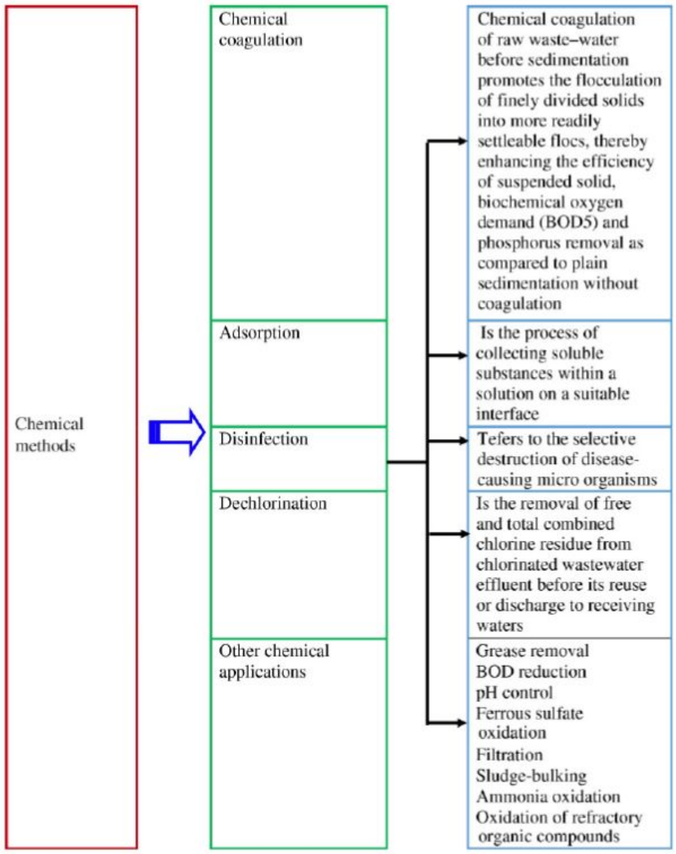

Figure 4. Chemical Purification Methods [5, Reproduced without permission]

Important considerations for choosing the optimal method and material for wastewater treatment are health/safety standards, absorption capacity and cost. As can be seen from [5, Figure 3] and [5, Figure 4], there is a main decision of choosing between a solely physical, solely chemical, or a combination of water purification techniques. The ideal absorbent should have a high absorption capacity, a rapid absorption kinetic, environmentally non-toxic properties, high reusability and ease of separation. Currently, magnetic nanoparticles (MNPs) with spinel structures are promising candidates for absorption based treatment methods as they have a strong absorption capacity, are easily separated by magnets, and have high thermal, mechanical, and corrosive stability.

Another option for wastewater treatment is the photocatalysis method which involves degrading organic particles via light [6]. Current photocatalysis techniques are easy and offer cost effective treatment however the low yield of the treatment process severely limits its usability.

Furthermore, there are many different water purification techniques that have arisen due to accessibility to resources and environmental factors. UV Water Treatment has become a universal technique to purify water for developing countries at large and local levels, affecting small households to whole communities. UV light is able to destroy 99.99% of microorganisms, operating on a 24/7 cycle with proper energy supply [6]. It is able to do so by using its UV rays to alter the nucleic acid (DNA) or viruses, bacteria, molds, and parasites, so that they cannot reproduce and are considered inactive. Using this method of purification, water can flow through a system without the need for a holding tank or reduce flow rate due to a physical filtration barrier. Additionally UV Water Treatment is completely chemical free and one of only four methods approved for disinfection by US Food and Drug Admin (FDA).

Although there are many benefits to using a UV Water Treatment approach, this technique is not meant to treat wastewater that is visually contaminated. Particles in water can block UV rays and allow harmful particles to survive, making UV water treatment only ideal when combined with pre or post filtration devices to produce safe, potable water. If the water is murky or contains “floaties” a pre-filter should be used otherwise UV light cannot effectively reach microorganisms. UV Water Treatment Does not remove other contaminants from water such as heavy metals, salts, chlorine, or man-made substances like petroleum products of pharmaceuticals, making it not the most effective water treatment solution for communities affected by industrial waste and runoff. Considering these factors, UV water treatment is only effective with a reliable source of energy and clear water, limiting its effectiveness for developing countries with water that is filled with sediment and debris.

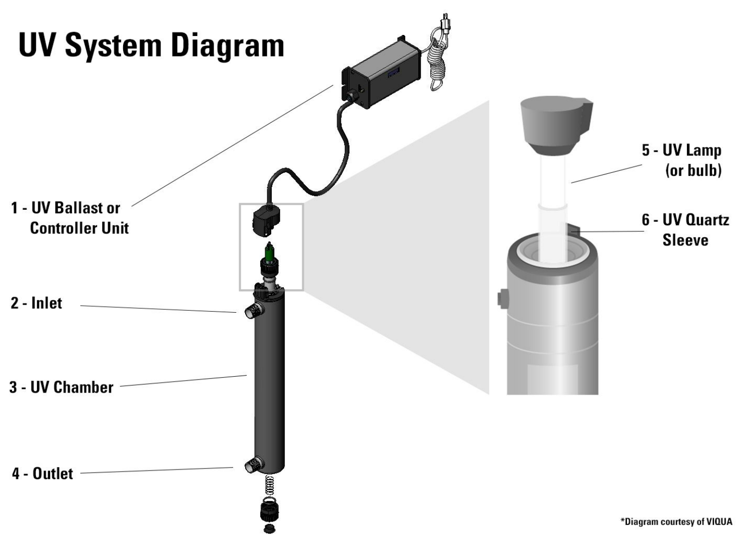

Figure 5. UV System Diagram [7, Reproduced without permission]

Another relatively new approach to water purification and treatment is Reverse Osmosis Filters. A diagram of a typical reverse osmosis filtration system is shown in [Figure 6] on the next page. While this technique to water treatment is considered one of the finest water filtration methods and reduces almost all organic and inorganic chemicals, bacteria, microorganisms, salt, metals and particulates that are found in contaminated water, it comes at a high energy cost. Reverse osmosis water filtration systems include a semipermeable membrane and a booster pump.

The ultra fine membranes have pores of approximately 0.0005 microns in size. Within this type of water treatment system, water can be pressurized to about 40-45 psi then forced through the membrane, removing anything larger that 0.001 microns. To eliminate large particles that might clog the ultra fine membrane, a pre-filter can be installed to remove silt, sediment, sand, and clay particle. An pre and post activated carbon filter is also recommended to further improve the smell and taste of water and to remove any leftover chemicals while trapping minerals such as chlorine which will shorten the membrane's life. [8]

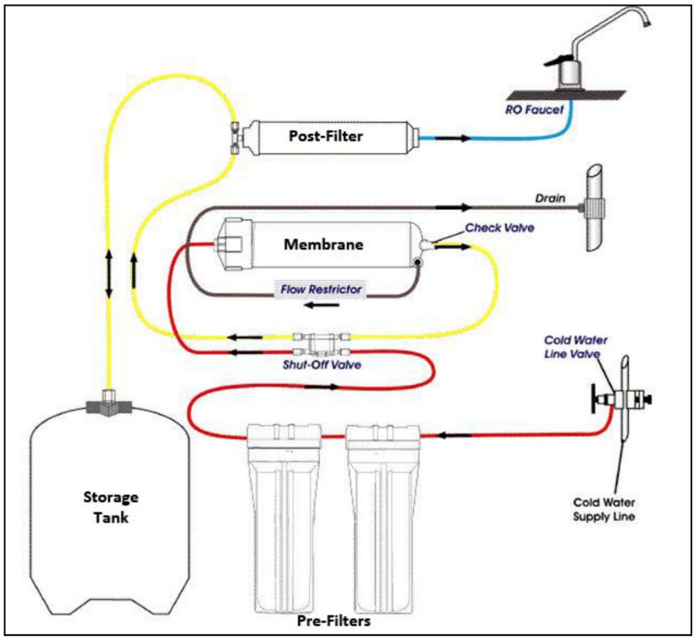

Figure 6. Reverse Osmosis Water Filtration System with Basic Components [8, Reproduced without permission]

Another technique for extremely fine purification of water is slow sand filtration. Slow Sand Filtration systems are commonly used globally in developing countries that require and cheap and sustainable approach to purify water. A general diagram of a slow sand filtration system with a slow sand filter, an effluent flow structure, and a clearwell is shown in [Figure 7, 9] on the next page. This system utilizes a biological process in a non-pressurized system to purify water. Slow sand filters are constructed with a bed of fine sand as the filtration media, and gravel to support the sand. On the sand surface, a biologically active mat known as "schmutzdecke" formed by solids, form the water being treated, establishing microorganisms and algae. It is within this layer that most of the treatment takes place. The presence of dissolved oxygen in the source water is essential for promoting the growth of the schmutzdecke. As water passes through the schmutzdecke layer, particles of foreign matter and dissolved organic material are absorbed and metabolized. Improvements in filter performance include the inclusion of a granular activated carbon (GAC) layer within the media to absorb organic chemicals and pre-ozonation ahead of the filter as another means of improving the removal of organics [9].

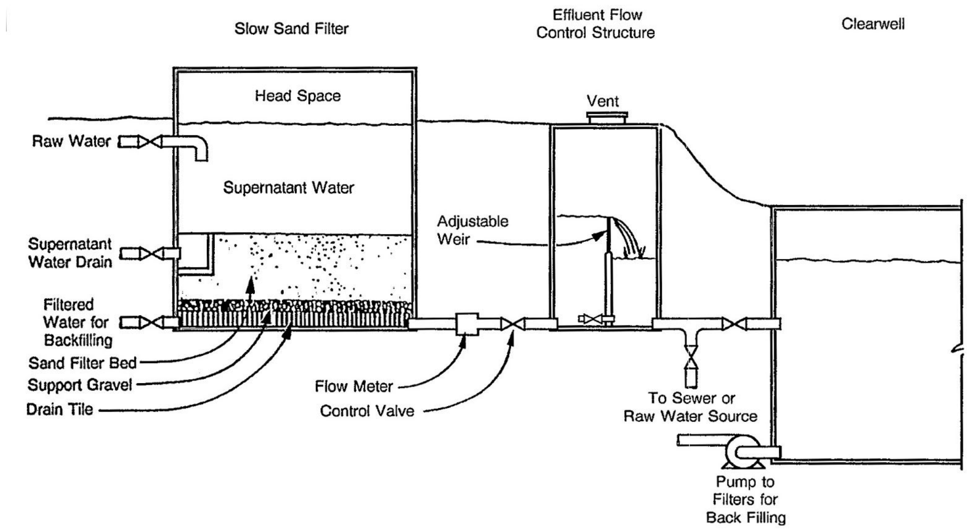

Figure 7. Diagram of Slow Sand Filtration system [9, Reproduced without permission].

While Slow Sand Filtration water treatment systems are the most affordable option for water filtration and purification, they are not defined whether SSF can be use with an influent water have high bacterial loads of greater than 105 MPN/100mL, which limits the overall capacity and efficiency [9]. While the overall flow rate of purification can be increased by enlarging the overall purification system tank size, for the use of a portable filtration device, SSF may not be ideal for a bike powered pump system. Due to its simple sediment layer configuration, any high level of turbidity of pipe flow from a pumped system can cause the filter to clog. Furthermore, flow rate of slow sand filters are directly proportional to the dimension. Slow Sand Filtration must have a steady slow flow at an average of 250L/h/m^2, and the height of sand can be no less than 75cm for the filtration method to work properly [9].

Yet another product that is commonly used to purify water is the activated carbon filter. A general diagram of an activated carbon filter system is shown in Figure 8. These filters are commonly used in the everyday lives of average water consumers, with the most common location being in a Brita Water filter. Activated carbon differs from regular carbon in a sense that activated carbon is processed with a slightly positive charge added to it, which makes it more attractive to harmful chemicals and impurities. The process of adding a charge is quite simple and can be done with an industrial oven. As an extremely porous material, activated carbon provides a high surface area to volume ratio which increases the rate of absorption, making it most effective at removing organic compounds including VOCs, radon, and chlorine. Activated carbon filters are commonly used as a precursor for other water purification systems such as reverse osmosis and ultraviolet (UV) water filters. Due to its nature as a naturally occuring resource, carbon can be obtained from a variety of sources such as coconut shells, wood, or coal. This aspect of activated carbon filters make them readily available almost everywhere in the world, making them a truly frugal resource that allows for innovation of water purification systems.

While there are many advantages for the use of activated carbon filters, they are effective only for a limited amount of time. Activated carbon bits cannot be reused and need to be replaced after filtering about 150 L of water.

Given these limitations, families would need to potentially replace filters on a weekly basis, given that the total use of drinkable water per person per household is approximately 2 gallons per day [10]. This amount of water per person only takes into account the amount of potable water consumed by the individual and does not consider any additional uses of the water for activities such as cooking, cleaning, and bathing.

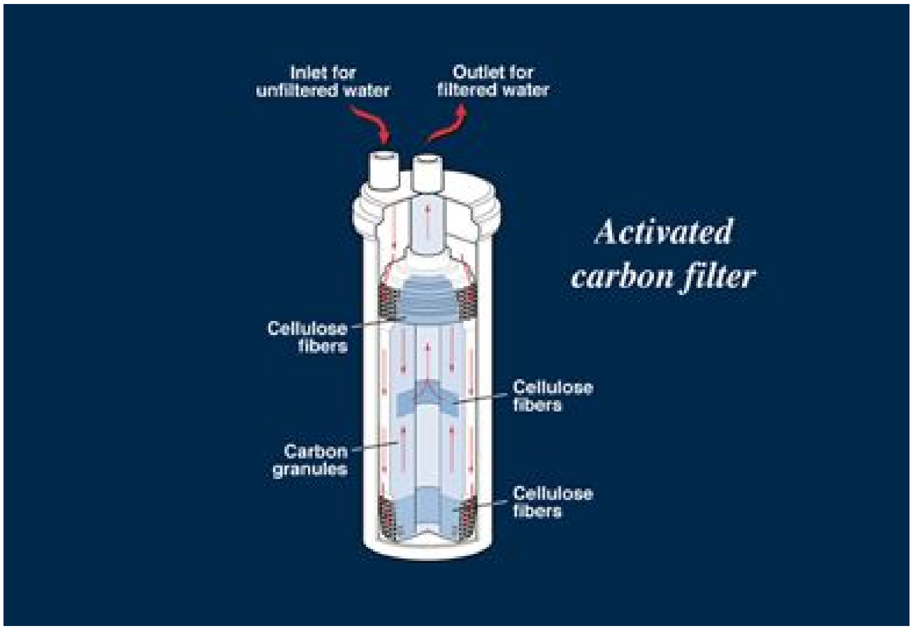

Figure 8. Diagram of Activated Carbon filter with inlet and outlet openings [10, Reproduced without permission].

Another robust solution for proper water purification that backpacks off of the activated carbon filtration mechanism is the ceramic filtration system. Ceramic filtration systems are primarily comprised of two different subsystems: pot ceramic filters and candle ceramic filters. Pot ceramic filters operate exactly as they sound. A filter is flowerpot shaped and holds about 8-10 liters of water, which sits inside a plastic or ceramic receptacle. To use the ceramic filters, families fill the top receptacle or the ceramic filter itself with water, which flows through the ceramic filter or filters into a storage receptacle. Foundations like Potters for Peace are making large strides forward to implementing this type of product into developing communities around the world. The effectiveness of ceramic filters at removing bacteria, viruses, and protozoa depends on the production quality of the ceramic filter. Most ceramic filters are effective at removing bacteria and the larger protozoans, but not at removing the viruses. A 60-70% reduction in diarrheal disease incidence has been documented in users of these filters [11]. However if due to improper treatment and quality of filters, bacteria contamination can form.

Figure 9. Pot ceramic filtration systems mass produced and used on a global scale [11, Reproduced without permission].

Candle ceramic filters follow their shape more so than their actual name. Candle filters are most commonly comprised of a series of candle ceramic filters fitted in a plastic housing unit. The candle ceramic filters are commonly filled with activated carbon and other microfiltration bodies that are surrounded by a diatom, porous ceramic housing that acts as an additional layer of filtration for larger particles.

Figure 10. Close-up cross sectional view of a single ceramic candle filter [12,Reproduced without permission].

Multi ceramic candle filters are perfect for everyday use due to its lightweight design and easy to use inlet and outlet connection points. Regardless of the somewhat high cost that comes with using this type of filters, ceramic candle filters return the highest volumetric flow rate in comparison to all other filters mentioned before, making it one of the most viable options for implementation into a bike pump system for developing countries.

Figure 11. Multi ceramic candle filtration system [13, Reproduced without permission]

A newly developed type of water filtration technique currently dominating the the water purification world is the use of microfiltration devices to purify water. These types of techniques can be most commonly seen in the design of the LifeStraw, a device that houses a hollow fiber membrane microfiltration with a 0.2 micron pore size. One filter alone can provide safe water for 1,000 liters (264 gallons) [10]. The LifeStraw does not, however, completely eliminate viruses which is quite a large issue when water is contaminated with harmful microscopic organisms. Although it is a frugally innovative device that offers a robust and simple solution to the potable water issue in communities that only have slightly polluted water, it does not address the issue of transporting water long distances.

Figure 12. Visual representation of a LifeStraw [14,Reproduced without permission]

Other companies similar to LifeStraw utilizing a similar technology is Life Sack, which can be seen in [11, Figure 13] below. The Life Sack uses SODIS technology, or Solar Water Disinfection Process, to purify the water using UV-A radiation and thermal treatment processes. The Sack exemplifies frugal innovation, as it is brought to communities filled with grains to help supply food. After the grains have been emptied the Life Sack doubles as a backpack and can hold up to 20 liters of fluid, allowing villagers to carry the heavy load from the local water source back to their communities with ease.

Figure 13. The Life Sack being used [15, Reproduced without permission]

Purification is an integral step in the Pedal 4 Purification design, but before the water is even purified it needs to be gathered. Modern technology allows easy access to all kinds of pumps which are capable of raising water by manipulating pressure using various techniques. The three most important characteristics of a pump system are pressure, friction and flow. Pressure is the driving force of the water while friction slows it down. Flow rate is the volume of liquid displaced over a unit of time. Pressure is created by forcing the water molecules closer together and is needed to overcome the elevation difference and friction force of the piping. Friction force can be generated in a number of ways, either by varying speeds of fluid within the pipe, or form water interacting with the surface roughness of the pipe. Friction depends on viscosity of the fluid, average velocity of fluid within the pipe, and pipe surface roughness. The Reynold's number is used to determine the fluid velocity and to determine if the flow is laminar or turbulent. The formula for Reynold's Number is

$$Re = \frac{\rho v D}{\mu} \quad [1]$$

where ρ is the density of the fluid, v is the average velocity of the fluid, D is the diameter of the pipe, and μ is the dynamic viscosity of the fluid. If the Reynold's number is determined to be less than 2100, the flow is laminar. If the Reynold's number is larger than 4000, the flow is deemed to be turbulent.

As soon as the velocity at the pump entrance is known, the 1-D energy equation can be used to estimate the height or pressure at which the water can be pumped under maximal operating conditions. The 1-D energy equation is as follows:

$$z_1 + \frac{p_1}{\rho g} + \frac{v_1^2}{2g} = z_2 + \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + H_L + H_M - H_P \quad [2]$$

where z is the height of the surface of the fluid of interest in relation to the reference ground, P is the pressure at the location of interest, ρ is the density of the fluid, g is the gravitational acceleration, v is the average fluid velocity, H_L is the head loss due to friction in the lines, H_M is the turbine head, and H_P is the pump head. Reasonable assumptions can be made about certain system parameters given the environmental situation in which the pump will be working. Furthermore, if the pump is known, certain limitations and parameters can be input into the 1-D energy equation to make the estimate more accurate.

An integral part of a pedal-powered bike pump system is the centrifugal pump. The centrifugal pump converts kinetic energy generated via cycling into a pressure force. The two basic parts of a centrifugal pump are the impeller, which converts the driving force into kinetic energy, and the diffuser which converts the kinetic energy into a pressure force. A key component of a centrifugal pump is the speed of fluid at the tip of the impeller vane. All of these different parts of a centrifugal pump can be observed in Figure 14 on the next page. The faster the impeller spins, the more energy that is imparted to the fluid. Rough estimates for the volume amount of fluid that a human-powered bike pump can generate hover around 30-40 Liters of water for a minute's worth of pedaling.

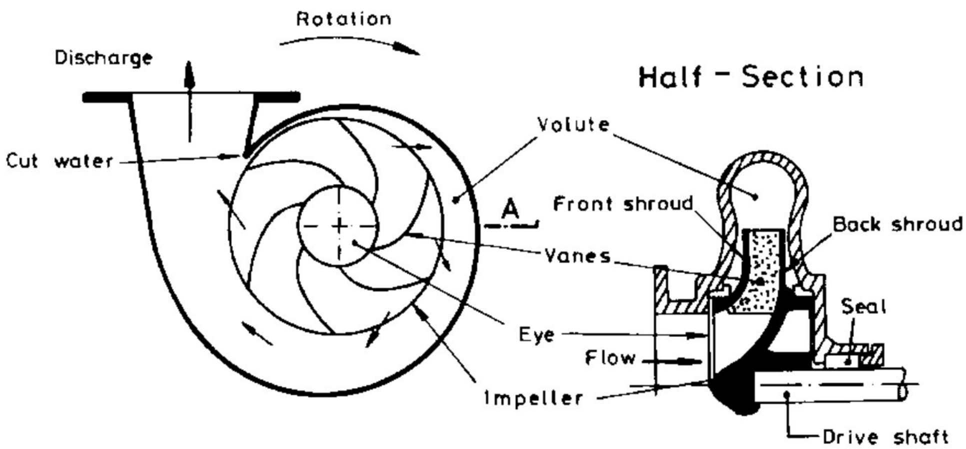

Figure 14. A diagram representation of a centrifugal pump [16, Reproduced without permission]

1.3. Statement of Project Objectives and Goals

The main objective of the Pedal 4 Purification project is to allow the user to purify water from a local resource and transport it back to their residence with ease and efficiency. The water purification process is simplified through the use of a multi-candle ceramic filter in combination with a mechanical pump. Modifications must be made to the pump in order to allow the rear bicycle wheel to transfer rotational mechanical energy to gravitational potential energy of the water. The goals for the purification process are to pass the EPA (US Environmental Protection Agency) standards for drinking water and to implement a filter that can provide safe water for at least 1,000 liters. The main objectives for the transportation of the cart are to allow any person who can ride a bike to carry 25 liters of water per trip from the local water source back to the user's residence and to house all of the necessary external components of the entire system [6]. The Pedal 4 Purification trailer cart must be universally attachable to almost any modern bicycle through the development of an innovative hitch system. The goal for the overall cost of the design is to come in at 10% of the current market leader's overall cost, making the Pedal 4 Purification a very frugal innovation that is available to developing communities all over the world. The detailed product design specifications for each subsystem of the Pedal 4 Purification can be seen in the Appendix of this report.

2. Design of System

2.1. Customer Needs

This product targets two types of customers: families without access to clean drinking water, and non-profit organizations. The first customer type, labeled *consumer one*, are families without access to clean drinking water who generally live in impoverished communities within 10km of a reliable water source. This customer has little relative purchasing power. The second customer type (*consumer two)* are global non-profit organizations, serving as potential subsidizers of the product. *Customer two* has a lot greater purchasing power, but also profoundly different needs. Receiving support from a non-profit organization would be the most successful way to introduce this product into the market. Non-profit sponsorship would allow customers with the greatest need for the product to purchase at reduced rates, allowing the product maximum customer exposure. Non-profits benefit from purchasing and promoting the bicycle/pump purification product receiving renewed consumer support for supporting a good cause. According to Horrigan, "91% of global consumers are likely to switch brands to one associated with a good cause, given comparable price and quality. 61% of consumers are willing to try a new brand, or one they've never heard of, because of its association with a particular cause. 50% of global consumers said they would be willing to reward companies that give back to society by paying more for their goods and services (44% in the U.S. and 38% in Canada)**.** Associating your company with a good cause proves an effective marketing strategy for corporations looking to improve public reputation and product sales, ultimately helping consumer base." [17]

This product is designed to unite these two customers, the family without clean water and the non profit organization, by simultaneously addressing the needs of both. *Consumer one*'s needs are shown in the table below categorized by priority level of either one or two.

This product strives to be a happy union between *consumers 1* and *2* and addresses the needs of both. In order to determine the needs of the two customers, raw data needs to be gathered from people using the product. This raw data can be gathered via direct interviews with the customer, or through focus group sessions with 8-12 customers in a conversation led by a facilitator. Auxiliary product information can be gathered by observing the product in use. We interviewed Allan Baez of the Santa Clara Frugal Innovation Hub to gather raw data about potential consumers. Allan has a great deal of experience with the developing world through his job at the frugal innovation hub and as an avid cycling enthusiast has important insight into the feasibility of implementing a bike based product in the developing world. Allan has traveled to Costa Rica, Nicaragua, Panamá, México, and Uruguay and mentioned that in his experience, bikes are very similar to cell phones in the sense that they are widely available in the developing world, are relatively inexpensive, and are used by everyone. Allan mentioned that the product should be designed to manage wet weather, as mud can prove detrimental to bike performance. He also mentioned the need for thicker tires even larger than the average mountain bike as paths get dangerously muddy during the rainy season. Allan provided perspective from the point of view of both *consumer 1* and *consumer 2* as his active involvement in the developing world gives him insight from *consumer 1*'s perspective, while his involvement with the Frugal Innovation Hub funding projects gives him insight as *consumer 2.*

Unfortunately, no extreme product users were contacted for an interview due to the relative dearth of similar products on the market.

The raw data was interpreted in terms of what the product must do, not how it might do it. Those needs were tabulated and ranked by importance and are displayed in **Table 1.** Below. Reflecting on the results of this process allowed the team to focus its attention on a product design that satisfies all of the customer's needs.

Table 1. Priority Ranking of Customer Needs.

Level 1 (Higher priority)	**Level 2 (secondary priority)**	**Latent Needs**
● Faster than walking* ● Less cumbersome than carrying the water on head* ● Less strenuous for the water gatherer than walking * ● Purifies water to potable levels * ● Filters water * ● Measurements in metric system * ● Child-safe * ● Device requires minimal management (purification system) (Instruction Manual to train user) * ● Affordable (our project pushes for the edge of cheapness) * ● Operable in wet weather* ● Operable with rough road conditions	● Device is easy to use ** ● Device is easy to set up ** ● Device is easy to dismantle ** ● Easily changeable filter (6 months) ** ● Materials available in country of use ** Can be constructed on location ** ● Quicker Speed of water purification ** ● Targeted more towards women? (emphasize in marketing stage) ** ● Replaceable parts, universally fitted parts ** ● Empower the local community**	● Handle for cart subsystem movement without hooking cart to bike ** ● Storage/ transportive capabilities (not pump) ** ● Child carrying capabilities **

2.2. System Sketch with User Case Scenario

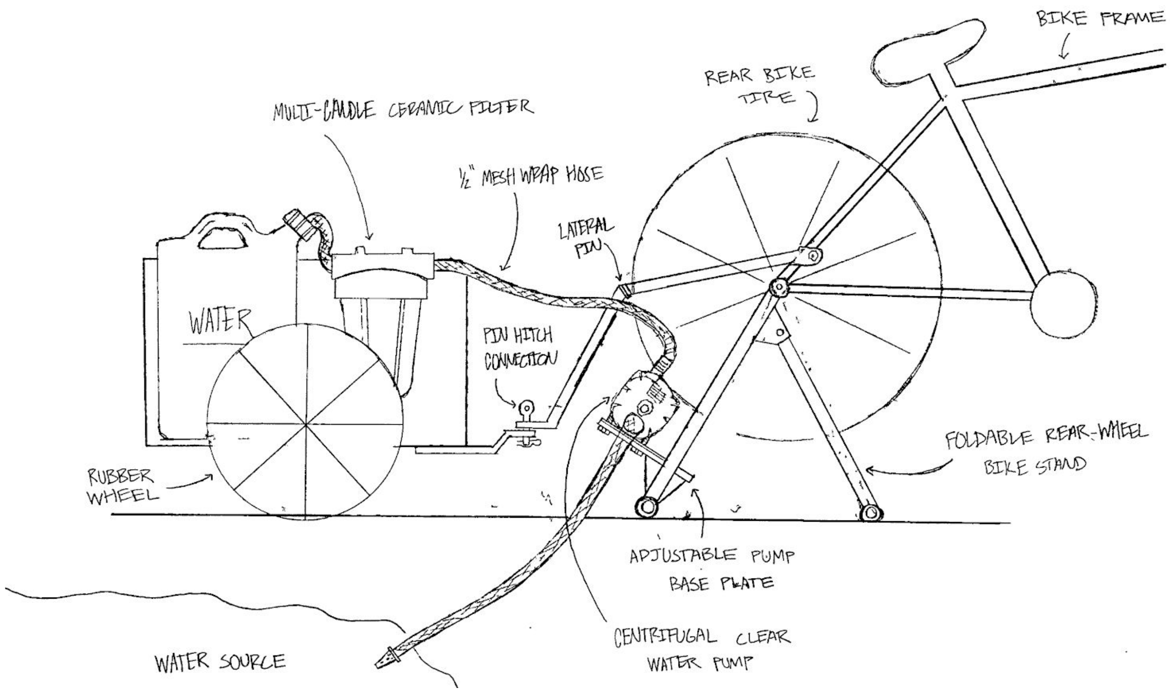

Figure 15. System Level Design Sketch [Cory]

Explanation

The intended users of the Pedal 4 Purification will be any individual who is capable of safely riding an adult-sized bicycle, whether it is a teenager or a middle-aged adult. An adult-sized bicycle is often classified as having a frame height range of 15 to 22 inches and wheel diameters of 26, 27.5, or 29 inches. Another common adult bicycle wheel size is the 700c classification. The bicycle must be sized for an adult because the pump adjustment module can only extend to a certain limit.

User Case Scenario

To begin using the Pedal 4 Purification, the user must obtain his/her bicycle and put on any personal protective gear in the case of an accident. The first task of operation is to check the status of the filtration system. If the green light flashes, the filtration system is still properly operating. If the red light is on, the multi-candle ceramic filter must be swapped with a new one to ensure that the water gets properly purified. Once the filtration displays a green light, the Pedal 4 Purification can be used. The hitch system must then be attached to the rear axle of the bicycle. The storage tanks, the hoses, and the kickstand component must be stowed away safely inside the cart for later use. Once the hitch system has been attached, the user begins operating the bicycle and rides to the local freshwater source. Once the individual has reached the water, he/she puts down the bicycle kickstand to ensure that the entire system does not topple over. The user ensures that the bicycle and the trailer are on level ground so that once the Pedal 4 Purification tank is filled, it does not travel backwards downhill and into the water. After that, the user locates the pump kickstand in the Pedal 4 Purification cart and places it underneath the rear axle of the bicycle so that the wheel is not touching the ground. The pump module must then be adjusted to ensure that there is sufficient frictional force between the tire and the impeller rod. The three hoses are then located inside the cart and placed on the appropriate locations of the pump to ensure a smooth flow of water. The entrance of the first hose is gently placed into the water. The final exit of the third hose must be placed within the top hole of a storage tank inside the cart so that maximal purified water is saved during the pumping process. To begin the priming process for the pump, the user must walk down to the water source and fills the bucket with water. The user then carries the water bucket up to the location of the pump and pours the water into the exit hole of the pump. Once the water has filled all the way up to the exit hole of the pump, the priming process is complete. Water can then be easily pumped from the freshwater source to the storage tanks in the cart. The user sits on the bicycle and pedals as he/she normally would to actuate the pumping system. Once the first storage tank is filled, the user dismounts from the bicycle and replaces the full tank with a new empty storage tank. As soon as all of the storage tanks are filled with purified water, the bicycle rider can stop pedalling. The rider then gets off of the bike and closes the priming valve to ensure that water remains trapped inside the first hose up to the pump exit. The storage tank lids are shut tightly and stowed away safely to reduce the chance of them coming loose or bounding around inside the cart. After rinsing off the hoses, they are then placed back in their designated location inside the cart along with the kickstand subsystem. A brush is then used to scrub off any debris that is on or inside the pump. After everything is stowed away safely inside the cart, the bicycle rider ensures that the hitch is still connected tightly. If properly secured, the rider then straddles the bicycle and begins riding back to the location of residence. Extra precaution must be used while operating the bicycle with a fully loaded Pedal 4 Purification cart. When the rider arrives at the location of residence, he/she stops the bicycle safely and dismounts. The bicycle kickstand must be put down to ensure system stability. The user removes the rear plate of the cart to make the removal of the heavy storage tanks much easier. Once all of the tanks have been removed, the user replaces the rear plate of the cart. The Pedal 4 Purification is then placed in a safe and shaded location for storage.

2.3. Functional Analysis

2.3.1. Functional Decomposition

The main function of the Pedal 4 Purification is to purify and transport freshwater from a local water source back to a residential community with greater ease when compared to walking. The overall system must house the following subsystems: purification, pump/kickstand, cart, and hitch. The purification subsystem function is to purify the local source's water to the 0.3 micron level and remove any pathogens that may be harmful to the community. The kickstand pump subsystem functions are to hold the rear wheel of the bicycle above the ground while the user is sitting on it and to allow for enough friction between the axle of the pump and the rear tire in order to generate mechanical power to extract the water from the source. The cart subsystem functions are to carry the filled water storage tanks across different types of terrain (gravel, grass, marsh, soil, etc.) and to house all of the external components of the Pedal 4 Purification. The hitch subsystem function is to establish a secure connection between the bicycle and the cart subsystem, even while it is travelling across rough terrain.

2.3.2. Specific Inputs,Outputs, & Constraints

Table 2. A list of inputs, outputs, and constraints for the Pedal 4 Purification.

Category	**Description**
Inputs	● Mechanical power generated by bicycle rider ● Unpurified water from local freshwater source
Outputs	● Potable water stored in tanks
Constraints	● Rider must be capable of operating an adult-sized bicycle ● Cart carrying weight limited to 150 lbs ● Pump must be primed ● Pump head ≥ 3 meters ● Hose length ≥ 7.5 meters ● Only compatible with adult-sized bicycles ● Limited to one rider ● Finite life of filtration system ● System maintenance ● Local water source must have flat ground within 15 feet of water's edge ● Bicycle must have a kickstand

2.4. Benchmarking Results

One of the two main players in the water purification bicycle industry is a Japanese-based company called Cycloclean. This company has created a bicycle that can be seen in [18, Figure 15]. The Cycloclean comes with a water purifying attachment already installed and uses the filter design shown in Figure 16. This product is incredibly efficient as it is able to deliver 5 liters of clean drinking water in a minute with the average cyclist. In fact, this flow rate is so high that it is enough to supply 1,500 people with clean drinking water for one day. In addition to this, the Cycloclean filters are estimated to last for two years, which demonstrates the company's incredibly sustainable efforts by minimizing physical waste. This bicycle is designed for locations where clean water is no longer accessible due to natural disasters. The filter system included the Cycloclean is able to purify and dechlorinate water, allowing people in these disaster sites to draw water from local water sources or even through their bathtubs or backyard pools. The current market price of the Cycloclean system is retailed at $6600 [18].

Figure 16. The Cycloclean Bicycle [18, Reproduced without permission]

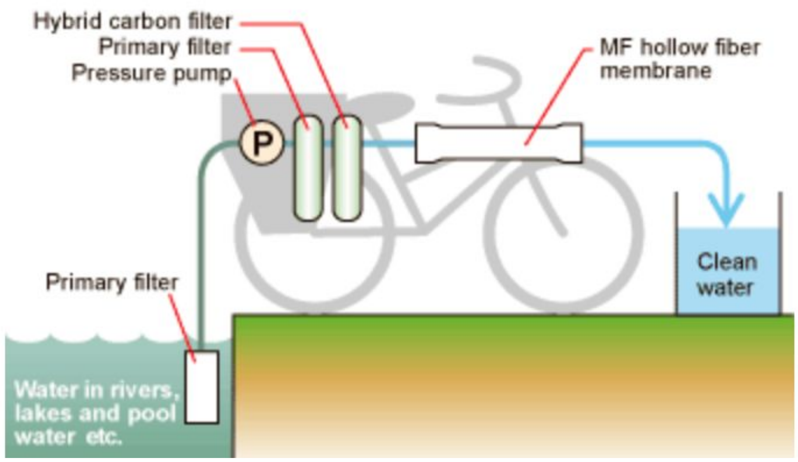

Figure 17. The Cycloclean Filter Design [18, Reproduced without permission]

Another leading product is the Aquaduct Mobile Water filtration system. This product is essentially a tricycle that has a tank of water on it and while riding the vehicle around a system powered by the pedals purifies the water. It contains a "dirty tank" in the back of the vehicle and "clean tank" in the front of the vehicle. The pedals power a peristaltic pump that draws water from the "dirty" tank, through a carbon filter, and into the "clean" tank. The bike also has the feature that allows the user to release the clutch and then the pedals strictly power the pump. The clean water tank is also removable and makes for easy transportation. This product is exceptional as it allows for the purification of the water while moving and has the tricycle style to avoid stability issues. However, much like the Cycloclean, this product is far too expensive to be implemented in the third world.

Figure 18. The Aquaduct water purifying tricycle [19,]

While the Cycloclean and Aquaduct seem to have little room for technological improvements, they do have a few flaws that limit them from being able to be used in the developing world. In other words, there are a few major improvements that can be made to the current technology. First, the two products are designed as a simple road bicycle with very thin tires. This type of bicycle is very difficult to maneuver when the surface is not paved. In many of the developing communities it is uncommon to have paved roads leading directly to a water source. Second, the bicycle purifies the water, however, it does not do much to alleviate the transport of the water as the front basket is the only storage container, and it can only hold about 6 liters of water. Finally, the price is incredibly high and limits the diversity of the buyer. The Aquaduct and Cycloclean both share a similar market price of $6,650 dollars, a massive number to pay for developing communities, making it almost impossible for it to be implemented. The Pedal 4 Purification would solve these three flaws as it is designed to be implemented on pre-existing bicycles. This would greatly reduce the cost of entrance into our market making it much more accessible to developing communities around the world. Also, since the bicycles are pre-existing in developing communities, they are most likely designed to handle the terrain of the surrounding area. The addition of the water tank would further improve the product as the goal of the project is to help developing communities that do not have clean water sources close to their homes.

Another possible solution could be the creation of a frugally designed tricycle with the same water purifying tank attachment. This design would fix the issue of stability when carrying a full tank of water. This tricycle could also be equipped with larger, impregnable tires so that the off-road terrain could be maneuvered as easily, sustainably, and with maximum stability. This design would allow us to also implement our gear shifter into the initial design of the tricycle which would limit the potential failures in shifting the drive-chain as adding a gear to a pre-existing bicycle could prove to be very difficult.

One other improvement that can be made to the concept of a water purification bike would be to engineer a bicycle trailing cart that stores and purifies water from rivers and streams using a very similar mechanism as that of the Cycloclean. This would be a huge advantage in terms of device cost because it could be attached to preexisting bicycles in areas where access to clean water is lacking.

In terms of mechanical design, the cart could either attach to the axle of the rear wheel or the tube seat joint of the bicycle and would follow behind using wheels attached to either side of it. Figure 18 and 19 below show the general ideas behind such a cart.

Figure 19. The seat rod connection mechanism for attaching the cart to a bicycle [20, Reproduced w/o permission]

Figure 20. The general overview of the rear axle connection mechanism [21, Reproduced without permission]

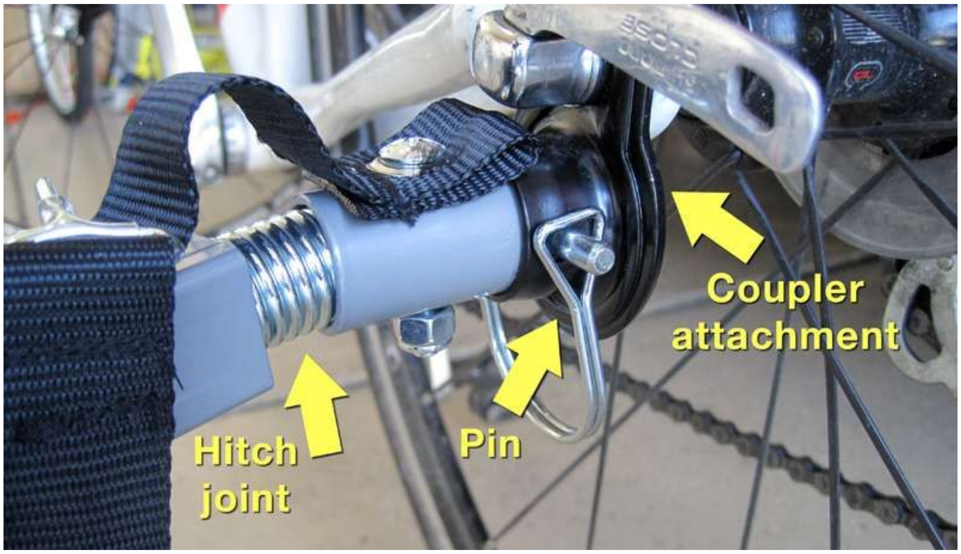

Figure 21. The rear axle connection mechanism for attaching the cart to a bicycle [21, Reproduced w/o permission]

The connection joint for the rear axle configuration is shown below. A stiff spring has been added to the joint for shock absorption. This would be particularly useful for developing countries without paved roads because there could be bumpy roads along the paths that the users would be driving on.

According to the Mayo Clinic, the average man needs to drink 3.7 liters of water every day [22]. Thus, the cart would have to be able to carry about 25 liters of water in order to have an overestimate of achieving the goal of providing enough drinking water for a family of 5 for one day. 25 liters of water is roughly equal to 44 pounds distributed along the axle of the cart. The main concern regarding this weight would be stress concentrations at the edges of the axle at the connections to the wheels.

2.5. Key System Level Issues

The Pedal 4 Purification product consists of four subsystems, a pump subsystem, a purification subsystem, a rear tire kickstand subsystem and a hitch-base subsystem.

The purification subsystem consists of several portions. A multi-candle ceramic filter comprised of standard Sterasyl filters with an external pre-filter is chosen for its ability to purify water contaminants down to a 0.2 micron level. This purification level remains below the drinking water EPA standards for the United States, which are set at 0.5 microns. The purification subsystem filters sediment and small particles from the water during pedal powered pumping and delivers the filtered water to 5 ceramic candle wick filters, each with a 1.5 liter/minute flow rate capacity. In summation, the 5 candle wick ceramic filters are capable of processing a volumetric flow rate of 7.5L/min. The candlewick ceramic filters purify the collected water and deliver it to the water storage units capable of holding 25 Liters of water. The filters are replaceable and have an average lifespan of approximately 8-9 months given that the filters are used on a daily basis processes anywhere from 20-100 liters of water each day. Other filter options were available, however the multi ceramic candle wick filters were chosen for their relatively low price, manageable volumetric flow rate, and ability to purify water contaminants down to a 0.2 micron level. The purification subsystem meets the customer need for access to clean drinking water. Furthermore, the purification system satisfies the customer need for easily replaceable/ universally fitted parts.

The pump subsystem manages the transportation of water from its source to the purification system. Many pumps satisfied the necessary specifications, so the pump decision making matrix shown in **Appendix C** helped select a final pump. The chosen non-priming centrifugal pump has a 5cm impeller blade, 3400 rpm angular velocity and flow rate of 31 L/min. Assuming the user bikes at an average speed of 15.5 km/hr, the pump powered solely by the user will rotate at 1618.71 rpm. This rpm correlates to a volumetric flow rate of 14.76 L/min for the water traveling from the source to the purification system. At this volumetric flow rate, it will take approximately 3 minutes of biking to fill the storage containers to 25L. This pump was chosen for its relatively low cost and small size while satisfying the necessary constraints imposed by the filter. The piping connecting the pump to the filter and the water source will have a total length of 6m with a diameter of 3.8cm. The pump subsystem helps satisfy the customer need for a less strenuous method of gathering water.

The rear tire kickstand subsystem provides a stabilizing force on the rear tire of the bicycle. The rear tire kickstand holds the rear tire in suspension over the pump, allowing only enough contact force to provide enough rotational force supplied by the rear bike tire in motion to power the pump. In most developing countries gathering water is delegated to women and children, so assuming an exaggerated human mass of 90kg, plus the average bike weight of 8kg, a loading condition of 500N was applied to the top edge of each weight bearing portion of the kickstand subsystem. In total, a forcing of 1,000N was applied to the kickstand subsystem using Solidworks simulation tool. The kickstand made of 6061 Aluminum alloy was easily able to support the assumed loading, with stresses in the subsystem remaining well below yielding. The rear tire kickstand subsystem helps the bike power the pump, ultimately assisting in meeting the customer need for a less strenuous method of gathering water. The rear tire kickstand is also made of durable material meeting the customer need for a product capable of handling heavy weathering.

The cart subsystem functions as the main storage unit for the pump, purification and kickstand subsystems. The cart subsystem is created with self contained storage slots to be able to transport the necessary materials to and from the water source. The cart subsystem is attached to the bike via a cart hitch which will receive tensile forcing. Using a tachometer, the average acceleration of the bicycle was estimated as 1.2 m/s^2. Assuming the hitch connects a cart mass of 100kg to a bike accelerating at an average of 1.2 m/s^2, the force applied to the inner part of the hitch is calculated as 120N. A similar force is assumed to be applied in compression of the hitch when coming to a stop however, failure due to this force can be assumed to be much lower than accelerating due to the gradual deceleration that a user would apply when operating the system. This load is applied in the constrained y-direction, simulating a pulling force on the cart. Stresses and strain in the cart hitch member made from 6061 Aluminum Alloy remained well below yielding. The cart subsystem is constructed with no sharp edges or unfinished materials, meeting the customer need for a child-safe product. Further storage space is added to the cart subsystem to address the latent customer need for a means of transporting materials not part of the Pedal 4 Purification product. The current cart subsystem design was chosen for its simple design consisting of inexpensive, easily replaceable materials. The addition of a cart subsystem addresses the customer need for an expedited method of collecting water. By supplying women and children with a quicker method of collecting the daily water requirement, more free time is available for them to devote to other activities, such as pursuing an education. This meets the latent customer need for community empowerment.

Finally, the hitch bar subsystem acts as a connecting subsystem between the rear of the bicycle and the cart subsystem through a series of pin and locking connections. The connection point between the hitch and the bike must be universally adaptable and require little to no significant modifications to the pre-existing bike frame or rear axle. This addresses the customer need for universally accessible, easily replaceable parts. The hitch bar is constructed to withstand constant fatigue loading and axial force along the length of the bar due to the fluctuating pulling forces produced when transporting heavy loads within the cart subsystem. By creating the hitch bar subsystem from a durable material, the customer need for a long lasting product is satisfied.

Overall, the Pedal 4 Purification allows the customer to collect water more efficiently than the current method of walking to a water source and carrying the collected water back in large vases. The Pedal 4 Purification provides a less strenuous way to collect water for women and children and expedites the overall process allowing them more time to pursue other activities, such as an education. Each subsystem component was selected with cost in mind in order to satisfy the customer need for an inexpensive, frugally innovative product.

When implementing the the Pedal 4 Purification system in developing communities, creating a user manual to help customers quickly acclimate to the product is a crucial future step in this product. Having a manual translate in the native language of the region can greatly reduce the learning gap when first operating the system. Furthermore, some type of covering will be added to the cart subsystem to help the product perform better in wet conditions.

2.6. System Level Design

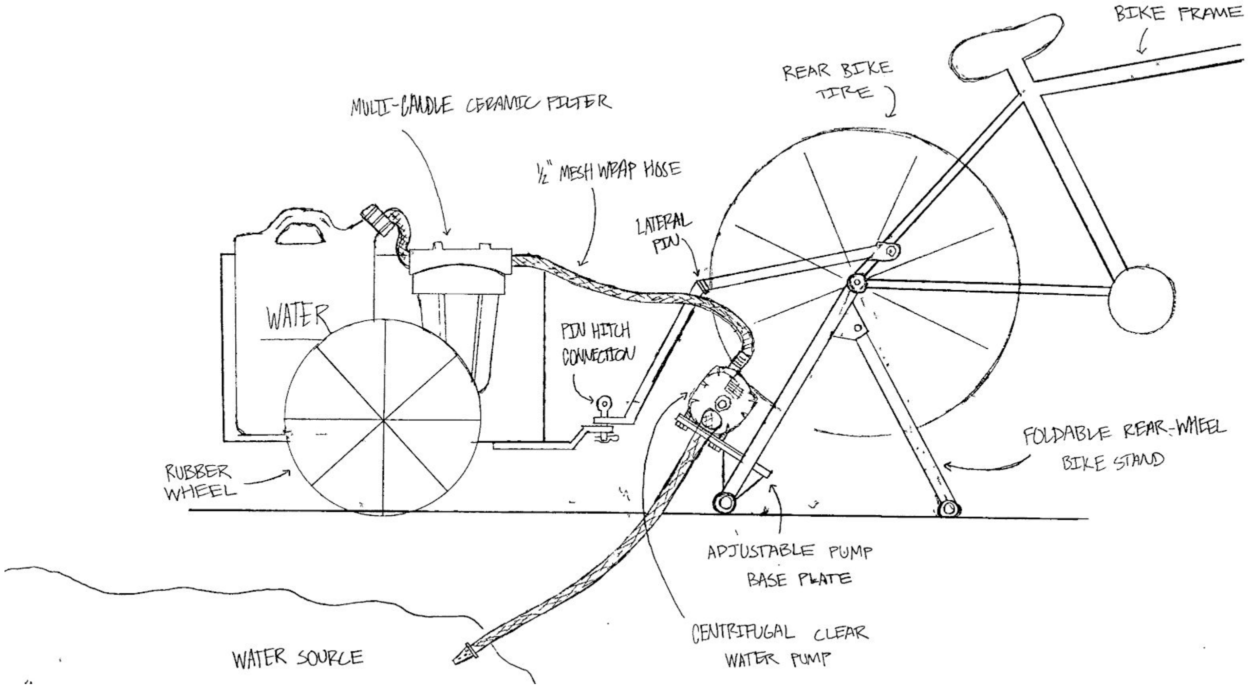

Figure 22. System Level Design Sketch [Cory]

2.7. Team and Project Management

2.7.1. Project Challenges

As the technology for the Pedal 4 Purification product is not revolutionary and for the most part already exists, the biggest challenge of this project is making it as frugally innovative as possible. This means meeting the exact needs of a community while also ensuring the product optimizes the following frugal engineering principles. Designing around specific constraints and parameters

Sustainability

It is crucial that this product is sustainable as the majority of the target communities do not have easy access to affordable gasoline or electricity. In addition to this, sustainable energy sources should be a priority for all engineering project in order to protect the world we live in. The Pedal 4 Purification project is 100% human powered and only runs off of mechanical power. This consumes no resources and produces minimal waste as the only physical output of the system in potable drinking water and the occasional worn out filter.

Simplicity

The product cannot be overly complex as the majority of the potential operators will have little to no experience using complex gadgets and machines. Also, if the product breaks down or requires regular maintenance this needs to be simple as there are most likely not machine shops or deeply knowledgeable engineers in these communities to be able to maintain the product. Not only is there not the personnel, but there is a good chance the community could not afford an expensive repair or even find the materials needed to repair it if it is not simple. This constraint was met by designing an easily interchangeable filtering system as well as being design around a bicycle, which the target community is already familiar with using and repairing. The most complex part of the system is the pump and this has been simplified by creating a intuitive operating system that requires minimal setup and maintenance.

Humancentric

It is important to design the product around the human to not only give a sustainable power source, but to also empower the individual. For the most part, the residents of these communities desire work as jobs are hard to comeby. By creating a human centric product, jobs can be created in addition to the benefits the product brings the community. In order to meet this constraint, Pedal 4 Purification is designed to be solely operated by humans with no external power source. This will allow for jobs to both be created and facilitated by finding an easier way to retrieve drinking water for a community.

Affordability

This is the largest constraint facing Pedal 4 Purification. What brings this project ahead of competing products is its affordability. The technology exists in the world today, but it is nowhere near affordable for developing nations where the most need is. In order to remedy this, the Pedal 4 Purification product has been designed around pre-existing bicycles which has drastically reduced the cost of entry into the market. Additionally the cart has been designed out of cheap, non-glamorous materials in order to lower the price.

2.7.2. Budget Plans

The budget for the Pedal 4 Purification project was $2,198.97 to cover costs of prototyping and final design testing. The main subsystems are broken down into four primary components that each require a unique level of design prototyping and testing to meet the necessary operating conditions of the overall project design. Many unforeseen budget issues arose due to the addition of subsystems to the overall conceptual design. The inability to weld on campus inflated the manufacturing cost for the cart subsystem. The addition of supplemental subsystems drove up the total cost of the project, and required extensive SolidWorks modeling and prototyping before purchasing to reduce production costs. While the costs of prototyping were originally factored into the overall cost estimates for the project, the numerous design iterations required due to limited material access available in Guatemala.

The cost breakdown for each subsystem is listed in [Table 3] below. These prices include the cost for prototyping as well as the outsourced welding for the cart subsystem. The outsourcing of the welding significantly drove up the cost and this would be done independently in a second iteration.

Table 3. Main Subsystem Costs Breakdown

Main Subsystems	**Costs (USD)**
Pump	$176.52
Purification	$399.16
Cart	$1,257.13
Kickstand	$230.42
Hitch Bar	$135.74
Total	**$2,198.97**

Note: Total cost of main subsystems does not include the cost of the bicycle

This cost was driven up additionally because many spare materials were purchased to leave with the community in Guatemala. This included additional filters, pumps, brackets, and aluminum. This will allow the community to be autonomous and self-sufficient.

Not shown in the table above is the cost of travel. The Pedal 4 Purification team received and additional $2,000 from the Santa Clara University School of Engineering to allow the team to travel to implement the product. This budget was exceeded due to higher than expected transportation costs. If this trip was to be done over again, it would be smart to get printed invoices from the agency as the team relied on word of mouth that did not end up being the correct price. The total spending for the implementation trip was $2,637 which puts the Pedal 4 Purification project $335.97 over budget. This deficit was funded by the team members themselves.

2.7.3. Timeline

The Pedal 4 Purification team began our design and thought process on June of 2018 and went through several project iterations before finally deciding on addressing one of the greatest problems affecting the developing world, lack of access to clean. From this idea, the Pedal 4 Purification project was born. The team first began by brainstorming several designs and techniques that can transport and draw water from a local water source while purifying it through the mechanically driven centripetal pedaling force of a bicycle.

The primary focus of the project rested on the development of a pump that could be purely mechanically driven in parallel with finding an adequate purification system that could decrease the amount of time spent purifying water for developing communities. By identifying the primary customer needs that needed to be addressed as well as the current market products that could be used to further development the design of the project, the Pedal 4 Purification idea was able to expand and adapt. Beginning in November of 2018, a small centrifugal pump, stationary bike trainer, and water purity testing device were purchased to begin prototyping and conceptual design testing of the overall system. In conjunction with prototype testing, substantial efforts towards reaching out to NGO's and non-profit organizations with help from the Frugal Innovation Hub were being processed to find a community to implement the project. After several more months of prototyping and further design testing, the Pedal 4 Purification team was able to find a local non-profit organization called Maya Pedal, located in San Andres Itzapa, Guatemala. Maya Pedal specialized in the creation of bicimaquinas (bicycle-powered devices) that aid in optimizing the tasks of everyday life. Once a consistent line of communication was established, the Pedal 4 Purification project took a different direction and began to adapt its system towards the needs of local community located in Patzun, Guatemala. This process began during the start of 2019 and progress further to final prototyping and testing of the cart, kickstand, and pump to record and analyze volumetric flow capabilities.

On April 2, 2019, the Pedal 4 Purification team traveled to Guatemala to work with Maya Pedal and construct the Pedal 4 Purification project. The duration of the trip lasted a total of 9 days which included the full construction of the project along with purchasing locally sourced materials while adapting to the constraints of the workshop. The Pedal 4 Purification was then taken to the Patzun community where it was implemented. The team spent the day showing the community members how to operate the project as well as help fix the lock-washer well they had installed. A large watch catchment was also installed alongside the well for further storage of water which could be more easily accessed and purified by the Pedal 4 Purification project.

All updated timelines for the entire length of the Pedal 4 Purification Project can be found in **Appendix E**.

2.7.4. Design Process

The Pedal 4 Purification team came together over a strong desire to create a product that would solve a major need facing the developing world today. With a great interest in finding a solution that would directly better the quality of life of a developing nation, the team decided that water scarcity was a prevailing issue that could be addressed. Over 844 million people lack basic drinking water and it is projected that by 2025 half of the world's population will be living in water-stressed areas [1]. Besides the malnourishment effects that this can cause on people, especially children, the lack of clean water kills one child under the age of five every two minutes. While there are many products that work on making water potable, 1 in 9 people in the world do not have a clean water source close to their home[1]. This means that even if the village has been provided LifeStraws, or other existing purification products, the villagers still may still have to travel long distances to get their water. In many cases this trip is able to be facilitated through the use of a bicycle, however, it is near impossible to carry a significant amount of water back home while riding a bicycle. According to UNICEF, women and girls worldwide spend an estimated 200 million hours daily retrieving water for their families. This is a colossal waste of time that could be spent in classrooms, other necessary tasks, or even relaxing if their access to clean water was facilitated [1].

In order to be a valuable product, the Pedal 4 Purification project would have to be designed to meet to crucial needs: purification of water and transportation of water. The team, composed of four mechanical engineers, resorted to the most mechanical system possible: the bicycle. As this is a frugal innovation project, the product must be sustainable and run on renewable energy. Not only are bicycles completely human powered and zero-emission vehicles, but are currently by the majority of third world communities. Since the community would not have to purchase the vehicle for a product centered around a bicycle, the cost of entry for the product significantly drops allowing Pedal 4 Purification to cater to a much more diverse, less wealthy consumer.

The Pedal 4 Purification project is a two part product: filtration and transportation. The first part is the purification system. As the design is to be centered around any universal bicycle, the team decided that the power should not be generated from the chain as this would require a difficult assembly and disassembly. An alternative method of drawing frictional power from the spinning tire was landed upon. The design is to consist of an impeller pump attached to a kickstand that could easily be attached and detached from the back wheel of the bicycle. This would allow the system to be easily swapped in between any bicycle in the community and would be a highly effective way to power the filtration system without require excessive physical exertion from the user. The pump would draw water from the source, through the filtration system and into the storage tanks.

For the filtration system, two main aspects were researched in order to find out which system would serve the projects needs best. First, the need for a high flow rate for efficient purification and, second, ensuring that the water is purified to pass EPA regulations for potable water. A multi-candle ceramic filter was then decided as the best fit for this project as it is has sufficient filtration capabilities and the highest flow rate. A main goal of Pedal 4 Purification is to save the consumer time on their water collection tasks so the flow rate was valued highly. Multi-candle ceramic filters have the ability to purify a flow rate of over 20 liters per minute enabling the user to fill their water tanks with speed and ease.

The second part of the project serves the need for transportation. The main constraint here was the stability of a two wheel bicycle carrying a load greater than 75 lbs. Many design iterations were run through in brainstorming sessions, but the need for stability mixed with the need for a large enough storage platform drove us into the direction of a trailing cart. This idea was inspired by the carts used to tow children in behind bicycles. Many adults are able to tow their children of roughly 80 lbs without extreme strength, exhaustion, or cycling expertise. The wider set, two-wheeled cart enhances the stability of the entire bicycle as it acts as a set of training wheels. This is very important for the Pedal 4 Purification project as the roads in the targeted communities will most likely be very bumpy and sloped. The cart could also easily be created completely in the majority of third world nations as it does not require any electricity, rare materials, or complex machining. This was another key design factor in the frugal innovation approach Pedal 4 Purification took to this project.

Overall, the key factors influencing all design process decision were a balance between meeting the need and creating a frugally adaptable product. This balance pushed us towards our best possible product as it is low cost, self-sustainable, able to be built in the community, human-centric, empowers the local community, and requires little maintenance. While at the same time is designed to greatly facilitate the transportation of water with minimal expertise needed and successfully purify water passed the EPA standards for potable levels.

2.7.5. Risks and Mitigations

The main risks and safety issues that come along with this product are all involved in the creation process. Once the product is completely constructed, the safety of the product will be no different than that of the average bicycle. In order to mitigate these risks, the following guidelines have been adopted by Pedal 4 Purification.

Manufacturing

A machine shop coordinator must be present at all times when group members are in the machine shop. Team members must wear safety glasses, long pants, and closed toed shoes during the total duration in which they work in the machine shop to ensure safety. The group will need to weld metal parts together to construct the hitch and the cart. Proper safety protection for welding such as safety glasses and gloves should be worn during the process. Metal parts will need to be sawed using the bandsaw in the machine shop. Follow the guidelines in *Mechanical Engineering Lab and Machine Shop Safety Instructions* for proper use of the bandsaw. During the pump modification process, team members will need to use the bandsaw to expose the impeller shaft. As previously mentioned, follow the guidelines in *Mechanical Engineering Lab and Machine Shop Safety Instructions* for proper use. No electrical power is required for the design or testing of the Pump 4 Purification, so any wires inside the pump will be removed. The team member who is removing the wires will wear gloves and ensure that nothing is plugged into a power supply.

Assembly

The assembly of the Pump 4 Purification will take place inside the machine workshop. Safety glasses, long pants, and closed toed shoes need to be worn inside the machine shop to gain entry. A machine shop coordinator must be present at all times when group members are in the machine shop. Assembling the manufactured parts together will include screwing, drilling, punching, and glueing. See the guidelines outlined in *Mechanical Engineering Lab and Machine Shop Safety Instructions* for proper instructions regarding each of these processes.

Testing and Operation

Only someone who knows how to operate a bicycle should perform the testing and operation of the Pump 4 Purification. During testing, the bicycle rider will need to wear a helmet, elbow pads, and knee pads to ensure protection in the case of a fall. Closed toed shoes need to be worn while operating a bicycle. Since the wheels will be rotating during testing, no one should attempt to get near them. The pump shaft will also be rotating, so no one should attempt to get near it. Ensure that testing occurs only in designated areas that are closed to the public. This will exclusively be done within the boundaries of the Santa Clara University Machine Shop Area. Dirty water should not come in contact with the eyes or mouth. If exposed to flesh, make sure to wash the area thoroughly with soap and water. Latex gloves should be worn when handling dirty water.

Storage and Display

The Pump 4 Purification will be stored in the machine shop. Each time the team modifies or uses it, they will put it back in its designated area and all loose parts will be unattached before leaving. Signs saying 'Do Not Touch' will be placed on the Pump 4 Purification to prohibit anyone from misusing it, leading to injury.
For displaying the Pump 4 Purification, group members will make sure to include the signs saying 'Do Not Touch' prohibiting anyone from touching or trying to use the device. The device will not be left unattended without the signs properly displayed. It will remain stood up by its kickstands while attached to a bicycle.

2.7.6. Team Management

In order to function as a unit with good chemistry, Pedal 4 Purification has adopted the following 20 guidelines for the team's code of conduct:

1. Every member of the team is responsible for the team's progress and success.
2. Attend all meetings and be on time unless otherwise communicated between the team.
3. Come prepared.
4. Carry out assignments on schedule.
5. Solicit input and then listen to, and show respect for, the contributions of other members; be an attentive listener.
6. Constructively criticize ideas, not persons.
7. Resolve conflicts constructively.
8. Pay attention, avoid disruptive behavior.
9. Avoid disruptive side conversations.
10. Only one person speaks at a time.
11. Everyone participates, no one dominates.
12. Be succinct, avoid long anecdotes and examples.
13. No one on the team has superior rank.
14. Respect those not present.
15. Ask questions when you do not understand.
16. Attend to your personal comfort needs at any time, but minimize team disruption.
17. The team shares in both successes and failures.
18. Strive to keep a healthy balance between the work loads of the team members.
19. Communicate clearly between teammates about prior engagements that may affect attendance of meetings or completion of project deliverables
20. Do not be shy about speaking out about ideas or concerns. Playing the Devil's advocate is encouraged when the time is right

If these rules are consistently violated by any team member, the team will discuss the changes that need to be made over the next meeting. If these violations continue to prevail, the issue will then be brought to the team advisor for further discussion and actions.

3. Subsystems

3.1. Pump Subsystem

3.1.1. Introduction

Centrifugal pumps are commonly used to transport large volumes of water for household and commercial use. A centrifugal pump operates by rotating a impeller blade to channel water through the eye or center of the pump. Due to the high rpm that most centrifugal pumps operate at, the centrifugal force compresses water against the outside of the blade. The pressure caused by this force pushes water out through the exit nozzle of the pump at high speeds that create pressure around the outlet of the pump, pushing water through the piping.

Small electric water pumps contain a small DC motor attached to the impeller, powered through a simple gear drive. In the center of the motor is a rotor with magnet coils that create a permanent magnetic field that flows through the rotor. When the motor is turned on, an electric current runs through the coils, producing a magnetic field that repels the magnets around the rotor, causing it to spin around 180 degrees. When the rotor spins, the direction of the electric current in the coils flip, driving the impeller through a series of pushes to power the pump. Depending on the size of the pump and liquid being transported, centrifugal pumps operate using an open, semi-open, or enclosed impeller blade design as shown in **Figure 22**. Open impeller blades are most commonly used in more robust designs that transport liquids that may contain various particles or sediment that could clog and harm the pump. Enclosed impeller blades provide superior centrifugal pressure forces but should only be used for clear water application.

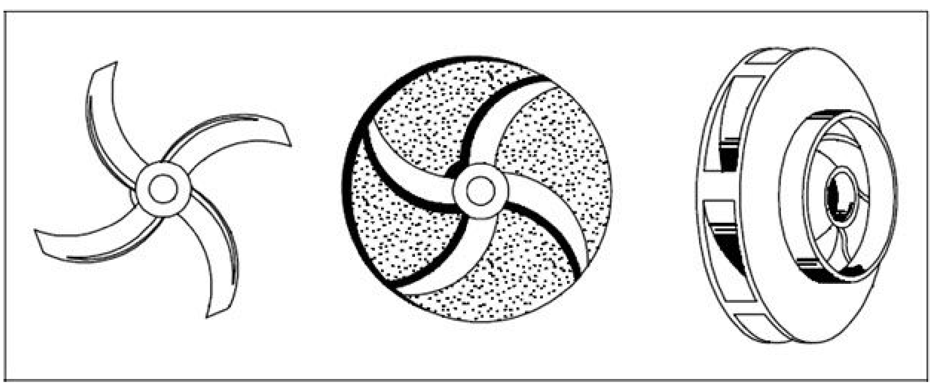

Figure 23. Open, Semi-Open, and Enclosed Impeller Blade Designs [23, Reproduced without permission]

It is common for centrifugal pumps used in household application to require some degree of priming, prior to use, in order to prevent any damage to the pump or piping system it interacts with. While self priming pumps do exist on the market, the addition of a self priming housing can exponentially drive up costs along with the additional weight of the cast iron housing. Pump priming is an essential step that usually requires a great deal of labor or an additional air pump to pull water through the piping and into the impeller housing for pumping.

The centrifugal online pump market provides extensive options when selecting a pump to fit specified operating conditions. However, despite the extensive range of options, finding a compact centrifugal pump to transport clear water is limited to a handful of companies that produce similar products that perform at identical product specifications. After further debate and discussion regarding the operating conditions of the pump, it was decided that the pump needed to achieve a minimum volumetric flow rate of 1.2 L/min while meeting a minimum head loss of 3.0 meters. The minimum volumetric flow rate was based on the recommended flow rate to purify water using a multi-candle ceramic filter. This operating condition will be mentioned in the following subsystem section addressing the purification system selection. A minimum head loss was estimated by proposing potential user scenarios when pumping from sources of water below the elevation of the pump. An estimated head loss value of 3.0 meter (9.8 feet) seemed to be a reasonable value, primarily focusing on the suction head of the pump. An additional operating condition involves the potential weight of the pump for transportation and operational purposes. Due to the additive weight of the pulling cart and kickstand, minimizing all potential sources of weight to the overall system is ideal project efficiency.

To operate within the frugal innovation product design parameters, the pump was set at a maximum price of $175.00. This price point was determined by factoring in the individual cost of each subsystem within the project design to reduce overall costs and maintain a total build cost of approximately $500.00. The two most expensive subsystems were predicted to be the pump and cart subsystems. By focusing on managing costs in both subsystems, a significant reduction in the total build cost of the Pedal 4 Purification project can be achieved.

3.1.2. Clear Water Centrifugal Pump Design Selection

After filtering through several options, the Tooluxe electric centrifugal clear water pump was selected as the best option to meet the constraints of the project shown in **Figure 23** below. The Tooluxe pump utilizes a compact DC motor surrounded by a cylinder magnet coils which will be removed in order to convert the pump into a frictionally driven mechanical pump. Due to the electrical driven rotor of the centrifugal pump, in order to turn the pump into a full manual, mechanically driven pump, all electric components will be removed. By removing the electrical coils that the rotor mechanism of the pump, the rotating axle housed in the cylindrical center casting of the pump will be able to float freely within the housing. The electrical components encased in the upper rectangular housing of the pump will also be removed to disconnect the motor from the primary rotor. By removing all electrical components housed within the pump primary aluminum housing, significant reduction to the pumps weight can be used to reduce the weight of the overall system.

Figure 24. Tooluxe Electric Centrifugal Clear Water Pump [24, Reproduced without permission]

Once all electrical components have been stripped from the pump, an angle grinder was used to remove a portion of the cylindrical cast iron housing, exposing the rotating axle of the impeller blade. By exposing the rotating axle of the impeller blade, a rotational friction force can be imposed onto the axle, converting the functionality of the pump into a fully mechanical system. The rear bike tire will act as the rotating friction force used to power the centrifugal pump. **Table 4** lists the product specifications for the pump that are well above the design parameters for the use of this project. To estimate the ability for a mechanically driven rotating bike tire to provide adequate rotational speed to produce a desired volumetric flow rate, a comparison to the pumps average rpm of 3400 will be compared to the rpm that can be produced using the rear bike tire rotation.

Table 4. Tooluxe Pump Product Specifications

Max Volumetric Flow Rate	Max Head	Max Head (Suction)	Pipe Size
31 L/min	28 m	9 m	2.54 cm

By determining the average cycling speed for an occasional biker traveling on level ground, an estimation of the pump rpm that can be achieved through the rotational power of the bike tire can be calculated. The average cycling speed for a biker traveling on flat ground is roughly 15.5 km/h (9.6 mph). This value was chosen based around the parameters that the cyclist was an occasional rider who had moderate experience riding a bicycle. After brief research into the accessibility of bikes in developing countries, a bike tire diameter of 26 inches was chosen to be the baseline for the project design. While 700C / 29 inch bike tires are also a commonly used tire on many bikes due to their advantage of rolling over holes and depressions in a road, 26 inch tires are more widely accessible for developing countries. Given the push towards a fully reproducible project using parts accessible to local areas of implementation, using readily available parts is crucial to the success of the design. The diameter of the rotating axle for the impeller blade was measured to be roughly 2.0 inches. Using these values, a reasonable estimate of the rpm of the pump impeller blade could be calculated as shown in **Appendix A**. The resulting rpm was 1618.71, nearly half the operating rpm to produce the maximum volumetric flow.

Based on the linear relationship between the speed percentage and pipe flow of a pump, following pump affinity laws as shown in [25, Figure 24**]**, the average volumetric flow of the bike powered pump can be calculated. By dividing the average rpm of the bike power pump by the operating rpm of the electric pump, the average volumetric flow of the bike powered pump could be determined by multiplying this ratio by the max volumetric flow rate of the electric pump as shown in **Appendix A**. The resulting average volumetric flow was 14.76 L/min, well above the minimum volumetric flow required for adequate purification of the water.

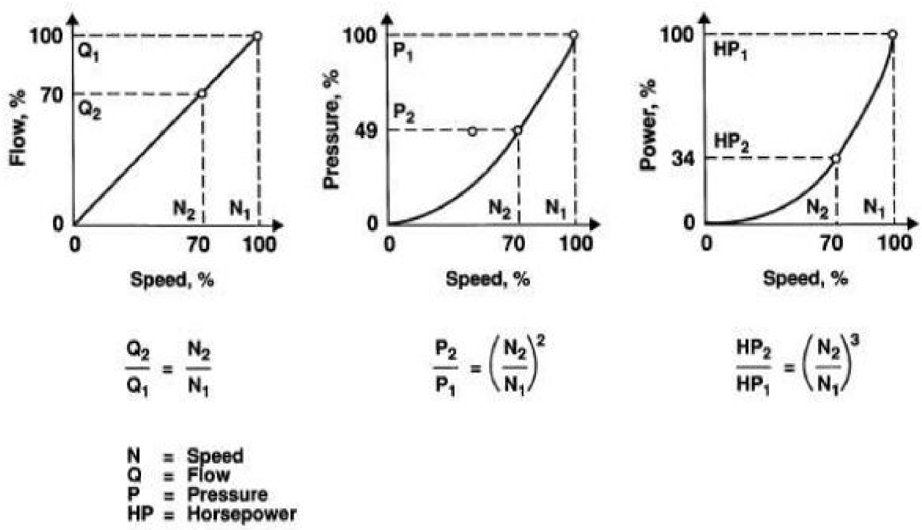

Figure 25. Pump Affinity Laws [25, Reproduced without permission]

3.1.3. Conversion from Electrical to Mechanically Driven Centrifugal Pump

In order to convert the electrical centrifugal pump to be mechanically driven, the sides of the pump had to be removed by unscrewing a series of six bolts, allowing the impeller axle and impeller blade housing to be completely removed from the primary center housing. Once these components were removed, the remaining insulation and copper wiring that would magnetically drive and rotate the impeller blade could then be pushed out of the center housing, allowing the impeller axle to be freely suspended within the pump housing. A u-shape cut using an angle grinder could then be used to expose the impeller axle to the outside environment and therefore come in contact with the rear bike tire.

Figure 26. Exploded Front View of Pump with Exposed Impeller Blade

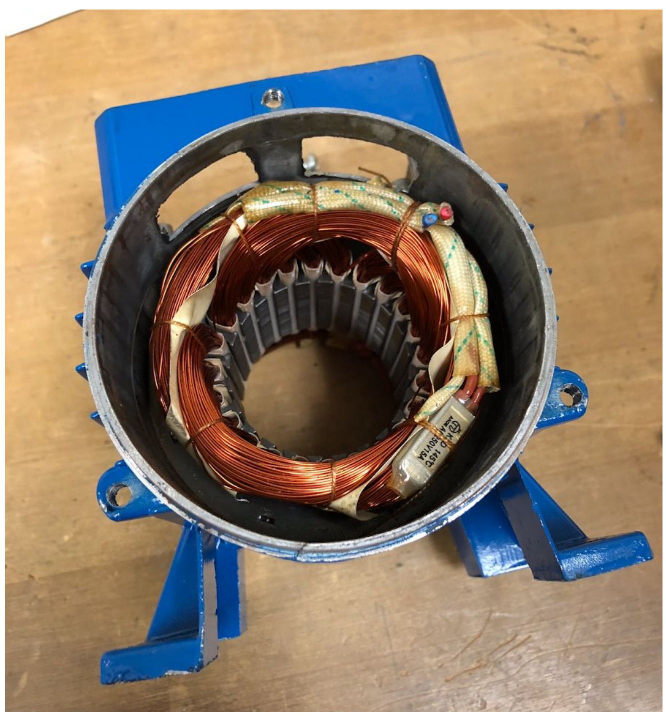

Figure 27. Inside of Pump Housing Prior to Removal of Inner Magnetic Components

This process of conversion was repeated in Guatemala with slight changes to the contact point between the impeller blade and rear bike tire. Given the operating conditions in which the pump would most likely experience, large amounts of dirt, sediment, or water is expected to come in contact with the rear bike tire. To overcome this issue, an old bike tire was sliced apart and wrapped around the exposed impeller axle to increase the frictional coefficient between its surface and the rear bike tire. A heavy gauge wire wrapped in plastic was used to securely fasten the bike tire to the impeller axle.

Figure 28. Mechanically Converted Centrifugal Pump in Guatemala

3.2. Purification Subsystem

3.2.1. Introduction

The purification system was selected around the initial operating conditions which included purification quality, volumetric flow rate, cost, and filter lifetime. An additional operating condition beyond the four primary areas of interest include a potentially sustainable purification system that could be created using local resources and/or possess the capability to be easily replaced and maintained when necessary. The purification system addresses the customer need for water purified to potable levels. Furthermore, the customer need for easily replaceable filter parts is satisfied.

Beyond the primary focus of the main purification system, preliminary water contamination tests were a pressing issue prior to pumping. In order to measure water contaminant levels within the sources of water a water purity measuring device/system would need to be implemented prior to the initial pumping in order to assess the effectiveness of the purification system.

To meet potable water conditions, the purification system must be designed to meet drinking water EPA standards for the United States. The EPA standard requires a filtration rating of 0.5 microns or below to eliminate bacteria, parasites, and microplastics within the contaminated water. In order to create an efficient product, the purification system must be able to purify potable water within a reasonable duration of time. Due to the intensive labor process mothers must endure to retrieve water, a minimum of 2 liters per day is recommended for drinking purposes alone. Designing a product around a hardworking family comprised of a mother, father, and two children, this number is expected to increase given the daily tasks and living conditions that come with living within developing countries. Taking into account additional uses of water such as cooking and cleaning may also lead to a significant increase in the required number of liters a family of four consumes on a daily basis.

To meet the increasing demands of potable water for drinking and household use, the purification system must be able to purify and produce potable water at a flow rate of no less than 4-5 liter per minute to keep operating times to a minimum. With consistent time reduction across all aspects of the project, including transportation and purification, an emphasis on the benefits of time availability within a mother's day can lead to development within the educational and family oriented aspects of life. Purification and time, are two central areas of improvement to serves as avenues of focus when designing this project.

3.2.2. Water Purification System Design Selection

After extensive research into potential purification systems, a filter within the ceramic family was chosen as the top candidate. Ceramic filters offer advance purification capabilities that are able to purify water contaminants down to a 0.2 micron level. This purification level lays in line with drinking water EPA standards for the United States set at 0.5 microns. Due to the versatility presented with ceramic filters for household and outreach applications, ceramic filters fit perfectly within the constraints of the product operating conditions mentioned prior. With various lengths, configurations, and compositions, ceramic filters can be customized to meet the needs of an individual or community. Variations in ceramic candle composition involve the addition of activated carbon blocks, lead, and heavy metal removal media within the medium of the candle. As increasing layers of filtration are added to the ceramic candle, significant reductions in the filters' capacity and flow rate are the result. Super Sterasyl and ATC Super Sterasyl provide the greatest filtration capabilities but are limited to gravity flow for optimum performance, eliminating both filters as potential options [26]. BioTect Ultra and Ultracarb candles contain carbon block cores with a secondary media to remove lead and heavy metals. Both filters can operate at optimum flow rates of 1.9 L/min, however, with filter capacity reduced to 2250L, a retrieval of 40 liters (~10.6 gallons) per day would reduce the filters' lifespan to two months. A Supercarb candle equipped with a carbon block core yields a slight increase in filter capacity of 3750L with a flow rate of 1.9 L/min, but only provides an increase of a month for the filters' lifespan. The most feasible option comes down to the standard Sterasyl ceramic candle filter with an optimum flow rate of 5 L/min and a filter capacity of 10,000 L, providing an estimated 9 month lifespan. To further extend the lifespan of a standard Sterasyl ceramic candle filter, an external pre-filter composed on granulated carbon can be used to reduce large particles from entering the main Sterasyl purification system while maintaining an optimum flow rate. Given that the flow rates and filter capacity are representative of a single ceramic candle filter, all operating values can be multiplied by a factor of five when implementing a multi-candle ceramic filter.

Reference to the composition, flow rate, and filter capacity of the ceramic candles mention above can be found in **Appendix B** of the report.

For the purpose of this project, a multi-candle ceramic filter comprised of standard Sterasyl filters with an external pre-filter will serve as the purification system. Although a potential service flow rate of 25 L/min could theoretically be achieved through this configuration, for optimum performance, water flow should be restricted to approximately 1.5 L/min. This in turn results in a max flow rate of 7.5 L/min, well above the proposed operating conditions of the purification system while maintaining a 0.2 micron level filtration. As shown in [8, Figure 28] the multi-candle ceramic filter configuration is housed in a cylindrical plastic housing that can easily be stored and transported during and after use.

Figure 29. Multi-Candle Ceramic Filter [8, Reproduced without permission]

3.2.3. Secondary Pre-Filter Systems

To account for any large sediment and dirt particles that may enter the impeller blade housing and cause serious physical harm to the impeller blade, a fine mesh pre-filter was attached to the inlet of the pump tubing using zip ties to securely fasten it around the outer surface of the tube. This type of mesh can be readily found in any local hardware store and is very cheap to purchase and can be easily cut and replaced if needed. Some minor head losses may occur as a result of using the pre-filter but are not enough to outweigh the added benefits of its use.

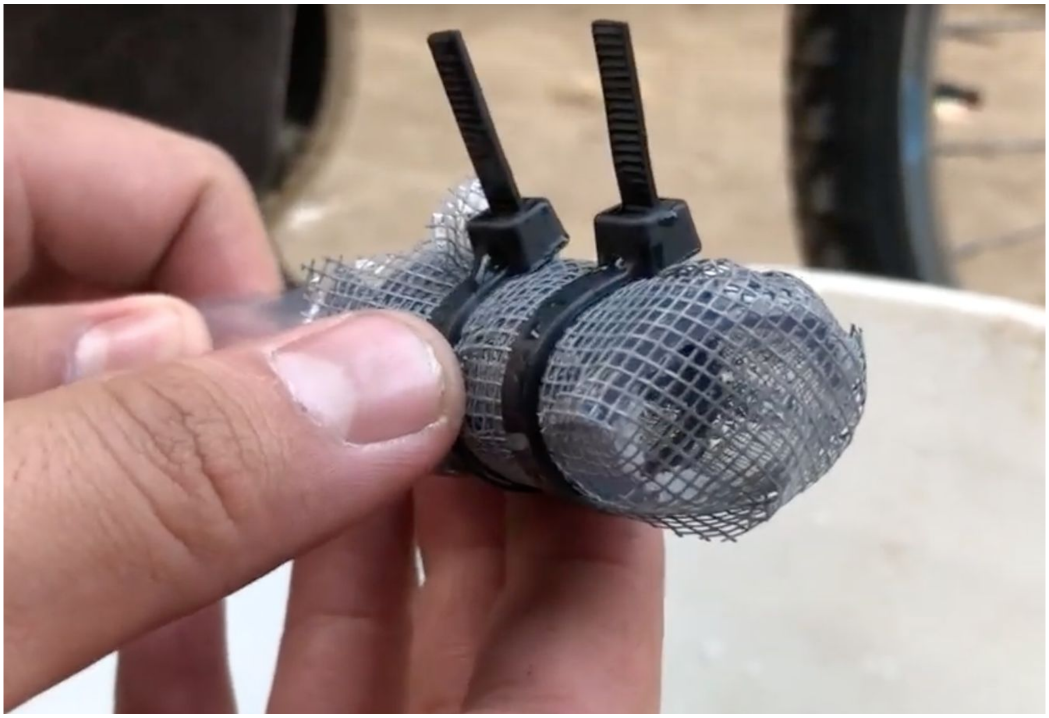

Figure 30. Fine Mesh Pre-Filter at Inlet of Tubing

3.3. Kickstand Subsystem

3.3.1. Introduction

The primary purpose of the kickstand subsystem is to provide a stable platform for the operator to use while the Pedal 4 Purification project is being used and operated. The kickstand should be able to support up to a 90 kg operator while maintaining a lightweight and compact profile for increased transportation and easy storage. It should be stable on various types of terrain given the nature of its operating parameters within developing countries and able to withstand any types of harsh wear and tear that comes from continuous daily use. Lastly, the kickstand should be constructed out of readily accessible materials found in the respective countries of operation. The use of reusable bike parts as well as readily available types of metal materials is essential to the sustainability and expansion of this project subsystem.

Beyond the operating constraints and parameters of the kickstand, its functionality should be logical and easy to understand. The bike's rear tire is held in suspension over the exposed impeller axle of the centrifugal pump with enough force to provide frictional contact to rotate the axle. Finding the optimal amount of frictional contact to provide the best results for volumetric pipe flow was overcome creating an adjustable mechanism that would allow the kickstand and pump to change locations to adapt to any size bike tire, making it universally adaptable. The user will know the system is set up for optimal contact when the tire is able to spin the impeller rod.

3.3.2. Kickstand Design Selection

Given the many operating parameters and constraints that the kickstand subsystem was designed around, there were several design iterations that took place throughout the full duration of the project. The first kickstand iteration was designed around a stationary bike trainer with a simple folding and unfolding mechanism that would allow for easy storability and simple operation as shown in [Figure 31]**.** below. However, given the complexity of welding that would be required to construct such a design as well as the limited access to welding during the preliminary prototyping stages, this iteration was deemed difficult to manufacture, especially given the limited access to resources within developing countries.

Figure 31. First Iteration of Kickstand Subsystem

The second and third iterations of the kickstand subsystem was designed around a more sustainable approach that focused on the idea of readily accessible materials and increased manufacturability as shown in [Figure 32] and [Figure 33] below. This design utilizes circular tubing similar to that found on a bicycle seat post with room for adjustment between the inner and outer circular tubing to accomodate for any size bicycle tire. The clamping mechanism used for this design is the same clamping mechanism used on a bicycle seat to reduce the number of parts that would need to be purchased or manufactured locally. The attachment point between the kickstand and rear bike tire is very similar to the first iteration, using a screw and lock method that can be easily unscrewed and released once the operator is finished pedaling and purifying water. While this was a major change from the first iteration, the manufacturability aspect of prototyping within the university setting limited the ability to weld which both designs would heavily rely on. Alternative routes to welding, such as L-brackets and bolts to attach corners of the angle beams together, raised concerns about the connections between the circular post rod and the angle beams that would support it. All alternatives to welding would require milling of custom parts to clamp and attach securely within the dimensions of the angle beams and would therefore diminish the manufacturability aspect of the project. With all these things considered, a further iteration to the kickstand subsystem was made.

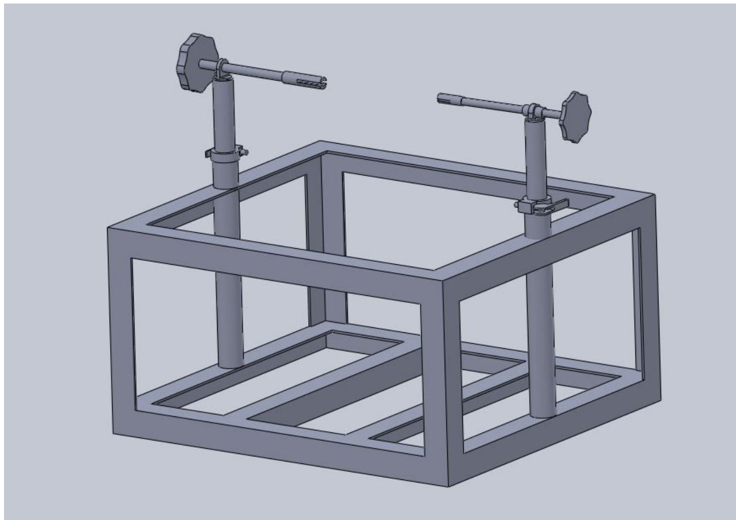

Figure 32. Second Iteration of Kickstand Subsystem

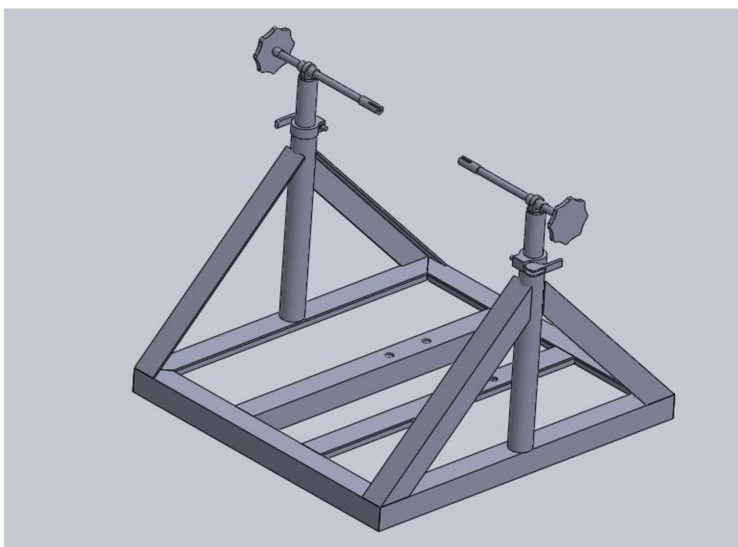

Figure 33. Third Iteration of Kickstand Subsystem

The fourth and final iteration of the kickstand subsystem, shown in [Figure 34] is designed around the use of simple hollow square tubing that would utilize a pin and locking mechanism to allow for adjustable between the height of the top posts, addressing the universally adaptable aspect of the project. By using a series of hollow square beams with equidistant holes along each face, the entire base of the kickstand could then be easily attached using L-brackets and bolts. Angle beams that run perpendicular to the base of the hollow square beams provide stability in the lateral direction while serving as the primary attachment between all other base components. Larger L-brackets are used to support the vertical hollow square beams which houses the smaller hollow square beams that moves freely within the outer square beams. The diameter of holes on both the small and large hollow square beams were drilled to equal diameters to allow for a simple pin to be inserted and securely adjust the height of the top square beam to multiple heights in increments. At the based of the vertical posts exists another pin-locking mechanism with a milled slot between two holes to allow for full collapsibility when being stored and transported. Angle beams with punched holes were used between the two primary base square beams to provide a platform to secure the pump during operation. The pump is attached to the wooden block using bolts and is to be easily removable. The bolts attaching the pump were put in facing upwards so that the pump could be removed without needing to flip the kickstand upside down.

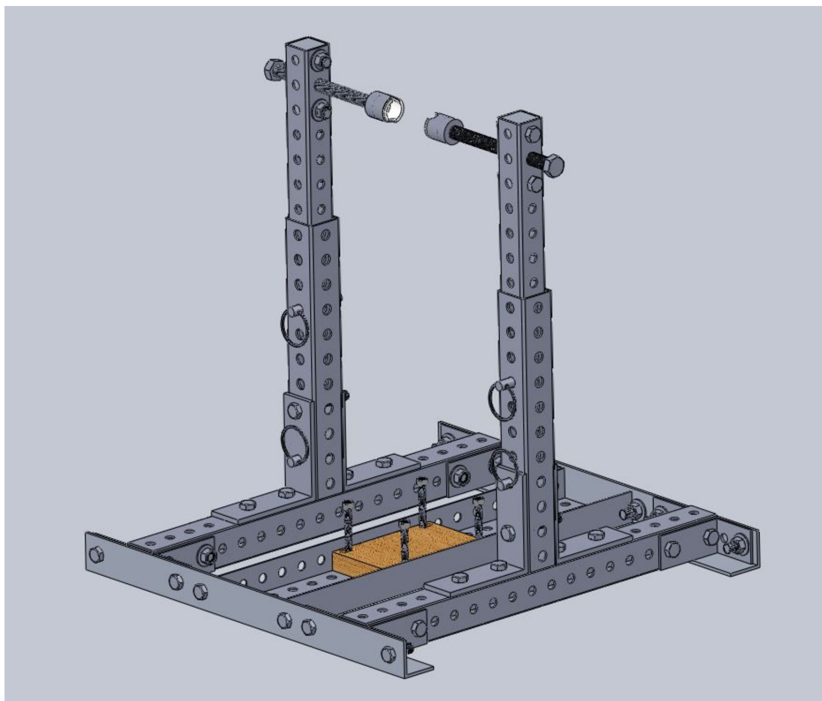

Figure 34. Final Iteration of Kickstand Subsystem

3.3.3. Kickstand Guatemala Iteration

When constructing the kickstand subsystem in Guatemala, there were several major changes made to the overall design, the first being the ability to readily weld any steel parts. Given the ability to weld, all L-brackets originally used to attached the components of the kickstand were then welded, drastically reducing the overall weight of the subsystem. Flat-plate steel supports were also added to the inner face of the vertical square beam to provide added stability in the lateral direction during operation as shown in [Figure 35] below.

Figure 35. Guatemala Iteration of Kickstand Subsystem

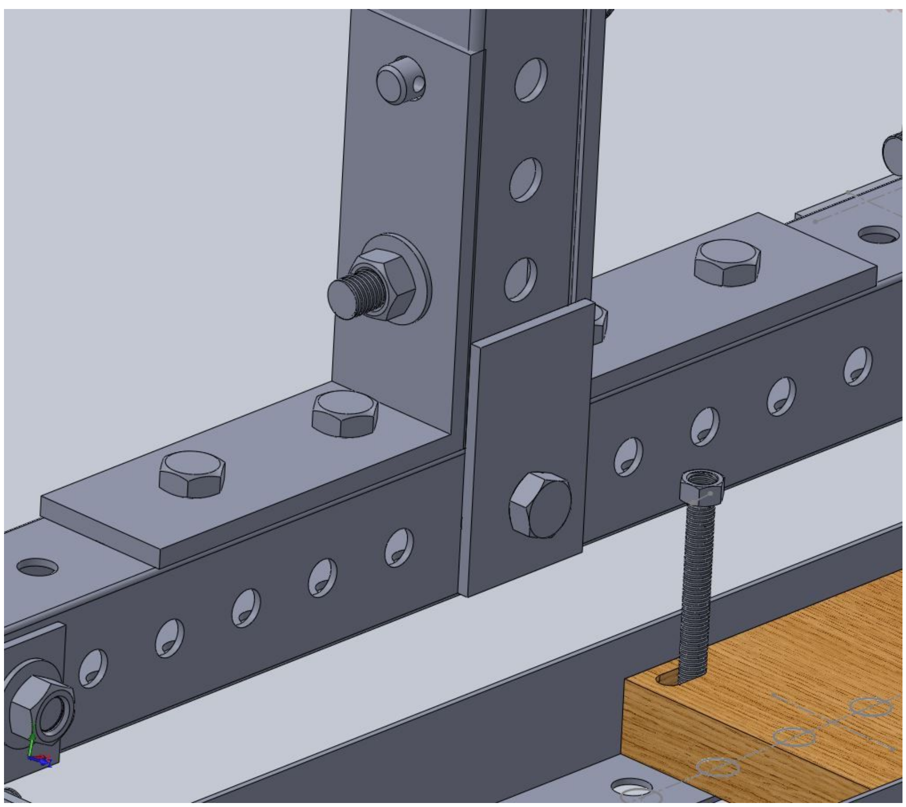

Figure 36. Inner Steel Flat-Plate Supports for Kickstand Subsystem

Figure 37. Kickstand Attached to Rear Axle of Bike with Pump and Removable Stabilizers

3.3.4. Kickstand FEA Analysis

The bolt connecting the rear axle of the bike to the kickstand was determined as a potential point of failure. The hypothesized method of failure is excessive stress on the small end radius of the bolt. This bolt is crucial to the integrity of the kickstand subsystem as it supports the rear tire of the bicycle over the pump, allowing the user to generate power and pump water. Using Solidworks simulation tool, an FEA analysis of static stresses in the bolt will be conducted to determine whether further design revisions are necessary.

A new study is started in Solidworks and the edge of the bolt is given a fixed boundary condition along its length. In actuality, a portion of the bolt will remain extended from the frame. The bolt is given a material type of plain carbon with properties listed in **Table 2.** Strength is the primary concern with the kickstand bolt so weight considerations are put on the backburner in lieu of a material with greater yield strength.

An average steel bike frame weighs 13.5kg, a large male biker weighs 86 kg. Assuming a gravitational force of 9.81 m/s^2, the total force is 971N. This simplified bolt was given a constrained z-direction, simulating a purely downward force, rather than a force normal to the face of the bolt. When in use, only half of the total weight of the bike and rider will rest on the kickstand bolt. Furthermore, this halved weight will be reduced once more by the addition of a secondary bolt on the opposite side of the kickstand. An extreme forcing scenario was chosen to determine feasibility of bolt design. The exaggerated forcing of 971N is placed along the open ended face of the bolt tail. Due to the complex geometry of the bolt threading, the meshing process took a considerable amount of time. A course mesh was chosen, and it still used incredible amounts of CPU memory to run the simulation. The bolt was simplified to allow for faster analysis and the threading was suppressed. A coarse mesh was applied to the bolt and the Von Mises stress diagram was acquired as shown in [Figure 38] below**.**

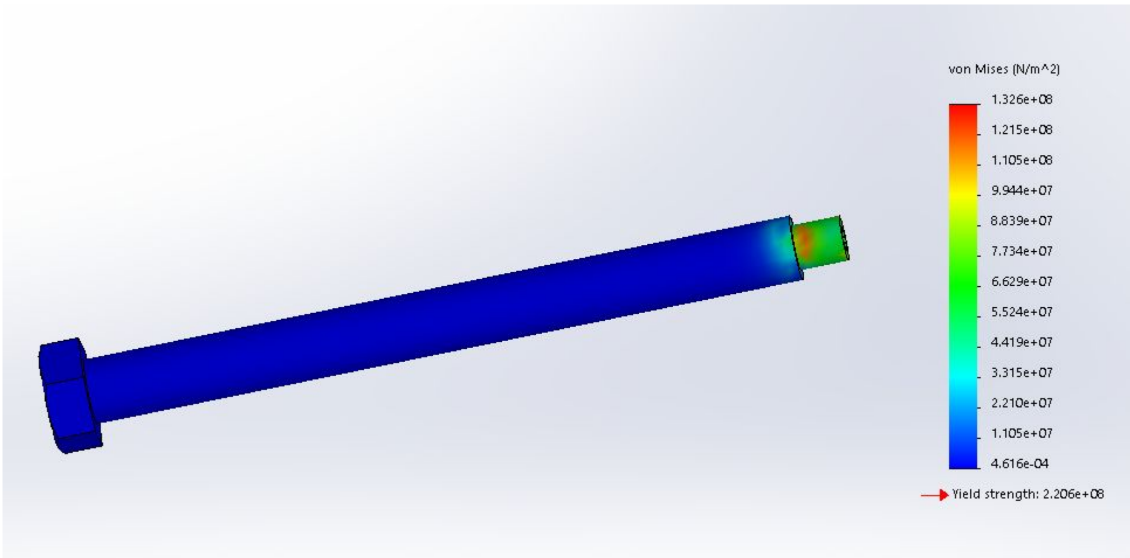

Figure 38. Undeformed Von Mises Stress Diagram for Kickstand Bolt Loading (Range from 4.616 e-04 to 1.326e08)

The results of the Solidworks static simulation trial indicate that stresses in the bolt will remain below yielding for the most extreme forcing scenario. This indicates that the current design will withstand static forces four times greater than the user will generate. The bolt had a factor of safety of 1.663 at the location of largest stress, again verifying the integrity of design selection. Equally helpful are the locations of highest strain in relation to the force. The constrained forcing causes compression in the bottom of the open ended bolt face and tension in the top. This screenshot is taken from a bottom-up perspective; the concentration of red, high-stress area is located in the bottom of the bolt. While no further design revisions are needed, one could possibly consider creating some form of reinforcement at the base of the inner bolt tail end radius to prevent necking. In future simulations, the entire support arm of the kickstand can be analyzed to determine more accurate forcing scenarios. More trials can be conducted on the directional loading of the kickstand and its ability to provide multi-axial support.

3.4. Cart Subsystem

3.4.1. Introduction

The cart subsystem serves a wide variety of purposes contributing to the overall efficiency of the system. The main function of the cart subsystem addresses the customer need for a less strenuous method of transporting large quantities of water. The cart bed will be flat and open for safely carrying containers of water, as well as the pump and kickstand subsystem such that the entire product is self contained. The cart also expedites the transportation process, allowing the consumer to pull the water using a bicycle. The cart will be designed with the customer need for longevity in mind with materials chosen for their durability. Furthermore, space on the cart subsystem is left to address the latent customer need for transportation of other products, or even a child.

3.4.2. Cart Design Selection

The first iteration is shown in [Figure 39] and [Figure 40]. This design was originally drawn in SolidWorks and was fairly over simplified. This iteration was designed around the primary use of angle beams to form the base and side walls of the cart body. However, in order to manufacture and prototype such a design, heavy amounts of welding would need to be used which limited this iteration as our final choice.

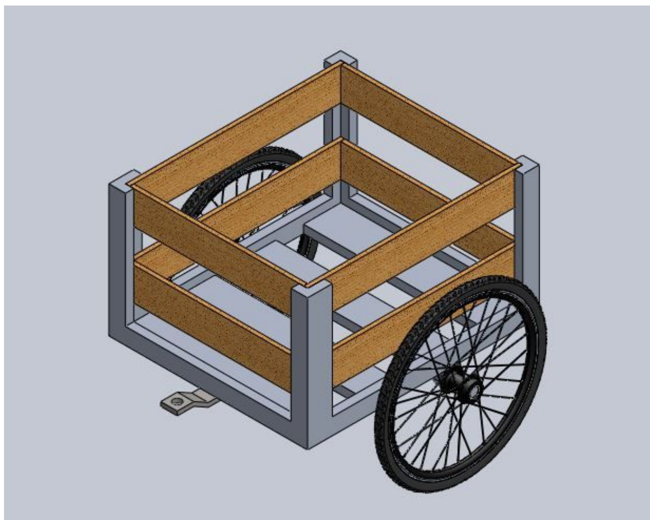

Figure 39. Isometric View of First Cart Iteration

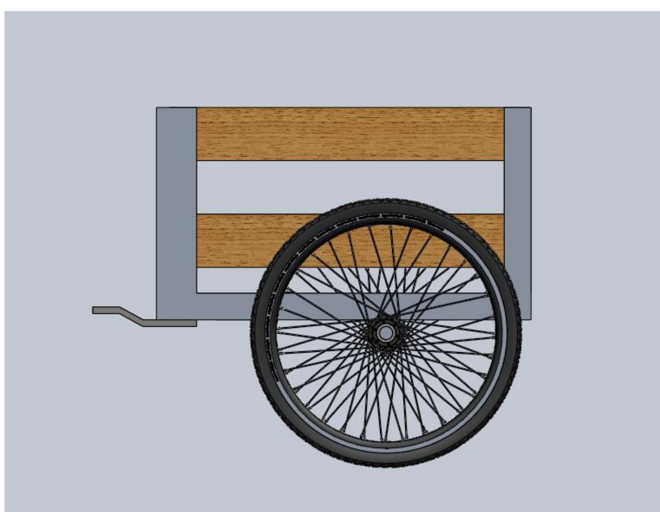

Figure 40. Side View of First Cart Iteration

The manufacturability and weight of this iteration proved to be very poor which prompted the movement to the second iteration shown in [Figure 41]. This simple design of the second iteration is easy to construct/deconstruct on location and can be made from locally sourced materials. This allows the cart to be easily storable as well as giving independence to the local community to improve/maintain the product as well as make new iterations. However, this cart contained a long axel running across the cart that would experience a large moment and would make the cart more difficult to maintain.. For this reason a third iteration was created.

Figure 41. Isometric View of Second Cart Iteration

The third iteration, [Figure 42], introduces the U-bracket that would allow the wheels of the cart to be gripped in a fork-like-manner like a classic bicycle. This would eliminate the axel, making the cart cheaper as well as simplifying the manufacturability. More wood was also added in order to eliminate the gap space to allow smaller objects to be transferred as a latent need.

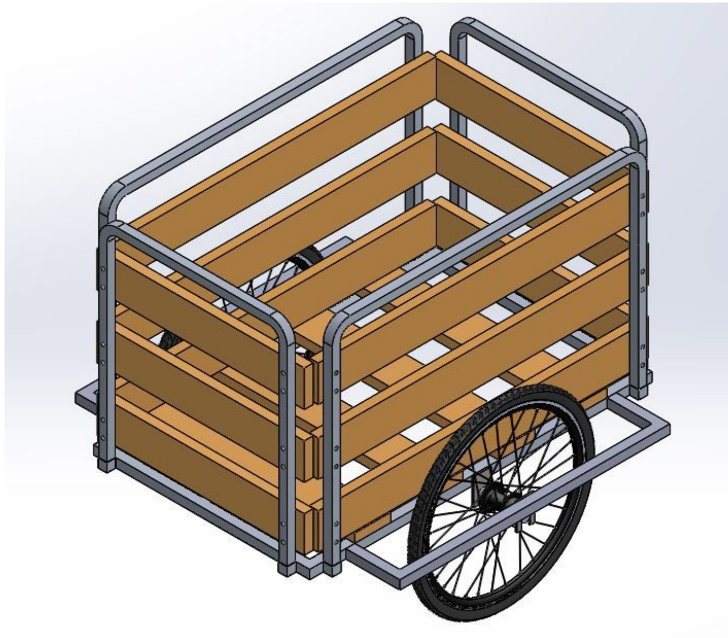

Figure 42. Isometric View of the Third Cart Iteration

The purpose for the fourth iteration was to drive down the cost. The previous base required complex welding which would be very costly. In order to avoid this, two frames were bolted on top of eachother to create the same shape and U-beam design as created in the third iteration. This also introduced the bolted on, bent metal sockets for the wall posts. This eliminates the need for welding therefore reducing the cost. The fourth iteration can be seen in [Figure 43].

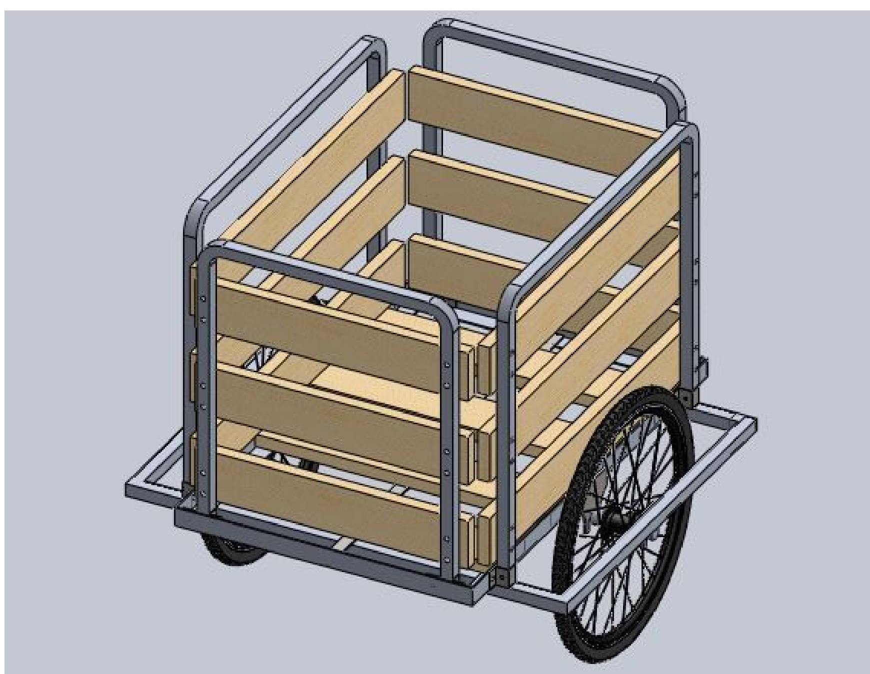

Figure 43. Isometric view of the fourth cart iteration.

While arriving in Guatemala, it was soon clear that there were overestimates in what would be available in the workshop. The fifth and final iteration is what was constructed in Guatemala and can be seen in [Figure 44]. The first change was removing the metal reinforcement beam down the center of the cart. The wood found in Guatemala was much stronger and thicker than what was purchased in the states proving the metal reinforcer to be unnecessary.

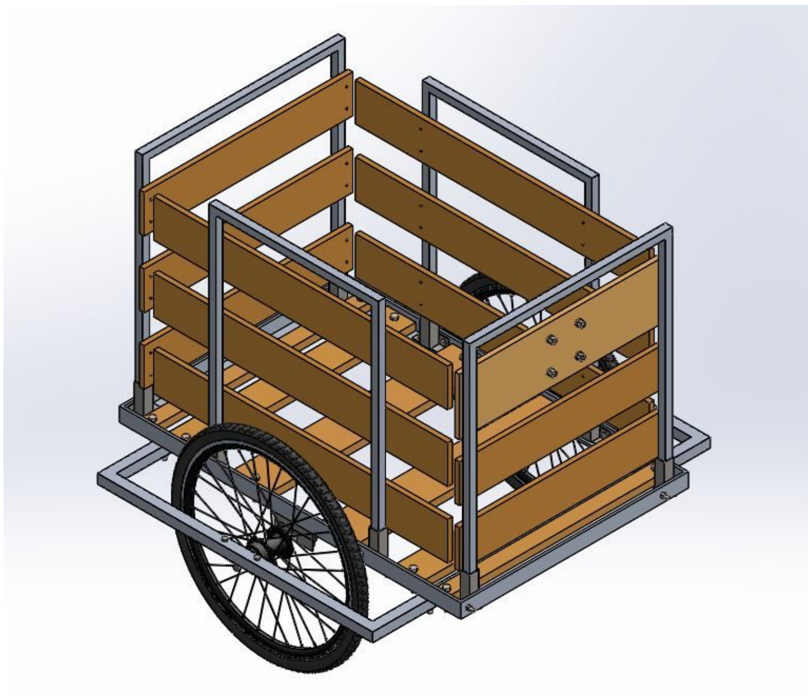

Figure 44. Isometric view of the fifth cart iteration.

3.4.3. Cart Guatemala Iteration

The biggest issue faced in Guatemala was that welding aluminum was not possible. This created some complications in adding the wall post sockets. In order to circumvent this, a steel socket post was welded onto a steel angle beam. Through holes were then drilled in this as shown in [Figure 45] so that it could be bolted to the aluminum angle beam. The assembled base can be shown in [Figure 46].

Figure 45. Modified Steel Wall Post Socket.

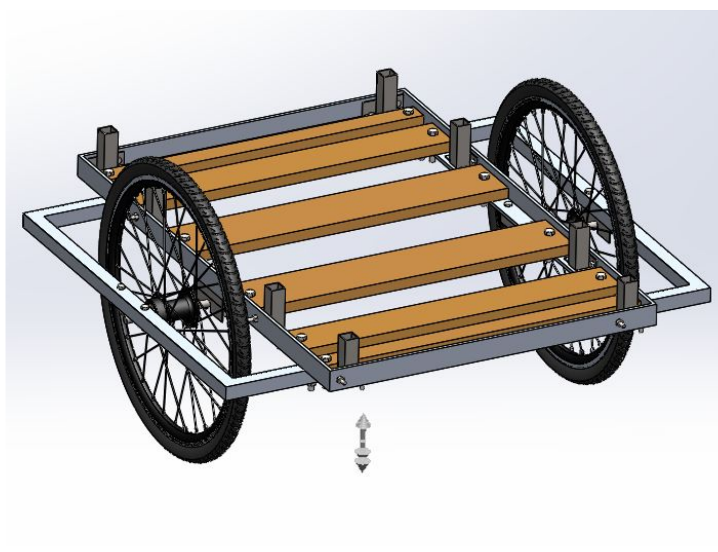

Figure 46. Fully assembled base of the Guatemala iteration of the cart.

The wheel gripping mechanism, as mentioned before, is shown in [Figure 47] and [Figure 48].

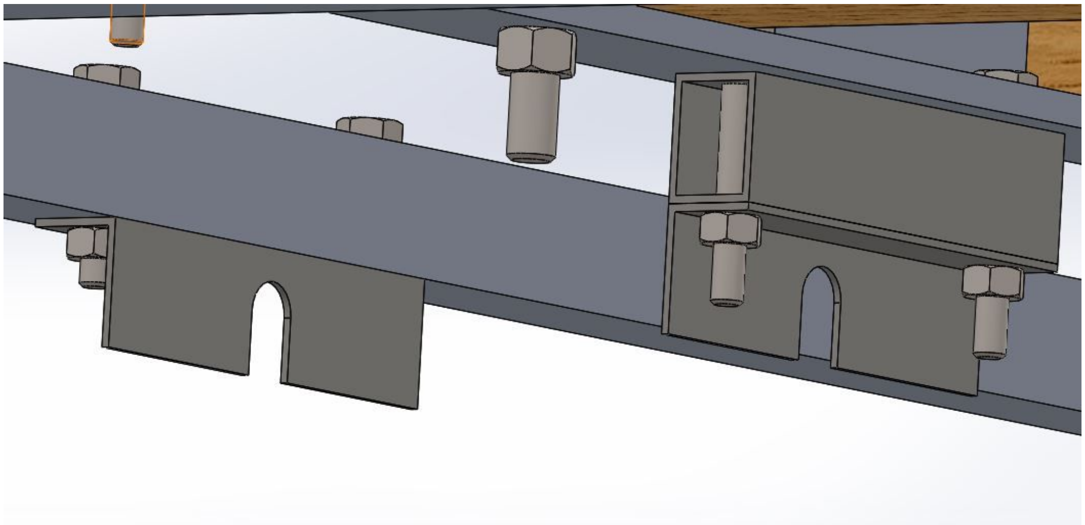

Figure 47. Isometric view of the wheel gripping mechanism.

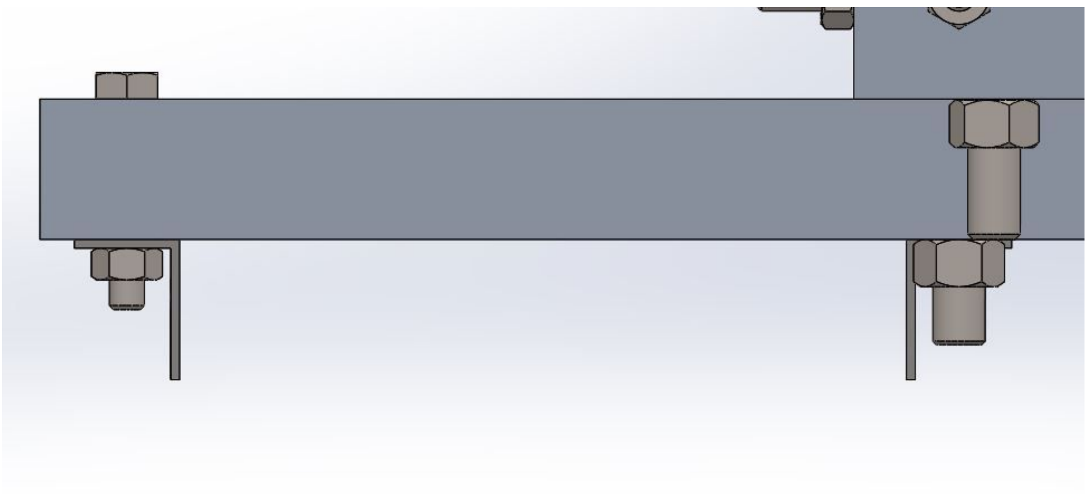

Figure 48. Front view of the wheel gripping mechanism.

Additional improvements include the addition of the locally sourced kickstand [Figure 49] and the purification module holder [Figure 50].

Figure 49. Final constructed cart with the kickstand visible.

Figure 50. Final constructed cart with the purification module and holder visible.

3.4.4. Cart FEA Analysis

The cart base frame subsystem is intended to carry the weight of the collected water, as well as the weight of the kickstand and purification subsystems. It is important that the cart is designed with weight in mind. A heavier cart is less user friendly, making it more difficult to move. Furthermore, the cart needs to be made from durable material capable of withstanding weathering and rough road conditions. The hypothesized mode of failure is excessive stress at the axle/cart connection. Another point of concern is the middle portion of the carriage frame, where the hypothesized method of failure will also be excessive stress.

First, the wooden baseboard slat subsystem is analyzed to see if it will sustain the required weight of water. The wooden slat is given a Balsa wood material type, the properties are displayed in [Table 5] below.

Table 5. Balsa Wood Material Properties

Balsa Wood	
Material source	Simulation
Material library	solidworks materials
Material ID	81
Model type	Linear Elastic Isotropic
EX	3E+09 N/m^2
NUXY	0.29
GXY	3E+08 N/m^2
DENS	159.99 kg/m^3
SIGYLD	2E+07 N/m^2
KX	0.05 W/(m.K)

After giving the wooden slats a Balsa wood material type, a fixed boundary condition is assumed along the edge of the beam. The fixed condition simulates the pressing of the wooden beam along the length of the cart carriage. The wooden slat is fixed in the x,y, and z directions. The goal of this experiment was to determine the efficacy of a steel reinforcement beam in dispersing loading in the cart.

To get a general idea for the amount of stresses present under loading, a simply supported beam is given a forcing. A loading of 355N, corresponding to a payload of 37 kg, is applied along the length of the beam. According to the Mayo Clinic, the average man needs to drink 3.7 liters of water every day. Thus, the cart would have to be able to carry about 25 liters of water in order to have an overestimate of achieving the goal of providing enough drinking water for a family of 5 for one day. 25 liters of water is roughly equal to 20 kg distributed along the axle of the cart. Since the whole system is self contained, the cart must also be able to support the weight of the kickstand, pump and purification module.

The wooden slat's expected mode of failure is yielding. After running the solidworks simulation, the wooden slat supported the assumed loading with a factor of safety of 13.736 at the most critical sections. The greatest amount of stress was concentrated near the fixed edges of the beam in bending. The wood is expected to deflect 0.489mm under the applied load. Due to the large factor of safety, no further design revisions are planned for the load bearing portion of the cart frame.

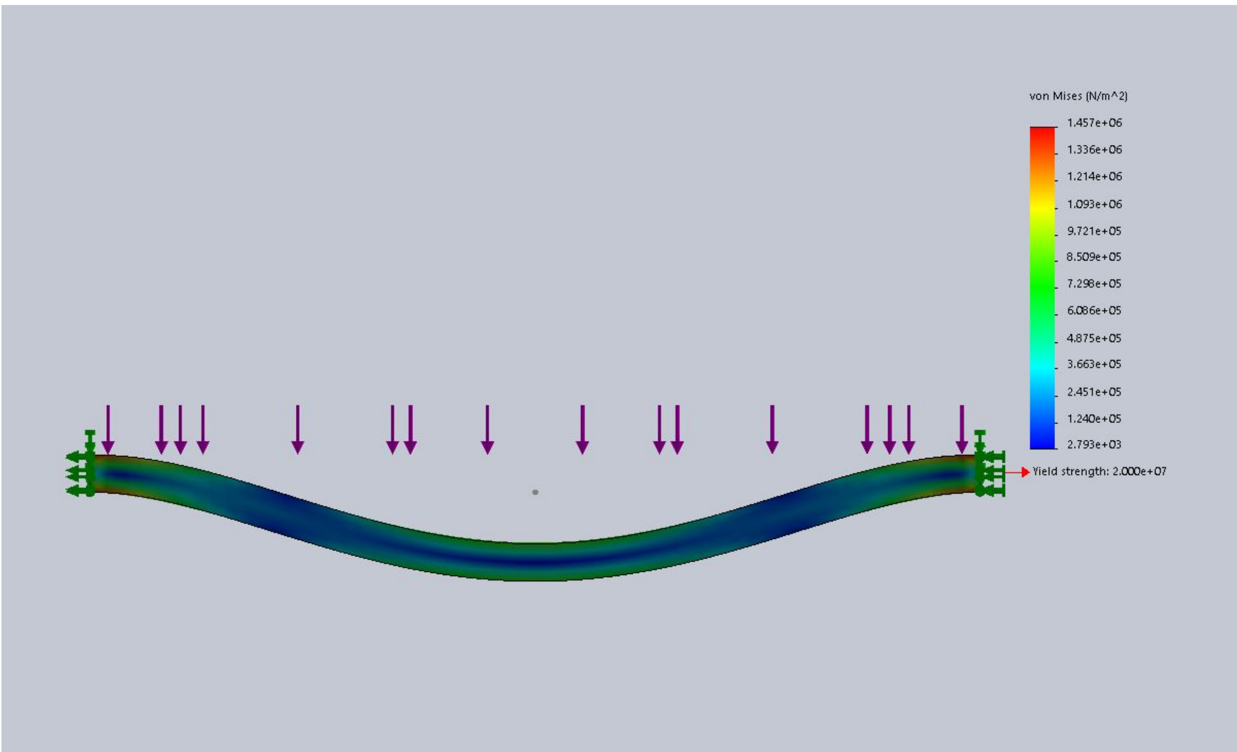

Figure 51. Wooden Slat with fixed edges and loading of 355N (Range from 2.793e03 to 1.457e06)

Next, the overall cart carriage frame was analyzed. The main purpose of the cart Solidworks simulation trials is ensuring the material and design selection support overall system functionality. The cart base must be capable of supporting the weight of the purified water, kickstand subsystem and purification module. The cart carriage is displayed in [Figure 52]. The cart must function in a variety of weather conditions. Unfortunately, Solidworks simulation tool cannot give insight into weathering damage sustained over time. However, it can give a rough estimate of the stresses encountered within the structure, as well as potential sources of failure.

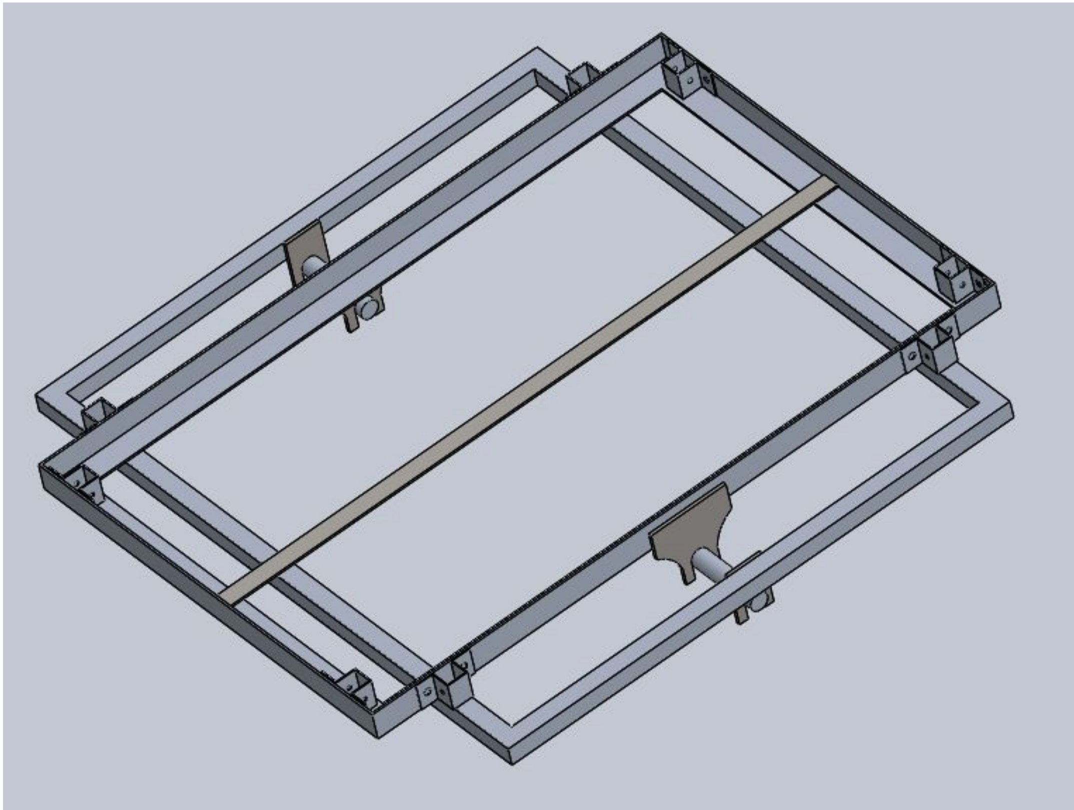

Figure 52. Cart Frame Carriage

The entire cart frame is constructed from 1060 Al except for the plain carbon steel reinforcing beam down the center of the carriage, and the steel hitch mounts for the wheels.

Table 6. Plain Carbon Steel Properties

Plain Carbon Steel	
Material source	Simulation
Material library	solidworks materials
Material ID	9
Model type	Linear Elastic Isotropic
EX	2.1E+11 N/m^2
NUXY	0.28
GXY	7.9E+10 N/m^2
DENS	7800 kg/m^3
SIGXT	3.9983E+08 N/m^2
SIGYLD	2.2059E+08 N/m^2
ALPX	1.3E-05 /Kelvin
KX	43 W/(m.K)
C	440 J/(kg.K)

Table 7. Aluminum Alloy Properties

1060 Alloy	
Material source	Simulation
Material library	solidworks materials
Material ID	14
Model type	Linear Elastic Isotropic
EX	6.9E+10 N/m^2
NUXY	0.33
GXY	2.7E+10 N/m^2
DENS	2700 kg/m^3
SIGXT	6.8936E+07 N/m^2
SIGYLD	2.7574E+07 N/m^2
ALPX	2.4E-05 /Kelvin
KX	200 W/(m.K)
C	900 J/(kg.K)

Aluminum alloy was chosen for much of the carriage due to its lighter weight. Plain carbon steel was chosen for portions of the cart where extra strength might be needed. The steel reinforcement beam and the wheel axle connection were chosen for reinforcement. These design choices were made to provide greater strength at points where the subsystem was more likely to fail.

Fixed boundary conditions were applied to the inner radius of the axle connection hitch. The weight of the cart and its contents will be dispersed through the frame, and channeled through the connecting axle hitch to the tires and into the ground.

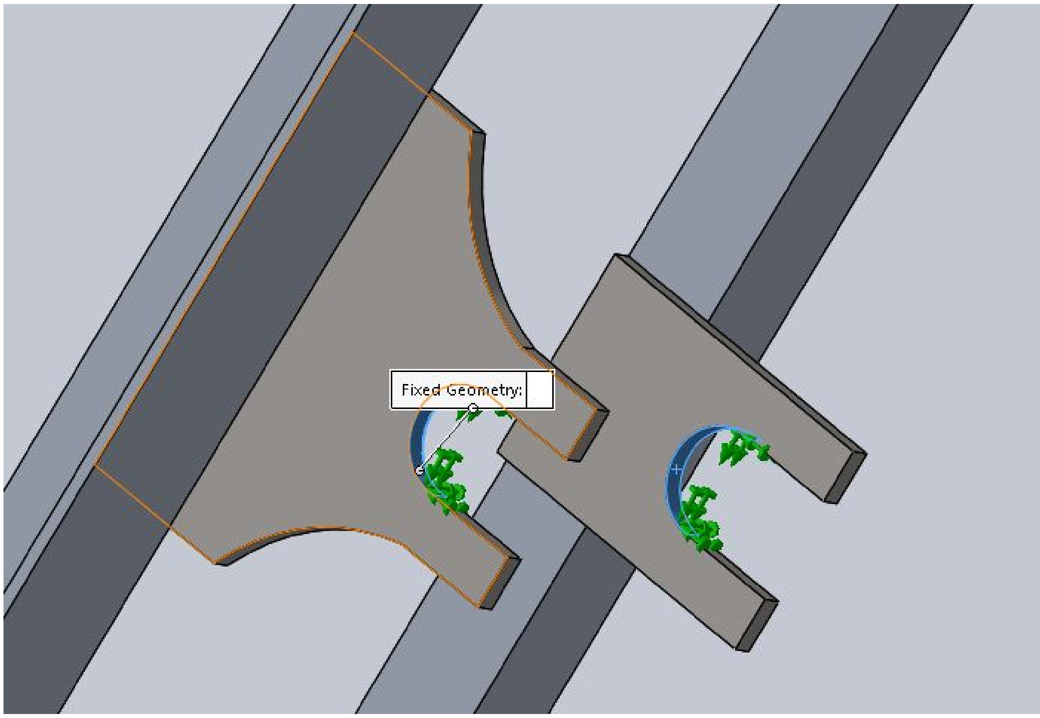

Figure 53. Fixed Boundary Condition Applied to Axle Connection

Assuming the cart mass is 133.45 N, the payload of the cart has been set to 355.86 N. In summation, this results in a 578 N forcing on the carriage of the cart. Care is taken to ensure that the force total is 578 N, meaning the cart mass and payload, is distributed evenly over the steel reinforcing beam as well as the aluminum cart carriage. Note, no forcing is applied to the wheel hub rectangular extrusions on the side of the frame. This portion of the frame is not intended to sustain forcing, rather, it allows for bike wheels to be connected to the cart frame.

Due to small and complex geometries comprising portions of the cart carriage, a fine mesh is applied with global element seed size of 0.014762 meters with a tolerance of 0.0007336 meters. The total number of elements used is 23,083. Decreasing global seed size and increasing the number of elements allows for more accurate simulation results. This results in a finer mesh better suited to complex geometries. Repeated trials are run until simulated stress values converge.

The analysis yielded interesting results. We were concerned about failure near the cart axle as design geometries narrow in size. Under the same loading, a smaller area will have a greater amount of stress than a larger area. Surprisingly, solidworks simulation tool revealed that the steel reinforcement beam will take a large amount of the loading. This validates our design choice of steel over aluminum alloy for the reinforcing beam as steel has a yield strength of 2.2059E+08 N/m^2 while aluminum has a yield strength of 2.7574E+07 N/m^2 .

Interestingly, minimal static stress due to loading is found near the axle/ cart connection. This assumed loading of 578N resulted in a maximum Von Mises stress of 1.13e008 N/m^2 found in the middle of the reinforcing beam. This maximum stress correlates to a minimum factor of safety of 1.98 for the steel reinforcement beam.

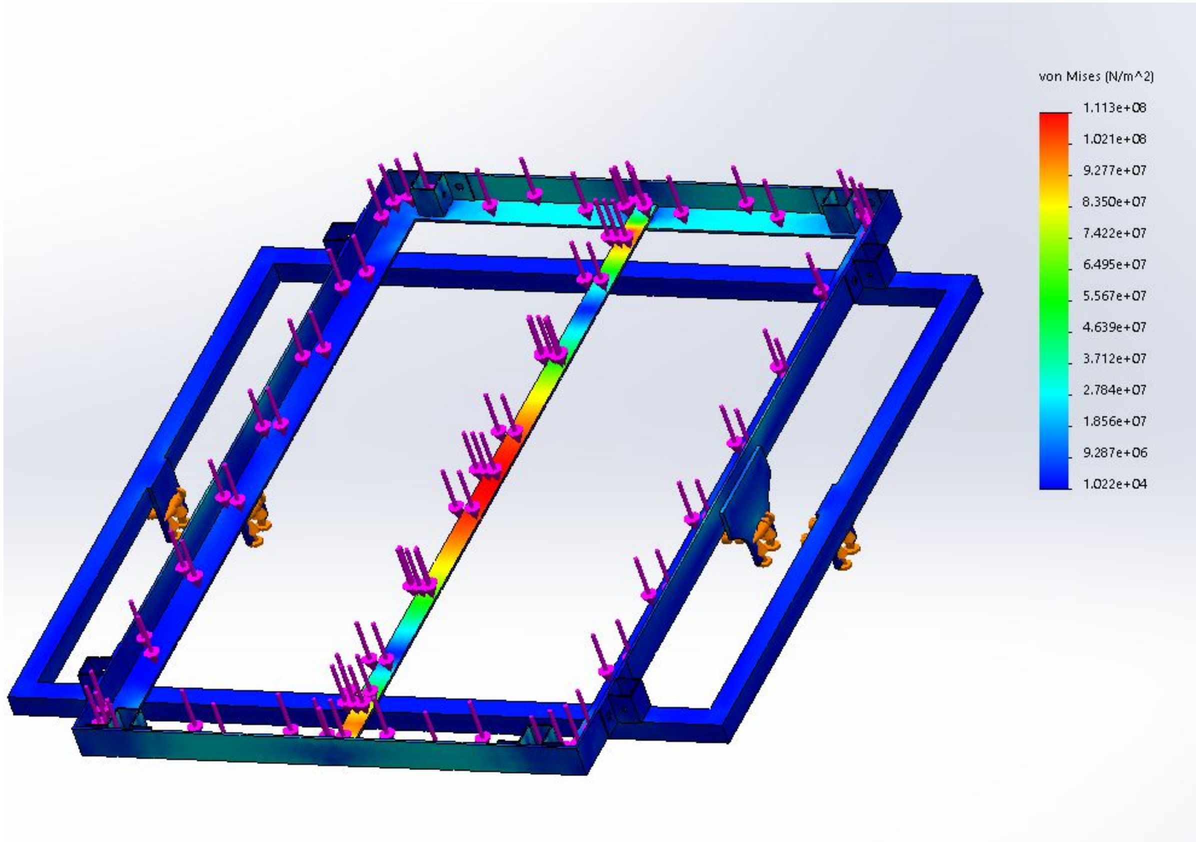

Figure 54. Stresses on Cart Frame Base (Range from 1.022e04 to 1.113e08)

Material displacement is an important consideration to avoid material interference. The bottom of the cart should strive for minimal displacement under loading in order to minimize crack growth and propagation within the material. The maximum displacement due to the forcing applied to the cart was found as 2.06mm at the middle of the steel beam. This is not an insignificant amount of displacement, and with continued loading, this material displacement is likely to increase. A design revision is needed to avoid too much material displacement. Furthermore, a design revision is needed to reinforce the reinforcing beam.

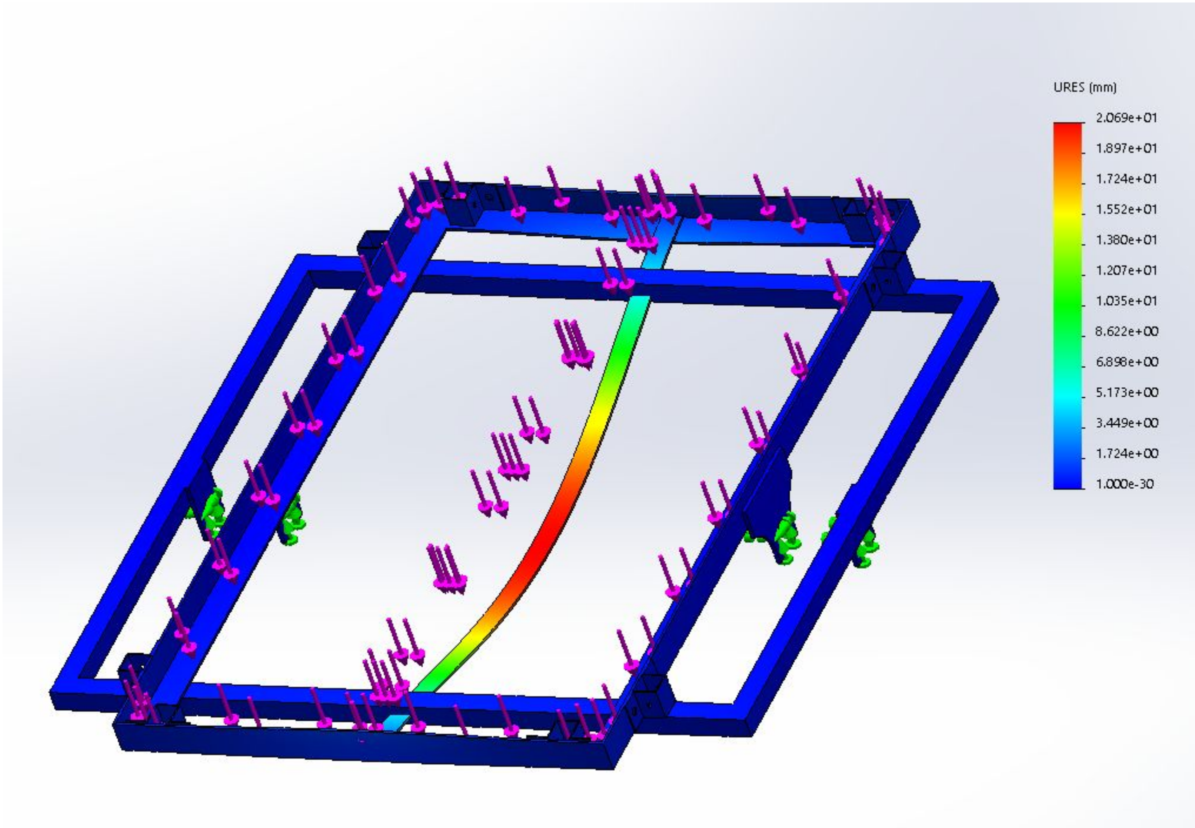

Figure 55. Cart Frame Displacement (mm) Analysis (Range from 1.00e-30 to 2.069e01)

Without the reinforcing wooden boards along its length, the cart came close to material failure under the prescribed loads. Solidworks simulation tool has an option that allows for visualization of factor of safety across the tested design. Out of curiosity, the graph was obtained for factor of safety and can be examined in [Figure 56] below. The only conclusions we can draw from this graph is that there are no places on the structure with a factor of safety greater than 6. This simulation revealed that design revisions are required to help support the center steel beam and more evenly distribute the applied loading.

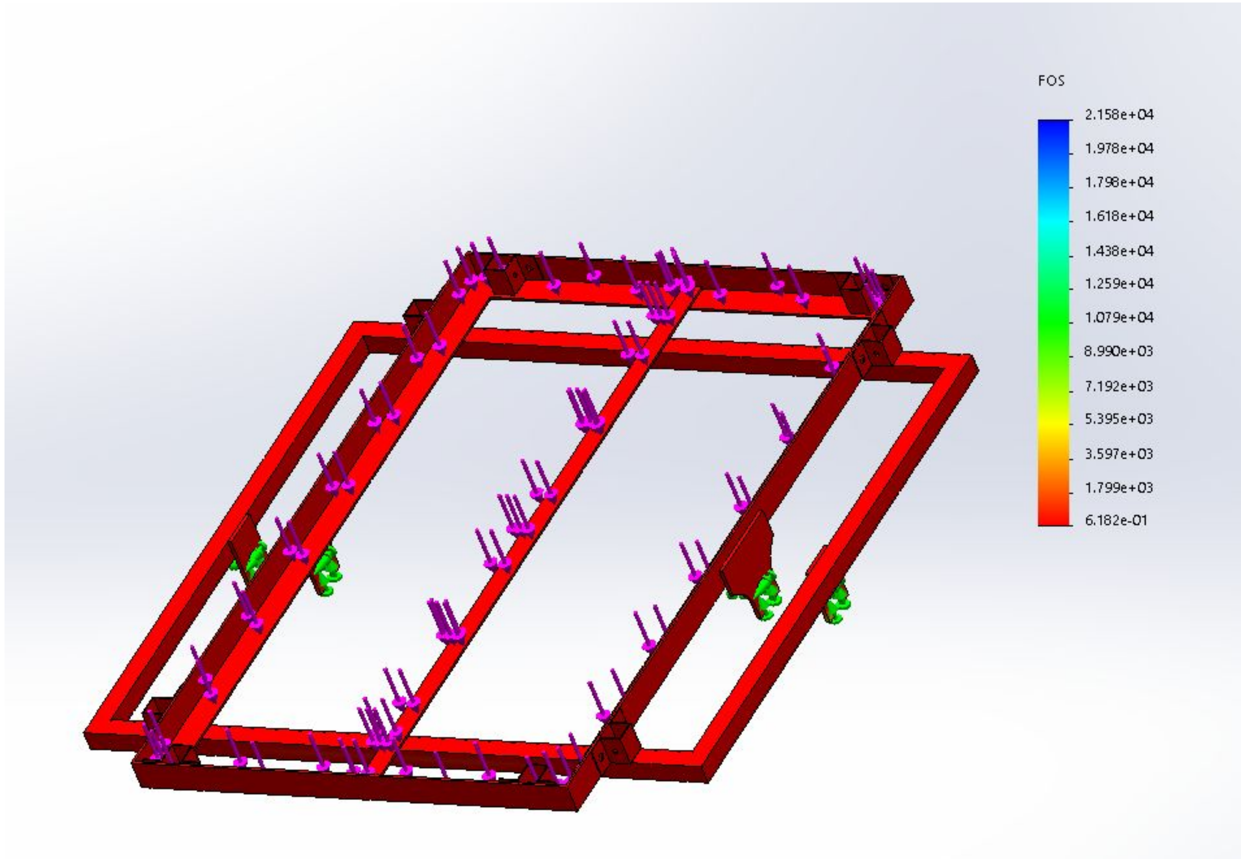

Figure 56. Cart Frame Factor of Safety Graphic (Range from 6.182e-01 to 2.158 e04)

A very similar trial is run on the cart frame, this time with the wooden slats included. The entire cart is once more given a material type of 1060 Al. The steel reinforcing beam and the axle cart connectors are kept as plain carbon steel. The wooden slats are given the same balsa wood material type as in previous trials. Both the carriage and wooden slats had been analyzed independently, by analyzing them together we hope to see smaller von mises stresses throughout the entire structure.

The axle/ cart connection portions are once again given a fixed boundary condition along the inner radius. The same loading of 578N is applied. However, in this trial the 578N load is dispersed evenly over the four wooden slats instead of along the inner edge of the cart carriage. The same fine mesh that was used in the previous cart base trial is applied to the structure to better accommodate difficult design geometries. A global element seed size of 0.014762 m with a tolerance of 0.0007336 meters. Once more, the total number of elements used in the structure is 23,083.

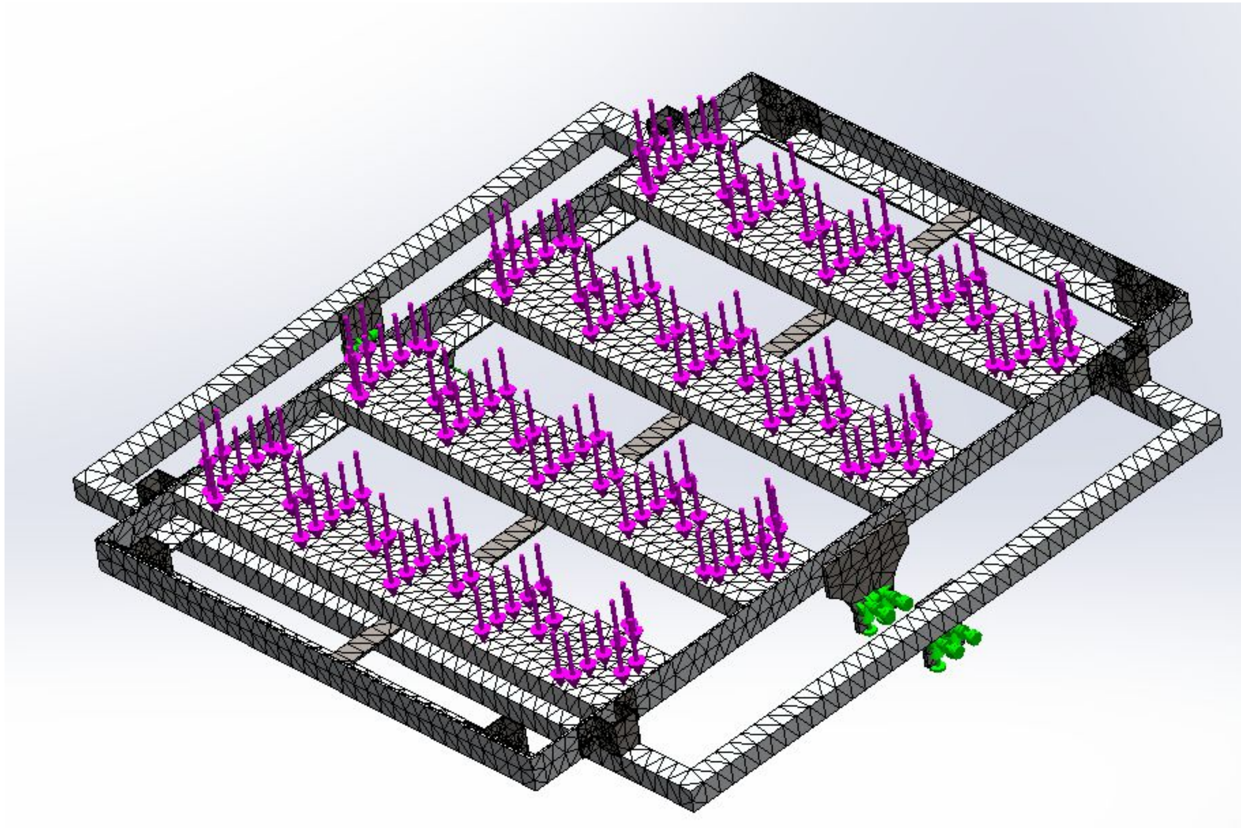

Figure 57. Cart Base with Boards- 578 N and Fine Mesh

Running the simulation provided similar results to what was initially expected. The cart frame with the boards experienced lessened Von Mises stresses across its entire structure than the cart frame without the boards. The wooden boards helped better distribute the loading so that the steel reinforcing beam isn't taking the brunt of the forcing. Now, the cart/ axle connection does provide some concern as stresses congregate around this part. However, these stresses remain well below the yielding point of steel resulting in a minimum factor of safety of 17 at this portion. The steel reinforcing beam received support from the wooden planks and experienced 1/30th of the stress it had in the previous study, at the center of the beam.

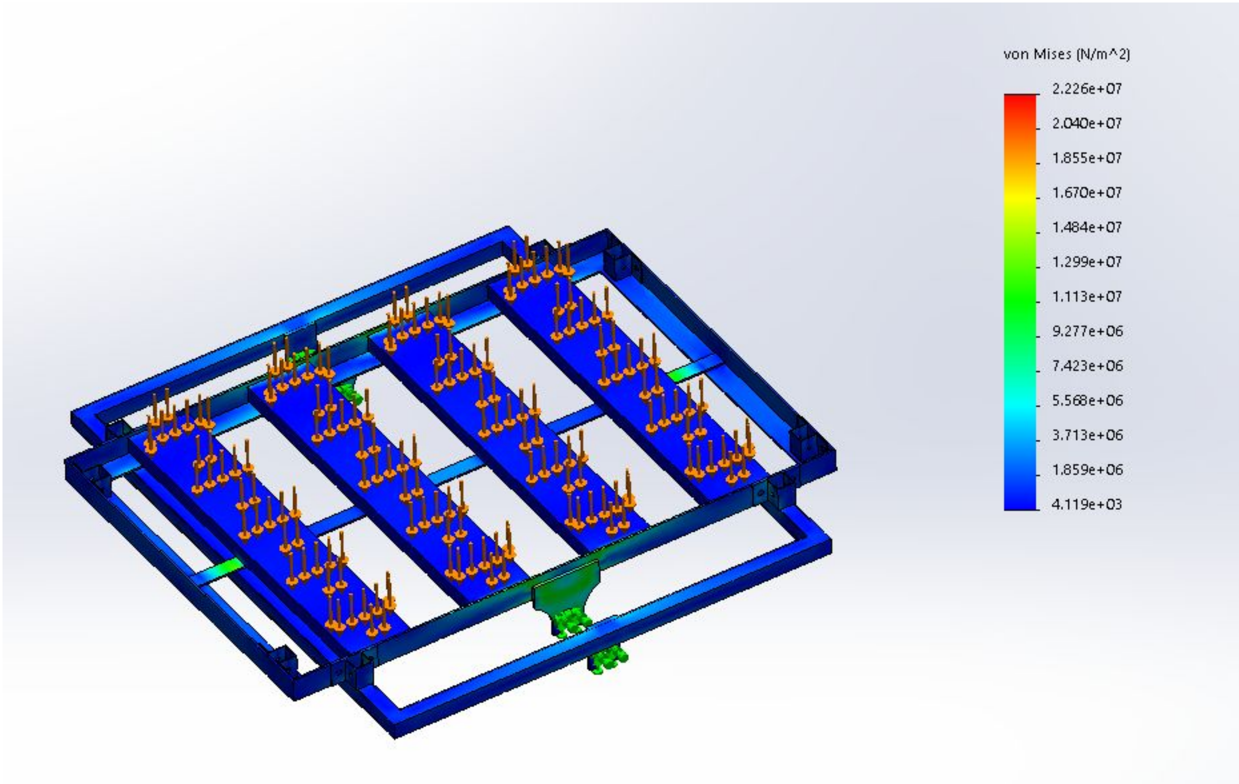

Figure 58. Undeformed Von Mises Stress Results for Cart Frame with Balsa Boards (Range from 4.119e03 to 2.226e07)

The deformed Von Mises stress results provide visual insight into the static failure of the cart base. [Figure 58] shows that with increased loading, the cart is expected to bend inwards until the material yield point is passed and the cart experiences ductile failure, indicated by plastic deformation of the frame. The balsa beams have a much lower yield strength than steel or aluminum and behave like a comparatively brittle material.

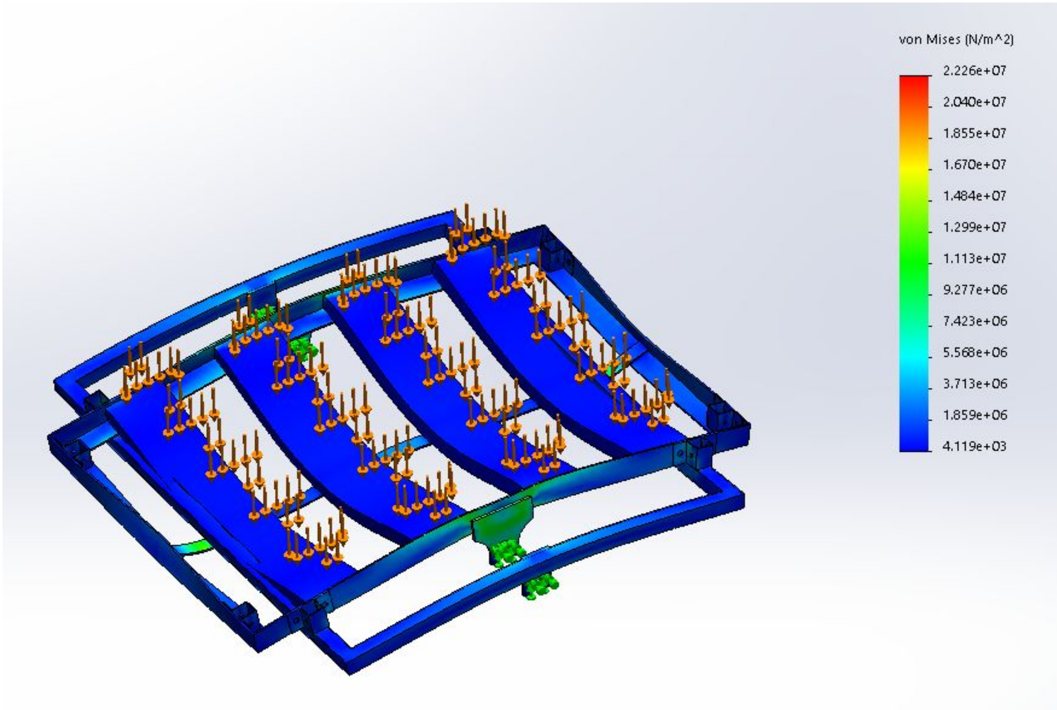

Figure 59. Undeformed Von Mises Stress Results for Cart Frame with Balsa Boards (Range from 4.119e03 to 2.226e07)

Once more, out of curiosity, the factor of safety graph is generated for the cart frame under loading. The default FOS graph doesn't provide much design selection insight due to the large range of FOS values presented. Perhaps reducing the maximum FOS expected from the cart on the chart will create a more helpful graphic. The FOS graphic indicates that the general factor of safety of the entire cart is 1.906, a dubious value seemingly unrelated to the differing stresses present within the structure.

In conclusion, the Solidworks simulation tool provided critical design insight for the cart frame subsystem. Adapting the cart frame design to help lessen stresses was confirmed effective by the various simulated trials. Using a stronger material for the reinforcing beam and the cart/ axle connection helped critical portions of the design avoid yielding. Using aluminum alloy for the majority of the cart frame helps substantially reduce the weight of the cart subsystem, an important consideration for a product intended to be pulled by the user.

3.5. Hitch Bar Subsystem

3.5.1. Introduction

The hitch bar subsystem acts as a connecting linkage between the rear frame of the bicycle and the front of the cart subsystem through a series of pin and locking connections. The connection point between the hitch and the bike must be universally adaptable to any bicycle and require minimal modifications to the pre-existing bike frame. Furthermore, the hitch bar should be constructed to withstand constant fatigue loading and axial force along the length of the bar due to fluctuating pulling forces generated by transporting heavy loads within the cart subsystem.

Due to the positioning of the hitch bar in relation the rear bike tire, major concerns arise in regards to stability and minimizing interference between the hitch bar and bike tire. To eliminate any potential contact between the hitch bar and the rear tire that could occur when making sharp turns, an axis point should be implemented beyond the leading edge of the rear bike tire to push all lateral movement beyond the edge of the rear bike tire. Considering the variation of bike frames and tires that result in difference between the height and configuration of the bike frame, an adjustable element should be added to the hitch bar system to account for this variation. By maintaining an optimal angle of attack of zero degrees in relation to the horizontal when pulling the cart subsystem, an increase in stability and efficiency can be seen when properly adjusted. To ensure that the system does not have any instability and also allows for easy mobility while turning the bicycle, it was determined that the hitch subsystem will have to have two degrees of freedom. When looking at the bicycle from a rear point of view, the two degrees of freedom that are needed are about the x and y axial directions. To further expand the abilities of the hitch bar, the connection points between the bike frame or axle and the cart hitch should be easily detachable to account for overall system constraints when operating the pump.

3.5.2. Hitch Bar Design Selection

In order to create an universally adaptable hitch subsystem, any modifications that will need to be made to the bicycle must be minimized. Pursuing this concept as the leading manufacturing constraint to the final design, a simple pin locking system that attaches to a coupler mounted on the rear frame of the bicycle was the most feasible design option. By attaching a coupler mount to the rear frame of the bike, a secure point of contact can be established to attach the hitch bar through a pin locking mechanism. The locking system will be easily removable to increase portability of the cart subsystem and increase the number of interchangeable parts within the overall design system to allow for easy repairs using locally sourced materials.

To begin the iterative design process for the hitch subsystem of the Pedal 4 Purification, a SolidWorks model was created with three main components: a frugally innovative universal joint, a bent hollow circular aluminum rod, and a simple journal bearing for the hitch-cart connection point. The SolidWorks model of the first iterative design can be seen below in [Figure 60]. As with many first iteration designs, there were a few problems regarding feasibility and subsystem stability. The first issue with this design was the use of a circular aluminum rod that was bent at two 90° angles along the span of the hitch bar. The Pedal 4 Purification group quickly discovered that circular aluminum rods are not as readily available as other aluminum rods, such as a square cross-section. Another issue with the circular rod was the fact that it would have to be bent in the developing community in which it was going to be implemented. During a consultation meeting with the most experienced mechanic on Santa Clara University's campus, the Pedal 4 Purification group learned that aluminum rod bending machines are very expensive and not very prevalent in developing countries. The other issue regarding this first iterative design was regarding subsystem stability. After careful analysis of the mechanism design behind the hitch linkages, it was determined that the journal bearing would give the subsystem one too many degrees of freedom and result in an instability in the entire device during use.

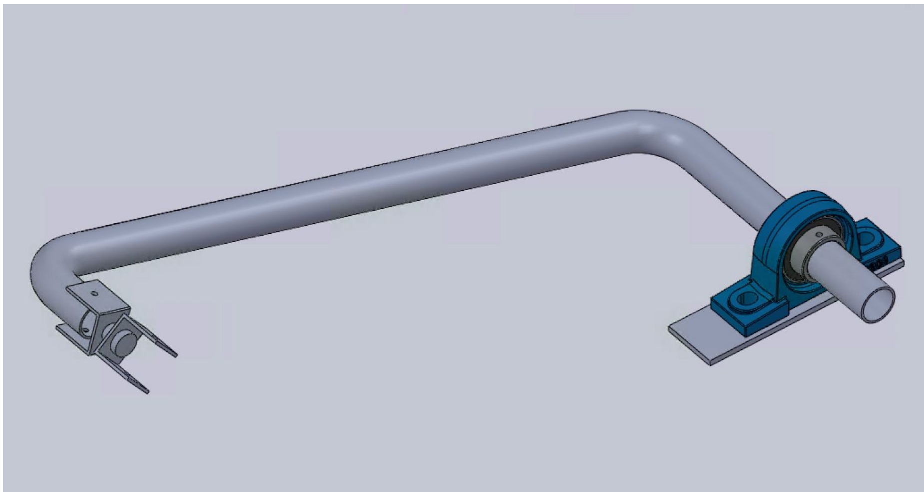

Figure 60. First Iteration of Hitch Subsystem

Interestingly, the major takeaway from the first iteration of the hitch subsystem was utilizing the frugally innovative universal joint mechanism at the bicycle-hitch connection point. This simple but genius component consisted of 16-gage steel sheet metal, a ⅜" galvanized steel bolt with corresponding hex nut, and a ⅜" washer. A manufactured implementation of the locking mechanism can be seen with the many components in [Figure 61] below.

Figure 61. A manufactured implementation of the hitch locking mechanism.

The second iteration of the hitch subsystem aimed to address the two issues that arose from the first iteration while also keeping the frugally innovative universal joint mechanism to attach the hitch to the bicycle frame. In this iteration, a hollow square aluminum rod was used to avoid the issue of availability of circular rods in developing countries. To address the issue of bending the hollow rod, a mitred, or 45° angle cut, was made at the end of the midspan and the longest span of the hitch bar. These two mitred corners of the hitch bar were then joined together to form a 90° angle that was then held together using two locally sourced corner braces. The longest span of the hitch bar would be attached to the front of the cart using 5/16” bolts and hex nuts.

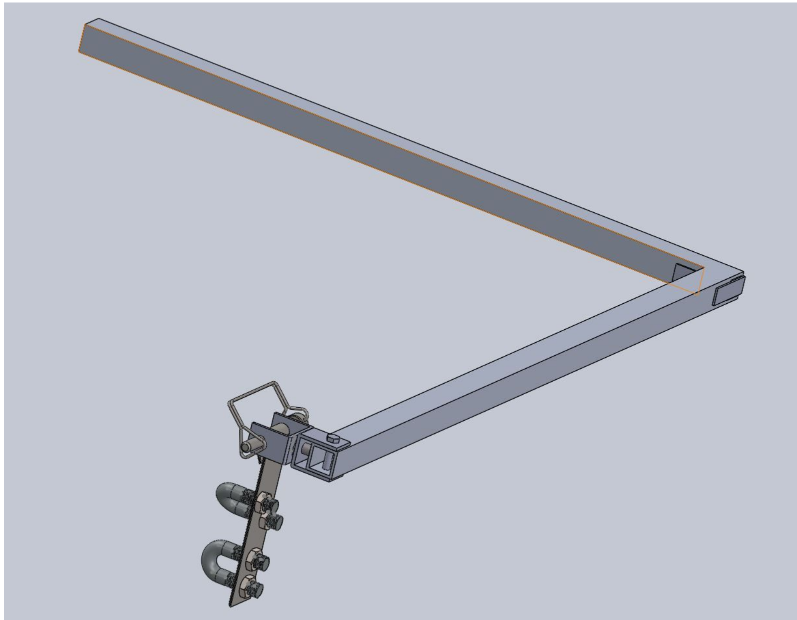

Figure 62. Second Iteration of Hitch Subsystem

After much deliberation, it was determined that four main components would make up the detachable locking mechanism for the hitch-bicycle connection: a frugally innovative universal joint, a power-take-off (PTO) pin, ⅝” cable clamps, and a ⅛” thick steel bar. The SolidWorks model of this iteration can be seen in [Figure 62] above. In this iteration, the frugally innovative universal joint is directly connected to the midspan of the hitch bar using a 5/16” bolt and hex nut. The other side of the universal joint was the attachment point to the bicycle frame that utilizes the PTO pin in combination with the 8-gage steel bar and ⅝” cable clamps. This end of the locking mechanism, which includes a PTO pin slot, can be seen in [Figure 63] below.

Figure 63. ⅛” Bent Steel Plate Connected with ⅝” Cable Clamps with PTO Pin Slot

Two issues arose from the second iteration of the hitch subsystem: maneuverability and impact stress at the hitch-cart connection. The first issue regarding maneuverability would arise when the bicycle driver would make sharp left turns, which would cause the midspan of the hitch to come in contact with the rear bicycle wheel tire. This strong frictional force would result in difficulty driving the bicycle. The other issue that arose after testing had begun was regarding impact stresses concentrated at the cart-hitch connection point. When the hitch was not connected to the bicycle using the locking mechanism, users were encouraged to hold the hitch as a handle to bring it close to the rear frame of the bicycle. In some instances, however, the user would accidentally drop the hitch and it would hit the ground with a large force, resulting in a significant impact stress concentrated near the mitred corner of the hitch bar. These two small design flaws had to be addressed for the final iteration that was made during manufacturing in Guatemala.

3.5.3. Hitch Bar Guatemala Iteration

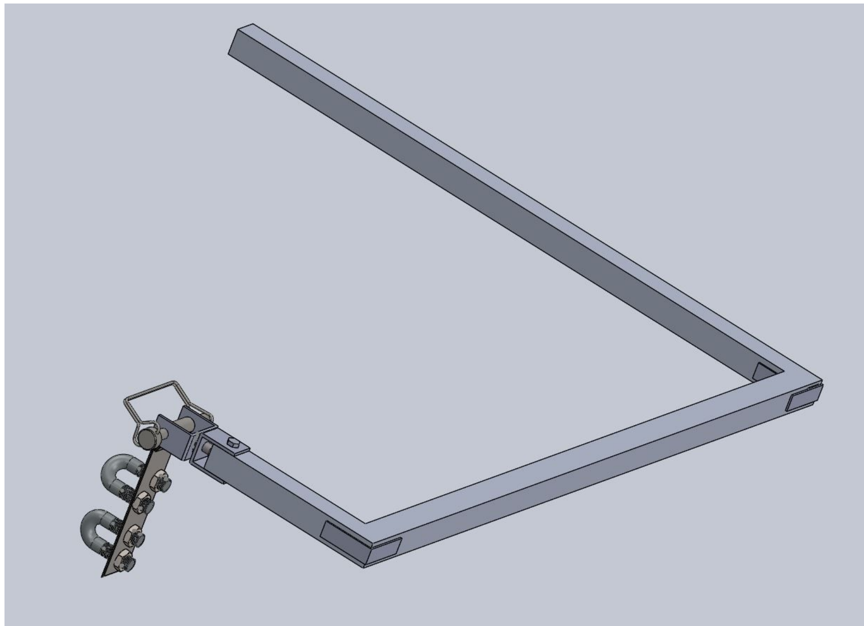

Figure 64. Final Iteration of Hitch Subsystem

As can be seen in [Figure 64], the final iteration of the hitch was made very similar to the second iteration design. However, after careful inspection it can be seen that a small extension was added near the locking mechanism. This small extension of about four inches was added using more 5/16" bolts with hex nuts and two more corner braces to give it enough strength the withstand the dynamic forcing associated with driving a bicycle. Four inches was just the right length to eliminate the issue regarding driver maneuverability and the midspan of the hitch hitting the rear bicycle tire. It was also purposefully designed to be not too long of an extension so that the narrow profile of the entire Pedal 4 Purification would not have to be sacrificed. A real-life implementation of the small extension bar can be seen in [Figure 65] below.

Figure 65. Extension of Hitch Connection between Bike for Increased Turning Radius

The other issue with the second iteration of the hitch subsystem design regarding impact stress at the hitch-cart connection point was eliminated using locally sourced materials in Guatemala by adding more corner braces at the mitred corner of the hitch bar. This extra reinforcing material provided significant strength to the overall subsystem and prevented failure under extreme loading conditions. A photograph of these reinforcement braces can be seen in [Figure 66] below.

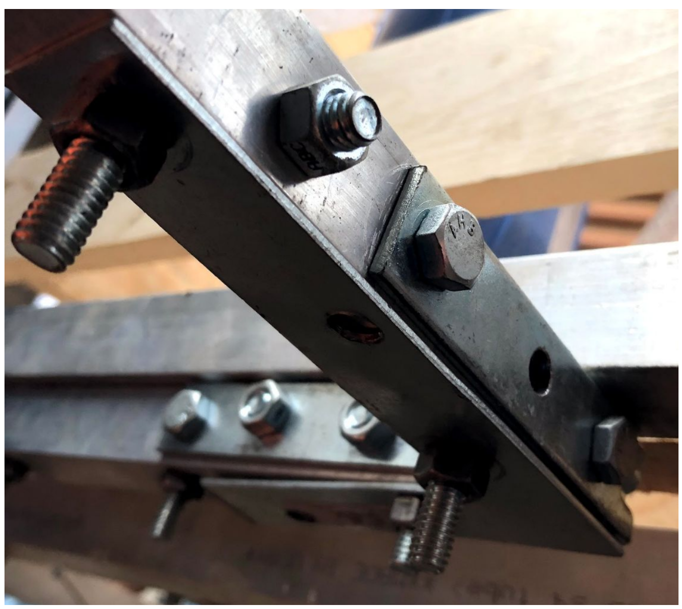

Figure 66. Addition of Corner Brace for Increased Support

3.5.4. Hitch Bar FEA Analysis

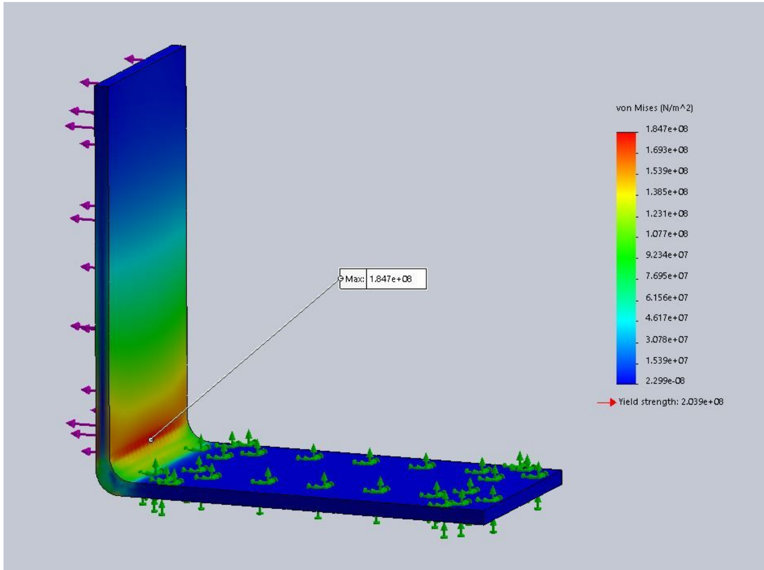

Figure 67. Von Mises Stress Diagram for L-Bracket Hitch Support Connection (Range from 2.99e08 to 1.847e08)

A simple finite element analysis was carried out to evaluate the strength of one of the corner braces at the mitred corner of the final iteration of the hitch subsystem. As can be seen from [Figure 67], the maximum Von Mises stress does not exceed the yield strength of the steel in which it is made, which suggests that the part could be deemed safe. This proved to be true, as the factor of safety was calculated to be 1.10.

4. System Integration

4.1. Experimental Protocol

During the manufacturing stage of product development for the Pedal 4 Purification, it was important to test prototypes as soon as they were prepared. [Table 8] below highlights the Experimental Protocol for these testing opportunities throughout the design process.

Table 8. Experimental Protocol for the Pedal 4 Purification.

Evaluation	Location/ Time	Equipment	Result and Accuracy	Trials	Expected Outcome	Formulae / Assumptions	Man Hours
Pump Test 1	Coleton's House, 3/ 22/19	Altered pump, Two marked volumetric containers, Stop watch, Bike, Hose, Filter	1.2 ± 0.2 L/min	21	Correlation between bike rpm and volumetric flow rate	Pump Affinity laws	12
Pump Test 2	Maya Pedal Hostel, 4/5/19	Altered pump, Two marked volumetric containers, Stop watch, Bike, Hose	1.7 ± 0.6 L/min	28	Correlation between bike rpm and volumetric flow rate	Pump Affinity laws	8
Kickstand Static Loading	Maya Pedal Hostel, 4/5/19	Kickstand, weights	N/A	5	Maximum Weight Capacity	Newton's Second Law of Motion (F= m*a)	1.5
Pump Test 3	San Itzapa, 4/7/19	Altered pump, Two marked volumetric containers, Stop watch, Bike, Hose, Filter	1.0 ± 0.1 L/min	10	Pump/Filter functionality	Pump Affinity Laws	12

As can be seen above, three different pump testing sessions were carried out to ensure that the actual flow rate was near the optimal flow rate outlined on the data sheet of the commercial filtration module used in the Pedal 4 Purification system. Interestingly, the first pumping test session yielded the optimal flow rate value of 1.2 L/min, matching the value on the Sterasyl Data Sheet. The accuracy for this pump testing session was found to be ± 0.2 L/min. The second pump testing session proved to yield the furthest value from the optimal flow rate of 1.2 L/min with a result of 1.7 ± 0.6 L/min. The larger accuracy window suggests that the modifications made from the first prototype to the second were not beneficial to the accuracy of the overall design. The Pedal 4 Purification addressed this issue in the third and final testing session in Guatemala by using a slightly longer tubing system to increase the fluidic resistance and thus reduce the flow rate through the filtration system. As can be seen in Table 8 above, the result recorded from the third pump testing session was found to be 1.0 ± 0.1 L/min. The small window of accuracy that resulted from these experimental efforts gave the Pedal 4 Purification team more confidence in the final design that was eventually donated to the small community of Patzun, Guatemala.

4.2. Pipe Flow Testing

In order to test the volumetric flow rate of the mechanically driven centrifugal pump, a baseline for the expected theoretical volumetric flow rate for an average cyclist was used to compare the accuracy of experimental data recorded. Three series of test were run at varying RPMs to create a graph of expected volumetric flow under different operating parameters. The first test measured the volumetric flow through the mechanically driven centrifugal pump without the attachment of the MCC Sterasyl filter. The second test measured the volumetric flow through the pump with the addition of the MCC Sterasyl filter attached to the exiting nozzle of the tubing. The third test measured the volumetric flow through the pump with the MCC Sterasyl filter using dirty water with heavy sediment and dirt particles mixed into the initial water sourced being processed. Each trial was run at RPMs in increments of 10 up to a reasonable RPM that the average user would be able to achieve during operation.

Unfortunately there was some human error associated with the action of manually pedalling the bicycle and trying to maintain a steady RPM value. It was assumed that the fluctuations from the specified RPM value averaged out over the course of each testing trial time period, as three of the Pedal 4 Purification team members were presently watching the tachometer as the experiments were carried out. If any of the members watching the tachometer value felt as though the actual RPM value deviated from the specified value for too long of a time period, he would announce his concerns and the trial would be thrown out. This protocol helped ensure that the assumption of disregarding the minimal fluctuations did not have a significant effect on the experimental results.

Furthermore, it is important to discuss scenarios in which this human error could lead to significant effects on the results. If the tachometer value stayed above the set value by a significant margin of about 1 RPM or more, the flow rate value would increase past the expected value. Oppositely, if the tachometer value read below the set value by about 1 RPM or more for a significant amount of time, the flow rate value would be reduced below the expected value at the set RPM.

While the theoretical volumetric flow rate did not take into account the head loss from the frictional forces of the inner tubing, the experimental results without the filter proved to be very consistent with the theoretical values calculated, as can be seen in [Figure 68] below.

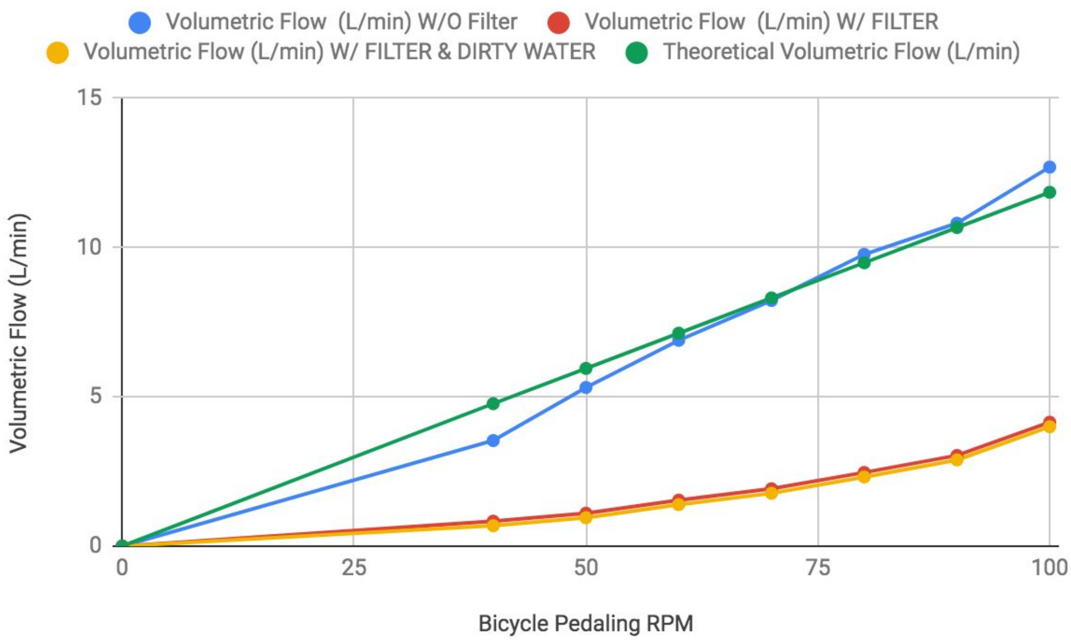

Figure 68. Volumetric Flow Testing for Varying RPM Values

5. Cost Analysis

The overall budget of the Pedal 4 Purification project was $2,500 which was donated to the team by the Santa Clara School of Engineering as well as the United Women of Marina Methodist Church. The total amount of spending on the project was $2,198.97 which was $301.03 under budget. The prototype spending breakdown can be seen in [Table 9].

Table 9. Estimated Production Costs for each of the Subsystems of the Pedal 4 Purification

Main Subsystem Final Prototype	**Costs**
Cart	$1,257.13
Pump	$176.52
Purification	$399.16
Kickstand	$230.42
Hitch	$135.74
Total	**$2,198.97**

This spending value was inflated due to the multiple iterations of designing the project as well as purchasing extra materials for maintenance and second iterations to leave in Guatemala for the community. If another iteration was to be created today with the Pedal 4 Purification team's current knowledge, the team is confident that the product could be created for $626. It is important to note that although labor costs will deviate from project to project, the fee that the Pedal 4 Purification team paid while in Guatemala was $50. Thus, it was assumed that this would be the cost of labor for future projects. See Section 6 for the detailed business plan regarding labor and shipping costs. The breakdown of the overall prototype cost for future projects can be seen in [Table 10].

Table 10. Overall Prototype Cost.

Subsystem	**Estimated Production Cost**
Cart	$261
Pump	$42
Purification	$162
Kickstand	$72
Hitch Bar	$39
Labor	$50
Total	**$626**

One of the main goals of the Pedal 4 Purification is for the final design to come in at no more than 10% of the current market leader, or the Cycloclean which costs around $6,650. The idea behind this goal is that the Pedal 4 Purification is a frugal innovation project and should be available for developing communities all over the world. Since the estimated cost of the final prototype comes in at $626, it achieves the goal of costing less than 10% of the current market leader.

It is important to run a cost analysis for each subsystem component to understand where most expensive subsystems. [Table 11] below shows the percentage of subsystem cost.

Table 11. Percentage of budget use for each subsystem of the Pedal 4 Purification

Subsystem	Budget Use Percentage
Cart	45.31%
Pump	7.29%
Purification	28.13%
Kickstand	12.50%
Hitch Bar	6.77%

It can be seen in [Table 11] that the cart accounts for nearly half the cost. It was easily seen that this would be the area to target to reduce cost in the next iteration. From talking to the locals in Guatemala, it became clear that the cart was overly intricate and many of its advanced functions were not necessary. The local community built their own version of the Pedal 4 Purification cart that was simplified and created out of steel. This cart could be produced for no more than $100 which drives the cost down even further.

6. Business Plan

6.1 Introduction

The Pedal 4 Purification is a groundbreaking frugal innovation device that aims to address the global issue of potable water scarcity. The device itself is a universally adaptable bicycle trailer cart system that allows people from all backgrounds to easily retrieve and purify local fresh water. The overall device is comprised of four main subsystems: a pump/filtration module, a kickstand, a cart, and a hitch. Since bicycles are ubiquitous in many developing communities throughout the world, the Pedal 4 Purification was designed to have the capability of attaching to any adult-sized bicycle. Although devices similar to the Pedal 4 Purification already exist, such as the Cycloclean, they cost upwards of $6,000 per unit which is much too steep of a price for many developing communities across the globe. Thus, the Pedal 4 Purification device was also designed to be made of locally sourced materials to reduce its retail price.

The team behind the Pedal 4 Purification consists of four mechanical engineering students and two academic advisors at Santa Clara University. Over the course of 9 months, the team has gone from the first few designs ideas to a full implementation in the small community of Patzun, Guatemala. After donating the first Pedal 4 Purification device and working with the locals of the Guatemalan landscape, the team working on the project has already expanded out to include the leaders and mechanics of an NGO called Maya Pedal in San Andres Itzapa, Guatemala.

One of the most attractive aspects of the Pedal 4 Purification is that its target market is quite broad. Originally, the device was intended to be implemented in developing communities in which unpurified fresh water resources were geographically far away from people's homes. This type of community certainly still remains within the scope of the target market for the Pedal 4 Purification. However, after implementing the device in Guatemala the team realized that it could be slightly tailored to fit the needs of many other kinds of developing communities to address the serious issues of potable water scarcity. After this realization was made, the team was able to confidently broaden the target market for the Pedal 4 Purification to be any community with a freshwater source within biking range and a terrain that allows for easy bicycle driving.

6.2 Goals & Objectives

The goal of the Pedal 4 Purification project is to provide potable water to developing communities all over the world for an affordable cost. The product is to be able to pump, purify, store, and transport this potable water using only the mechanical energy produced by an average bicycle. The objective is to allow the community to become fully self-sufficient in their water needs and allow them to take on the project as their own. In order for this to be done, the product must be fully locally sourced, the locals must be trained on the mechanics behind the product, and the product must be culturally adopted. This is a very important goal as it would allow the developing community to no longer rely on outside help as well as give them framework for further progress and benefits.

More specifically, the product should be able to filter local water sources/groundwater to below a 0.5 micron level. This level was decided in order to meet the standard for clean water set by the EPA. Additionally, the product should be able store and transport enough water for a family of 5 in one trip. This would result in 10 Liters and the average human drinks 2 Liters a day. In terms of cost, the goal is for the Pedal 4 Purification product to cost less than 1/10th of the market leader so that it is more available to those who need it most. This would set the max cost of the product to be $660 as the Cycloclean costs $6,600. This vast price reduction was done through making the product universally attachable to any bicycle such that the cost of investment is much lower as bicycles are very common in developing nations.

Another issue that the Pedal 4 Purification project is designed to fix is the amount of time spent on collecting water by the females of the family. Women around the world spend 200 million hours daily retrieving water for their families. This time could be spent on much more beneficial tasks such as education. In order to combat this, another goal of the project is to halve the time required to retrieve and purify water for a family.

6.3 Description of Product

Pedal 4 Purification is product designed to transport and purify water down to potable drinking levels for a small community within the developing world. The product consists of 5 primary subsystems which include, 1) Cart

2) Kickstand 3) Hitch 4) Pump 5) Filter. Each subsystem plays a vital role in the overall operation of this product and its essential to ensure the product is operated in a safe and efficient manner.

1) Cart Subsystem

The cart subsystem was designed to support a load up to 90 kg, including the water contained within the storage containers as well as all other moving subsystem components that encompass the Pedal 4 Purification product. The walls of the cart are constructed to be fully removable for increased storability when not in use or to store from the harsh nature elements that may decrease its lifespan. A connecting outer U-beam is used to support the axle of the bicycle tires used to allow for the use of locally sourced materials within the developing world.

2) Kickstand Subsystem

The kickstand subsystem was designed to support the rear bicycle tire during pedaling and operation. The square zinc plate tubing allows for variable adjustment between upper and lower vertical posts that can be universally attached to any size bicycle tire using a pin-locking system. The base vertical posts are slotted to allow for easy folding and storage in the cart subsystem. The large bolts used to securely attach the kickstand to the rear bike tire axle is able to support up to a 90 kg load, assuming the average weight of most operators of the product as well below its point of failure tolerance.

3) Hitch Subsystem

The hitch subsystem is designed to connect between the rear frame of any bicycle and the front base of the cart subsystem. The hitch uses a ⅝" piece of bent steel attached with ⅜" u-clamps that can be adjusted to fit on any size bicycle frame, making this hitch universally attachable. A simple power take-off pin is used to securely lock the hitch into the bent steel slot, allowing for 2 degrees of freedom to account for turning and added stability during travelings and transportation.

4) Pump Subsystem

The pump subsystem is comprised of a centrifugal mechanical pump that is converted to be mechanically driven by the centripetal pedaling force of a rear bike tire. The mechanical pump is able to provide a maximum flow rate of up to # L/min at an average cyclist pace of roughly 55 km/hr. Added traction was attached to the impeller axle to increase the friction coefficient between the rear bike tire and the impeller rod's surface. This task was executed by utilizing a recycled bike tire, wrapped together using plastic coated steel wire.

5) Filter Subsystem

The filtration subsystem is comprised of two systems, a primary multi-candle ceramic filter and, a secondary fine mesh pre-filter that blocks any large sediment from entering the pump impeller blade housing. The primary filtration utilizes a sterasyl multi-candle ceramic filter able to purify and remove all bacteria, protozoa, and viruses down to the 0.2 micron level, in line with US EPA drinking standards.

6.4 Potential Markets

The potential markets for the Pedal 4 Purification product is vast and ever growing. By addressing one of the most pressing issues in the developing world, the lack of access to clean potable water, the potential markets for this product is limitless. The primary focus of potential markets revolves around the outreach to NGO's and non-profit organizations around the world. By communicating between these organizations around the globe, the Pedal 4 Purification product can expand into communities that lack representation through a simple search on the internet.

Beyond the immediate scope of NGO's and non-profit organizations, this product can be implemented into disaster relief scenarios, helping those within all aspects of life, not just the developing world. With this in mind, the potential market can expand even further to disaster relief organizations like the Red Cross which may result as the lead consumer of this product. Addressing the severe effects of tsunamis, hurricanes, wildfires, and other related natural disasters, the Pedal 4 Purification product can be easily implemented into any affected communities that lack electricity and furthermore access to clean running water for consumption.

In reaching out to non-profit organizations like Maya Pedal in San Andres Itzapa, Guatemala and seeing the positive affect a single product can have on a community, there is positive hope towards further expanding this product into communities within developing countries that lack access to potable water with a common abundance of bicycles.

6.5 Competition

One of the two main players in the water purification bicycle industry is a Japanese-based company called Cycloclean. The Cycloclean comes with a water purifying attachment already installed and uses the filter design. This product is incredibly efficient as it is able to deliver 5 liters of clean drinking water in one minute with the pace of an average cyclist. In fact, this flow rate of 5L/min is so high that it is enough to supply 1,500 people with potable water for one day. In addition to this, the Cycloclean filters are estimated to last for two years, which demonstrates the company's incredibly sustainable efforts by minimizing physical waste. The Cycloclean is designed for locations where clean water is no longer accessible due to natural disasters or moderate pollution. The filter system included the Cycloclean is able to purify and dechlorinate water, allowing people in these disaster sites to draw water from local water sources or even through their own tap water faucets, bathtubs, or even backyard pools. Unfortunately, the Cycloclean is currently priced at $6,650, which is a massive number to pay for developing communities almost making it impossible for it to actually be implemented.

Another leading product is the Aquaduct Mobile Water filtration system made by the innovative company IDEO. This product is essentially a tricycle that has a tank of water on it and while riding the vehicle around a system powered by the pedals purifies the water. It contains a “dirty tank” in the back of the vehicle and “clean tank” in the front of the vehicle. The pedals power a peristaltic pump that draws water from the “dirty” tank, through a carbon filter, and into the “clean” tank. The bike also has the feature that allows the user to release the clutch and then the pedals strictly power the pump. The clean water tank is also removable and makes for easy transportation. This product is exceptional as it allows for the purification of the bicycle while moving and has the tricycle style to avoid stability issues. However, the Aquaduct has not yet been rolled out for large-scale applications and does not have a commercial price associated with it. As a result, one can conclude that there is a great window of opportunity to create a frugally innovative product similar to these two current products.

While the Cycloclean and Aquaduct seem to have little room for technological improvements, they do have a few flaws that limit them from being able to be used in the developing world. In other words, there are a few major improvements that can be made to the current technology. First, the two products are designed as a simple road bicycle with very thin tires. This type of bicycle is very difficult to maneuver when the surface is not paved. In many of the developing communities it is rare to have paved roads leading directly to a water source. Second, the bicycle purifies the water, however, it does not do much to alleviate the transport of the water as the front basket is the only storage container, and it can only hold about 6 liters of water. Finally, the price is incredibly high and limits the diversity of the buyer. The very steep price of $6,650 for the Cycloclean is too problematic for widespread frugal innovation applications in developing communities. The Pedal 4 Purification would solve these three flaws as it is designed to be implemented on pre-existing bicycles. This would severely limit the cost of entrance into our market allowing making it much more accessible to developing communities around the world. Also, since the bicycles are pre-existing in developing communities, they are most likely designed to handle the terrain of the surrounding area. The addition of a water tank would further improve the product as the goal of the project is to help developing communities that do not have clean water sources close to their homes.

Since this specific type of frugal innovation is just emerging, it is difficult to segment the two existing products on the international market. The Cycloclean is intended for wealthier communities in which natural disasters are more common, which explains why it is a Japanese-based company. Since there is not much financial data regarding the Aquaduct, it is hard to segment it into an appropriate bracket. However, IDEO is one of the most well-known designs firms in the United States so one can reasonably assume that the price of the Aquaduct would be much too high for developing communities just because of the cost of the many designers’ labor to create the product. Consequently, the market for a bicycle-powered, mobile water purification system can be divided into two segments: one for wealthier communities and one for developing communities. The Pedal 4 Purification aims to address the latter segment by drastically reducing the overall price of the product to 10% of the Cycloclean, or $665.

Thus, the Pedal 4 Purification seems to fall under a market segment in which there are no other large-scale competitors.

6.6 Sales/Marketing Strategy

The Pedal 4 Purification is a product intended to assist and uplift those living in water stressed areas. As such, there is no sales quota that needs to be met, nor any profit margins.

The marketing strategy involves team members reaching out to large non profit organizations willing to sponsor a product order for a community in need.

The advertising branch will use Facebook, Instagram, and Twitter to generate a public following and media interest. A lot of marketing revenue will be focused around social media outreach as it offers the greatest amount of access to the largest audience. Social media campaigns will be focused on spreading awareness of the World Wide water crisis and emphasizing the Pedal 4 Purification product's ability to make a positive impact. A greater social media following will increase overall product publicity and allow the Pedal 4 Purification team to make connections with larger NPO capable of sponsoring product orders.

A main function of the sales team will be finding and stabilizing connections with large NPO as well as local disaster relief programs. An online website will be created to work in conjunction with the social media campaign to allow interested parties more information concerning product purchase and implementation.

The Red Cross will be targeted as a potential sponsor as the Pedal 4 Purification product has a lot of benefit in disaster relief situations as well.

6.7 Manufacturing Plans

The Pedal 4 Purification product is designed and constructed out of several subsystems that each require unique manufacturing processes and materials in order to execute the most effective and efficient production possible. Given these constraints, the most intensive manufacturing process that this product would require is the ability to weld. Due to the unknown circumstances and access to materials and machining tools within developing countries around the world, the most effective way to construct this product would be to manufacture all major components within the United States then distribute them globally through other NGO's or non-profit organizations like Maya Pedal or the Red Cross.

Given access to welding and industry standard machine tools, The Pedal 4 Purification product could be constructed within a one to two day period, respective to the number of individuals working on the product at a time.

The primary areas of struggle that our team faced while constructing our product within Guatemala was the lack of access to materials and industry standard tools. This led to a large consumption of time spent trying to retrieve materials while this problem is something we would not face when manufacturing within the United States. Further manufacturing of this product and each of its subsystems can easily be streamlined to reduce overall build time.

In most cases, the Pedal 4 Purification product will be made to order and distributed to NGO's or non-profit organizations within developing countries to then be distributed into the local communities. Inventory will be primarily based upon having large quantities of raw materials on-hand that can be readily cut and assembled for distribution on a need to need case basis. Ordering in larger quantities with minimal waste of materials is the most ideal approach to maintaining a cost effective inventory that allows customers to receive their product in timely matter that does not elevate the products overall costs.

The estimated total cost of the Pedal 4 Purification product was calculated to be roughly around $626. This number includes the costs of materials and need to outsource welding during the prototyping and preliminary manufacturing stages of this product. If materials are purchased in bulk and produced using machining tools in house, the total manufacturing costs of product can be driven down dramatically to reduce its overall costs by nearly 20-25%.

By driving down the overall costs of manufacturing, the Pedal 4 Purification product can be produced at an elevated efficiency that is able to be assembled and ready for distribution within days of ordering. Since the product is not focused around profit but rather sustainability by helping the developing world, further expansion of the product will revolve around reaching out to other global NGO's and non-profit organizations within developing countries and within local organizations within the United States.

6.8 Product Costs

The Pedal 4 Purification product is not to be a mass produced product as a main goal of this project is for it to be locally sourced and easily maintained by locals. The need to instruct the locals on how to assemble the product on their own limits the ability of using mass production as the goal is to make them self-sufficient and not reliant on factories. Additionally, this product is to be custom made to order as not every community has the same exact use case or need. This makes the product cost a little more tricky to nail down. However, the Guatemala iteration of this product, for example, was determined to cost $626.00 and the cost breakdown can be seen in Table 1 below.

Table 1. Product Cost Breakdown

Category	**Spent**
Pump	$42.00
Purification	$162.00
Kickstand	$72.00
Cart	$261.00
Hitch	$39.00
Labor	$50.00
TOTAL:	**$626.00**

This cost, while meeting our goal of 1/10th of the market leader, is still planning to be reduced. A second iteration of the cart and hitch subsystems was created in Guatemala for $100 which would reduce the cost by $200. The design was created out of steel, was welded, and the collapsibility feature was removed. These features were deemed overly intricate and unnecessary. The simplified version would most likely be the design that would be used moving forward as it is more easily locally sourced and cheaper which are two main goals of the project.

In terms of implementation, these costs do not include the cost of travel and transportation of the product. In terms of the Guatemala implementation this was an additional $2,637, but this cost could be greatly reduced. It is not necessary to fly our 5 team members which would significantly reduce the transportation cost to near $700. This additional travel cost is planned to be eliminated by training locals on site so that team members do not need to be shipped on site frequently.

6.9 Service/Warranties

It is the responsibility of the Pedal 4 Purification team to create connections with the sponsor to ensure service checkups are scheduled on a regular basis.

Once a Pedal 4 Purification product has been ordered and manufactured, it is the responsibility of the sponsor and the Pedal 4 Purification team to introduce the product into the local community. Product introduction will require a translated instruction pamphlet as well as a live demonstration ensuring satisfactory functionality. Should the product fail to operate at the marketed flow rate, it is the responsibility of the Pedal 4 Purification team to make any necessary modifications to ensure a properly functioning product. Once a fully functioning Pedal 4 Purification has been successfully introduced into a community, it is then the responsibility of the sponsor to schedule community checkups to ensure the product is receiving proper use and care. Service checkups should be scheduled for 2 weeks after initial introduction, then for 4 month intervals such that the filter is replaced every other checkup.

The Pedal 4 Purification subsystem with the shortest service life is the multi candle ceramic filter. Depending on the amount of use, the multi candle ceramic filter needs to be replaced every 9-10 months. The Non Profit organization that sponsored the implemented Pedal 4 Purification product is responsible for the upkeep and replacement of the sterasyl filters. Depending on how rural the community, the pump subsystem may require sponsorship as well. However, all other subsystem components should be replaceable using locally sourced materials. Thus, upkeep of every other subsystem is the community's responsibility.

The cart subsystem has an expected lifespan of 15 years, an estimate which can be extended by protecting the product from excessive weathering. The pump subsystem has the most variable service life and can be expected to function for 5 years if the community is capable of keeping the inner axle clean. Proper maintenance protocol requires the cleaning of the inner axle after every use.

An important part of the Pedal 4 Purification service/ warranty plan is the continued improvement of the Pedal 4 Purification product. The Pedal 4 Purification team is expected to update the sponsored product during the next scheduled servicing should a superior design be created.

6.10 Financial Plan

The goal of the Pedal 4 Purification team is to provide the means to allow developing communities to be self-sufficient in their quest for potable water. The goal is not to become profitable, but only sustainable while helping those in need. For initial iteration and research phase, the funding was provided by the Santa Clara University School of Engineering. This was by far the most expensive phase and there were many tricks to figure out. As mentioned in Section 8, the commercial cost of one Pedal 4 Purification unit was estimated to be $626.00 for materials. However, this cost is believed to be able to be reduced in further iterations as it was concluded that the prototype created was more intricate and complex than necessary. Since the Pedal 4 Purification team is partnering with other NGO's, labor and maintenance costs can be assumed to be negligible. The cost of sending out a team member to serve as a instructor/consultant to the community in which the product is to be implemented is estimated to be about $500. This would vary depending on the location of the job site. This would leave the cost per project to be $1,076.

It is assumed that all team members would be working for Pedal 4 Purification on the side of a full time job, therefore there is no need for steady profits. Each system is custom made and made to order so fundraising would start at the beginning of a project. This fundraising would be done in coordination with the NGO that the team would be working with. This funding would come from NGO's, crowdfunding, and university/government donations. As mentioned previously, the goal is not to have dividends returned on investment, but rather the ROI would be the positive social impact created by the implementation of the Pedal 4 Purification product. These social impacts include increased access to potable water, less diseases, more opportunity for women to receive education, and most importantly making the communities self-sufficient.

Once the full design ideas have been solidified and accepted by all engineers involved, fundraising would immediately start taking place. As previously mentioned, this would include using the team members points of contact, the NGO leaders' networks, local university and government funding opportunities, and other crowdfunding platforms such as GoFundMe. As these funds are added to the overall budget of the project, Pedal 4 Purification team members could use them to develop the custom-made prototype for the specific community. Once the prototype has been manufactured, one team member will use funds from the budget to travel to the community and act as the project manager. This would entail creating the system with the locals as well as educating them fully on the mechanics of it and how it operates. The trip is to be fully documented so that the parties who donated can get a visual aid to see the great impact their donations have caused in the lives of others.

One interesting idea that the Pedal 4 Purification team has already come up with to incentivize donors to donate to each project would be to develop a reward program based on the monetary amount of each donation. For example, for donations of $1-200 a donor would receive a package of custom Pedal 4 Purification stickers, patches, and a water bottle. For donations of $200 or more, donors would receive the previous package as well as a custom made backpack with the Pedal 4 Purification logo. All donors would receive a commemorative video of the implementation of the project they helped fund.

7. Engineering Standards and Realistic Constraints

Sustainability

It is important that our product is sustainable as it is a frugal engineering product, but also because it is important to support sustainable communities. A sustainable community is a community that uses the resources available to it and does not exceed this. This is important as it preserves sufficient resources for future generations. Through sustainable engineering, this project can help promote sustainable communities. Sustainability is especially important in today's world as the population continues to grow and therefore demanding more resources from the world. The only way to live sustainably is to limit growth, minimize personal need for resources, or switch to renewable resources. As an engineer, the best possible procedure is the latter.

In Pedal 4 Purification, there are no resources consumed by operating the system. The only concern of sustainability is what to do with the wasted filters. This is a minimal amount of waste, however, and potable water is an end that definitely justifies that mean. This product uses only mechanical energy, generated by a human, which is perfectly renewable and sustainable. This product is also sustainable as it is completely reusable and the material is all biodegradable as there are no plastics used. Pedal 4 Purification also has taken durability as a strong point of focus. Limiting the failures limits the amount of materials wasted so this not only helps the user, but also the sustainable community.

Manufacturability

The manufacturing of the Pedal 4 Purification project is to be done within the community it is to be implemented in which is planned to be a third world community. This means that the simplicity of the required manufacturing and assembly must be stressed. One way this can be done is to simplify the design and reduce the amount of parts required. The more parts there are the higher chance for error there is and the more expensive the product and assembly labor costs become. This is incredibly important for a frugal innovation project as cost and simplicity are two of the most paramount constraints. Additionally, the Pedal 4 Purification product is to be designed out of common, easy-to-find parts and materials so that equipment gathering will not be an issue while manufacturing in a developing community. The amount of material should also be reduced in order to simplify this process as well.

Simplifying the manufacturing and assembly process can be, and has been, done in many ways. Pedal 4 Purification contains no tapered parts, no overly thin/hard to pick up parts, all mounting and fixture areas are on large parallel surfaces, and requires no overly difficult machining processes. The assembly should come with a poka-yoke instruction manual in order to ensure that the assembly is able to be completed with maximum efficiency. In addition to this the assembly is designed to be perfectly vertical in order to minimize the need to reorient the product.

Health & Safety

Health and safety is paramount to any engineering project in order to ensure the product does more good than harm. One of the largest reasons for failure is human error. It is important to ensure that the users of Pedal 4 Purification are well educated on the safety guidelines for the product. This product, for the most part, is a generally safe product with not much more risk than the average bicycle. However, it does contain moving parts that hair and fingers need to stay away from. Another potential safety risk is the combination of material failure and environmental effects. This product will most likely endure large amounts of sun wear which will weakened the material. That is why it is important to ensure the hitching system is made of a durable material that can sustain the environmental effects and cyclical loading. Poka-yoke principles are planned to be implemented into this project in order to ensure that operation and assembly of the product is mistake proof. By eliminating the possibility for mistakes, the risk of human error is greatly lowered. This will be done through an educational training session on the system and a clear and concise assembly instruction manual.

Social Impact

The Pedal 4 Purification aims to target water scarcity issues in the developing world, enacting positive short term social impact.

The Pedal 4 Purification is a product that not only reduces travel time to the local water source, it also lowers the user's level of exertion while collecting water. It's most important feature is its ability to pump and purify water down to a 0.02 micron level (below the EPA standard of 0.05 microns) [8]. Empowering a local community with safe water is important in more ways than one. According to water.org, "when people have access to safe water, they get time back to go to school, earn an income and take care of their family. It changes their world" [27]. Furthermore, the global water crisis remains intricately intertwined with women's rights issues. Because the burden of water collection often falls on women and children, finding clean drinking water takes away valuable time that women and children could be using in a more productive fashion. The Pedal 4 Purification aims to address this need for an increase in time savings.

The Pedal 4 Purification is comprised of 5 subsystems; pump, cart, hitch, purification, and kickstand. In an ideal use case, one Pedal 4 Purification system would be shared by a small community of about 20 people. The case scenario community would live within 3 kilometers of a water source. In Africa, the average woman walks approximately 6 kilometers carrying 20L of water on her head [19]. Assuming the average walking pace of 5 km/hr, it takes women in Africa around 72 minutes to collect water. Using the Pedal 4 Purification, the user is able to move to and from the local water source at 13 km/hr. This cuts the transit time down to 27 minutes. That is a 266% increase in time savings. Furthermore, the pedal 4 Purification will be able to comfortably transport 40L of water--enough drinking water to satiate 20 people for the day. Instead of making multiple trips back to the water source, the Pedal 4 Purification allows the user to collect more than enough water in only one journey. This 266% increase in time savings allows users the freedom to focus on other pressing issues present within their community.

Optimizing flow through the filter requires the user to pedal at 7.5 km/hr, or 60 rev/min on the bicycle. With the optimal flow rate of 1.5 L/min, the user can pump 40L of water in 26 minutes. In the ideal case scenario, collecting 40L of water with the Pedal 4 Purification product takes a maximum of 53 minutes. Without the Pedal 4 Purification product it takes 72 minutes to collect 20L of water on unfiltered water. These values correspond to a Liter to minute exertion ratio of 0.755 L/min using the Pedal 4 Purification product versus 0.013889 L/minute without it. Using the Pedal 4 Purification results in 54 times the amount of water per minute of exertion. Not only does the Pedal 4 Purification allow the user an immense increase in time savings, it also affords the user more water per minute of exertion. These numbers showcase the Pedal 4 Purification immense potential for social change if correctly implemented.

Thus, the social impact of the Pedal 4 Purification product can be categorized into three sectors: health, humanitarian, efficiency. The Pedal 4 Purification filters water down to a 0.2 micron level, keeping the user safe from a plethora of harmful bacteria and sediment. This has a direct impact on the user's immediate health, staving off water borne illness. The time savings afforded by the Pedal 4 Purification product allows users to combat other social/ political issues, furthering general human welfare within the community. The time savings component allows the Pedal 4 Purification to make an impact in the humanitarian sector. Time saved by using the Pedal 4 Purification allows women and children to pursue other pressing issues, such as education and social empowerment. Finally, from an efficiency standpoint, the Pedal 4 Purification allows users to collect 54 times the amount of water per minute of exertion than their previous method of water collection.

From an ethical standpoint, the Pedal 4 Purification may come under fire for being a short term solution to a long term problem. Looking at the big picture, our product is not intended to act as a permanent solution to the global water crisis. The Pedal 4 Purification allows for community empowerment by putting the ability to collect and purify water into the community members' hands. However, for lasting socio economic improvement, these communities will need to implement long term piping/sewage infrastructure. These kind of improvements are only possible through government intervention. While the Pedal 4 Purification is certainly an ethical product that's very creation was intended for good, it may receive condemnation from those that focus on the lack of long lasting change brought about by the product.

As a counter argument, the time savings brought about by the Pedal 4 Purification product will allow for greater community involvement in enacting long lasting change. Hopefully, the Pedal 4 Purification can serve as a short term solution to the world wide water crisis and function as a jumping stone for true, proper water transportation systems.

In conclusion, the Pedal 4 Purification product is potential agent of immense social impact. Touching the three sectors of Health, Humanitarianism and Efficiency, the product aims to alleviate suffering in water stressed communities. By filtering water below the USA EPA standard, the product ensures better protection from water borne illness. The 266% increase in time savings gained by using the Pedal 4 Purification allows for humanitarian growth, affording community members the time to target other issues. Finally, the Pedal 4 Purification allows for 54x more water per minute of user exertion reducing the physical toll on the water collectors. While the purification subsystem requires replacement about every year, many of the other subsystem components may be created using recycled parts and material. This reduces the overall negative environmental impact of the product. While not a long term solution to the world-wide water crisis, the Pedal 4 Purification acts as an effective short term solution in water stressed communities.

Economic/ Environmental Impact

Price point is a big concern with the Pedal 4 Purification product as it is manufactured for frugal use. The Pedal 4 Purification is capable of pumping and purifying water at 1/10th the cost of the market leader, resulting in a cheaper method of water purification for those in need.

The ideal distribution plan for the Pedal 4 Purification would involve non profit organizations subsidizing the manufacturing cost for the product. These organizations would then supply the Pedal 4 Purification to a local community within biking distance of a local water source. Ideal candidate communities would be near a school, allowing women and children to use their newly free time to further their education.

It is crucial that this product be run by a sustainable energy source as most of the target communities do not have easy access to affordable gasoline or electricity. Not only is sustainable energy convenient for use in these communities, it negates the negative impact of releasing more fossil fuels into the environment. The Pedal 4 Purification project is 100% human powered and runs only off mechanical power. This product consumes little resources and produces minimal waste, as the only physical output of the system is potable drinking water and the occasional worn out filter.

The respective subsystems comprising the Pedal 4 Purification have different estimated service life spans (and thus have different levels of environmental impact). The least enduring subsystem is the purification module, which has an estimated use span of 1 year. The multi candle ceramic filter is the least easily replicable subsystem component and requires replacement approximately every year according to the ideal use case scenario. The candle wick filters are also rather fragile, and great care should be taken to ensure they last through they're filtration lifespan. The Multi candle ceramic filters are not easily disposable and need to be treated in the same way as broken glass. While it is unfortunate that the most difficult to obtain subsystem component also requires the most frequent replacement, the multi-candle ceramic filters have a much longer lifespan than similar market products. Furthermore, a firm bristle brush may be used to clean the outside of the ceramic filters, extending its lifespan.
The pump subsystem is another rather fragile component. Care should be taken not to apply too much force on the exposed inner pump axle. While relatively inexpensive and easy to obtain, the mechanical pump might still prove somewhat difficult to manufacture in a rural community, as the top housing needs to be removed in order to expose the impeller rod axle to frictional contact. The pump has an expected lifespan of 3 years, though it may tire more quickly if dirt/mud is not regularly cleaned from the inside cavity in and around the impeller axle.
The rest of the Pedal 4 Purification subsystem components are expected to last a minimum of 10 years when treated with sufficient care. The environmental impact of the Pedal 4 Purification can be minimized by using locally sourced resources to manufacture the cart, hitch and kickstand systems. These subsystems are simple enough that simple design changes can be made to cater towards locally available material. The pump subsystem can also be created by converting any available electrical pump into mechanical by opening up the outer housing and exposing the inner axle rod. In this regard, the previously mentioned subsystems are quite sustainable, comprised of parts that can be easily replaced with materials found in most developing countries. Depending on scaling, the amount of waste created by the Pedal 4 Purification could vary greatly. The purification system is moderately sustainable, but needs replacement after its lifespan of 1 year. The overall product value increases with the number of operators, so a larger community would result in a greater benefit/ cost ratio for community members.

A major concern when introducing a frugally innovative product into a community is the lack of sustained use of the product. Often, if a product is not developed with a specific user in mind, the difficulty of operation may become a deterrent for community members. In these scenarios, the users end up reverting back to their original methods, and the project becomes unsuccessful in enacting change. In these scenarios, the entire product transforms from a product of utility to a pile of junk and the entire system contributes negatively to the environment. In order to ease operation, an infographic user manual has been created for the Pedal 4 Purification system. This user manual will serve as a visual aid, helping the user remember the order of operations for the Pedal 4 Purification Product. If all else fails, the phrase: Prime, Pedal, Purify acts as a basic instruction manual guiding the user towards correct operation of the product. Priming the pump is an essential step in ensuring adequate fluid transport. Pedalling once the pump is primed allows the unfiltered water to pass through the purification module. This pedalling purifies the water, the ultimate goal of the product. Thus, the sustainability of the Pedal 4 Purification product has been adequately inspected and measures have been taken to extend the service life of the product.

8. Guatemala Community Implementation

Upon arrival to the Maya Pedal Hostel in San Andres Itzapa, Guatemala the Pedal 4 Purification team met Mario, the founder of the hostel and a main point of contact for any visitors. Mario welcomed the team warmly and introduced his four main workers: David, Lupita, Dana, and Virginia. David was a middle-aged mechanic who specialized in welding and constructing custom 'bicimaquinas,' or bicycle machines, for the hostel and surrounding community. Lupita also helped work on the bicimaquinas, but she mainly helped out with translating Spanish to English and vice versa, as well as spearheading a bicycle maintenance course for the local women of the community. Dana was the main receptionist and spokesperson for each bicimaquina. Virginia helped showcase the bicimaquinas to the Pedal 4 Purification team once all four of the engineering students had settled in to their quarters in the hostel. After learning about each bicimaquina and how they work, Pedal 4 Purification team members got the privilege of trying them all out. There was a coffee grinder, a blender, a well pump, and even a tortilla maker in operation at the hostel.

Once the Pedal 4 Purification team had completely learned how Maya Pedal operates its machine workshop, the team immediately got to work in brainstorming how manufacturing would take place in the unconventional workspace. The team used a whiteboard to outline the many steps it would take to successfully build each subsystem component and finish the entire product for use on implementation day just three days after arrival. Once the whiteboard had been translated to Spanish with the help of Lupita and Pedro, everyone sat down at the kitchen table of the Maya Pedal hostel and finalized these steps given the constraints of the machine shop tools. One issue that the team immediately ran into was regarding welding the aluminum cart frame to allow for the side walls of the cart to securely stay in place while in operation. The main issue was that there was a miscommunication before the team arrived; David could only weld steel parts. The Pedal 4 Purification team and the members of Maya Pedal quickly resolved the problem using the bolted steel slot mechanism outlined in the product description for the cart that was previously discussed in Section 3.4.3 of this thesis paper. Once the two teams had reached a finalized plan for the manufacturing processes required to assemble the entire Pedal 4 Purification system, everyone walked the short distance to Mario's house for breakfast. Mario's wife, Veronica, and Mario's brother's wife, Mama Dumi, cooked the team and Lupita three meals every single day while the team was working in the machine shop at the hostel. As a result, the team was well-fed and got to experience very authentic Guatemalan meals throughout their time at the Maya Pedal hostel.

Once everyone had finished their first Guatemalan meal, the group headed back to the machine shop and immediately got to work. While manufacturing each subsystem component, the team ran into the issue of not having enough small hardware fasteners lying around the machine shop. Thus, team members were constantly having to translate words like “nut,” “bolt,” “screw,” and many more while on journeys to the local hardware store to pick up these important parts. Since there was a 3-day time constraint on the manufacturing process, some team members stayed back at the shop and kept working on subsystems that could be manufactured without the missing parts.

On the third and final day of the machine shop manufacturing process, the Pedal 4 Purification team, David, and Lupita had finished the entire device and prepared for implementation the next day in the rural highland community of Patzun, Guatemala. The team packed the bicycle, cart, hitch, kickstand, pump, and purification module into Mario’s truck and began the drive to the community early in the morning. On the way there, however, there was a major construction project taking place which completely blocked the road headed to Patzun. To pass the time, the team stepped out of the car and played a few mobile phone games with Lupita. Once the construction project had cleared, the team packed themselves back into the minivan and arrived at Patzun after a total of 3 hours in transit time.

The team was greeted by two young Guatemalan boys who were ecstatic to be able to help out with implementing the Pedal 4 Purification device in their home, which was situated just off the main road. Upon entering the plot of land where the home was, team members noticed that there were three makeshift shelters made out of corrugated steel, tree branches, and mud. A fire was constantly burning using trash inside of one of the shelters, where many women were cooking over it. The shelter closest to the road provided open space for the residents to eat and gather around. The third shelter was closed off but it could be assumed that this was the main space for living. A well that had been previously made by Maya Pedal was located near the back of the compound behind the shelter with the fire burning inside. The two boys helped the team unload the many subsystems from the truck and brought them inside the gathering shelter so that Jonathan, Matt, and Pedro could instruct the women and boys how to use the device from start to finish. Jonathan and Matt actually assembled the device while Pedro instructed the Guatemalans in Spanish. Meanwhile, Coleton and Cory helped David dig a large hole to house a holding container for the water that would be drawn from the contaminated well. In addition, they aided in the process of fixing the bicimaquina that powered a pump which drew the contaminated water up from the 30 meter well. The ‘bicibomba,’ or this bicycle-powered pump, was not working upon arrival and the chainring needed to be modified to allow the bicycle chain to remain on the correct section of the chainring. After the bicibomba was working and the instruction session had concluded, the team along with the two boys transported the entire Pedal 4 Purification device over to the well to begin the implementation demo.

Once the device had been assembled near the well, the Guatemalan women and boys were invited to begin riding the bicycle to extract the contaminated water from the holding tank, pull it through the purification module using the power generated by the mechanical pump, and store it in a tank inside the cart behind the bicycle. The brown color of the contaminated water completely disappeared after it had gone through the purification module and into the storage tank inside the cart, indicating that the water had been filtered thoroughly. To evaluate the purification levels of the water that had been treated more accurately, however, the team used a simple PPM stick to measure the levels of particles in the water. All of the readings measured lower than 200, which was in the range for safe drinking water according to the PPM device manual.

One small issue that that team did not foresee was regarding the lower weight of the children when riding the bicycle. Since their weight was much less than those of the adult women, the bicycle would not be pushed down far enough for the rear wheel to come in contact with the impeller rod of the pump and therefore no water would be extracted from the contaminated holding tank. This issue was easily fixed due to the adjustability mechanism implemented on the kickstand subsystem, however. The team asked the boys to stop riding the bicycle, step off, and then they adjusted the height of the pinned locking system on the kickstand down one peg to allow the boys to operate the device. Once this had been done, the boys were able to operate the Pedal 4 Purification device successfully and actually achieved flow rates higher than their older counterparts.

Before leaving the Pedal 4 Purification device with the people of Patzun, the entire team took small cups of the purified water from the cart's storage tank and made a toast with the local women and boys. Not only was this a bonding experience for the team and the members of the local community, but it verified the success of the purification module as no one got sick from drinking the water. After the toast, everyone made sure to say their "Thank You's" and Pedro made a donation to the women for additional infrastructure for their living space. The team drove home overwhelmed with joy that the device had been successfully implemented in an arbitrary community in Guatemala.

9. Summary and Conclusion

9.1. Evaluation of Final Design

The final design of the Pedal 4 Purification project focused on the creation of a universally attachable system that would be able to transport and purify water down to potable drinking levels with enough storage space to hold enough water for a community of 20 members. Numerous design iterations resulted in a Pedal 4 Purification system capable of pumping dirty water through a multi candle ceramic filter at the desired flow rate of 1.5 L/min. This flow rate ensures that the filter is capable of purifying water down to a 0.2 micron level, 0.3 microns below the EPA standard. The cart is capable of transporting 25L of water, as well as the weight of the other subsystems. With this capacity, 25L of drinking water is enough to satiate 10 people for the day [22].. Using the Solidworks simulation tool, the design selection for the cart, kickstand and hitch components were all verified. The kickstand subsystem is capable of supporting the full weight of an 86kg rider, an exaggerated loading used to verify design selection choices. The cart is capable of sustaining the necessary loading even without the addition of the central support rod on the carriage frame. Designed to maximize social impact, the Pedal 4 Purification allows the user to collect 54x the amount of water per minute of exertion. Furthermore, use of the Pedal 4 Purification product results in an increase in user time savings of 266% compared to traditional methods. Frugally designed, the Pedal 4 Purification is intended to maximize social impact while minimizing negative environmental effects. While perhaps a short term solution to the world wide water crisis, the Pedal 4 Purification aims to alleviate suffering by empowering users to collect and purify their own drinking water. A long term solution for water insecurity issues requires government involvement to design and implement effective piping infrastructure. The implemented system can be seen with the Pedal 4 Purification team in [Figure 69].

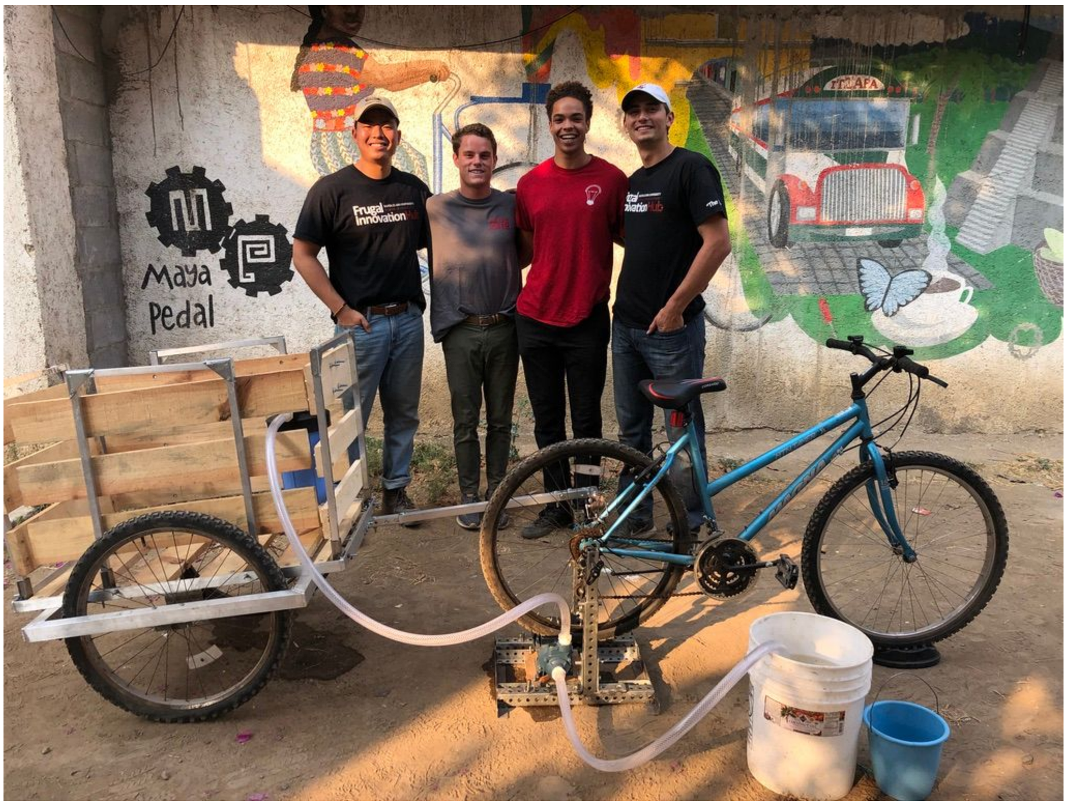

Figure 69. Pedal 4 Purification team with the implemented system at the Maya Pedal workshop.

Future Improvements to Design

While the Pedal 4 Purification project was able to successfully achieve its primary goals, there is still additional room for improvement within the overall structure of the project. The first improved to address is the somewhat overly complex number of components and subsystems that make up the overall design. In order to simplify the project while increasing the user friendly aspect for local members of developing communities, a combined system that contains the hitch, cart, and kickstand could be designed and manufactured. In doing so, the amount of space that each subsystem current encompasses can be easily store within one overarching system able to operate within the same constraints and parameters as previously set.

Another major improvement to the design would be the ability to use 100% locally source materials and manufacturing techniques to build and construct all parts of the project within the developing country in need. In regards to Guatemala, the workshop conditions and access to raw materials and parts were not clearly defined, limiting the ability to build and construct the subsystems as intended. This resulted in an increased level of frugal innovation involved within the project that resulted in major revisions, consuming large amounts of time. Being able to make a project universally adaptable is one thing, however making a project that can be made using locally sourced materials anywhere in the world is another. This is a huge hurdle that is unique to every community the Pedal 4 Purification project could be implemented to help.

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Appendices

Appendix A: Hand Calculations

Clear Water Pump RPM Calculations for Rear Bike Tire Rotation

Diameter of Pump Axle (d) = 2.0 inches = 5.08 cm
Diameter of Average Bike Tire (D) = 26 inches = 66.04 cm

Circumference for Pump Axle = $2\pi\left(\frac{d}{2}\right) = 2\pi\left(\frac{5.08cm}{2}\right) = 15.96\ cm$
Circumference for Bike Tire = $2\pi\left(\frac{D}{2}\right) = 2\pi\left(\frac{33.02cm}{2}\right) = 207.47\ cm$

Gear Ratio = **13:1**

15.5 km/hr = 25833.33 cm/min $\rightarrow \frac{25833.33}{207.47\ cm}$ = 124.52 rpm × 13 = 1618.71 rpm

Average Operating Pump RPM = 3400 rpm
Average Bike Powered Operating Pump RPM = **1618.71 rpm**

Max Volumetric Flow Rate = 31.0 L/min

Average Bike Pump Volumetric Flow Rate $= 31.0\frac{L}{min} \times \left(\frac{1618.71\ rpm}{3400\ rpm}\right) =$ **14.76 L/min**

Pipe Flow Hand Calculations

Pump Specifications Calcs

Question: Which pump to choose

Hydraulic Power: energy imparted on fluid being pumped (P_h)

$$P_h = \frac{\dot{V}\rho g h}{3.6\times10^6} = \frac{(2.5\times10^{-5}\,m^3/s)(998\,kg/m^3)(9.81\,m/s^2)(3m)}{3.6\times10^6} = 2.039\times10^{-7}\,kW$$

Parameters:

D = diameter of pipe = 0.025 m

$A = \frac{\pi D^2}{4} = 5.067\times10^{-4}\,m^2$

l = length of pipe = 6 m

ρ = density of H_2O = 998 kg/m³

h = 3 m

V = fluid velocity = $\frac{\dot{V}}{\rho A} = \frac{9.5\times10^{-5}}{(998)(5.067\times10^{-4})} = 5\times10^{-5}\,m/s$

μ = kinematic velocity = $1.0035\times10^{-6}\,m^2/s$

H_p = pump head

$H_L = f\frac{L}{D}\frac{V^2}{2g}$

$f = \frac{64}{Re}$ for Laminar flow

$H_{L_1} = (0.0507)\left(\frac{6}{0.0254}\right)\left(\frac{(5\times10^{-5})^2}{2(9.81)}\right) = 1.526\times10^{-9}$

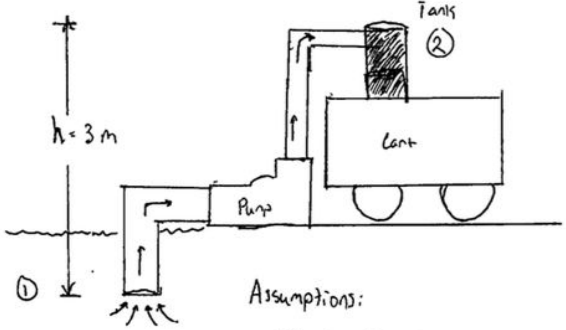
3 90° bends → 3k = 3(0.75)

$H_{L_2} = 3(0.75)\frac{(5\times10^{-5})^2}{2(9.81)} = 2.867\times10^{-10}$

$H_{L_2} = (K)\frac{V^2}{2g}$

Bernoulli's Eqn:

$$Z_1 + \frac{P_1}{\rho} + \frac{V_1^2}{2g} + H_p - H_L = Z_2 + \frac{P_2}{\rho} + \frac{V_2^2}{2g}$$



Assumptions:

1.) $P_1 = P_2 = P_{atm}$

2.) Velocity at ① = 0

3.) V_2 is velocity at filter exit

Calcs: $\cancel{Z_1} + \cancel{\frac{P_1}{\rho}} + \cancel{\frac{V_1^2}{2g}} + H_p - H_L = Z_2 + \cancel{\frac{P_2}{\rho}} + \frac{V_2^2}{2g}$

$H_p = 3 + \frac{(5\times10^{-5})^2}{2g} + 1.526\times10^{-9} + 2.867\times10^{-10}$

$\boxed{H_p \approx 3\,m}$

Take-aways:

1.) Choose a pump with head >= 3m

2.) Flow rate constrained by filter

3.) Pumping Power determined by user

Appendix B: Product Design Specifications

Pump Product Design Specifications

Manufacturer	Tooluxe
Product Dimensions	27.94 x 17.78 x 12.7 cm
Item Weight	4.54 kg
Max Volumetric Flow Rate (Q_{max})	16.71 L/min
Max Output Head ($H_{max,out}$)	14 m
Max Suction Head ($H_{max,suc}$)	4.5 m
Pipe Sizing	3.81 cm
Pump Housing Material	Cast Iron
Impeller Blade Type	Open
Impeller Blade Material	Brass

Cart Product Design Specifications

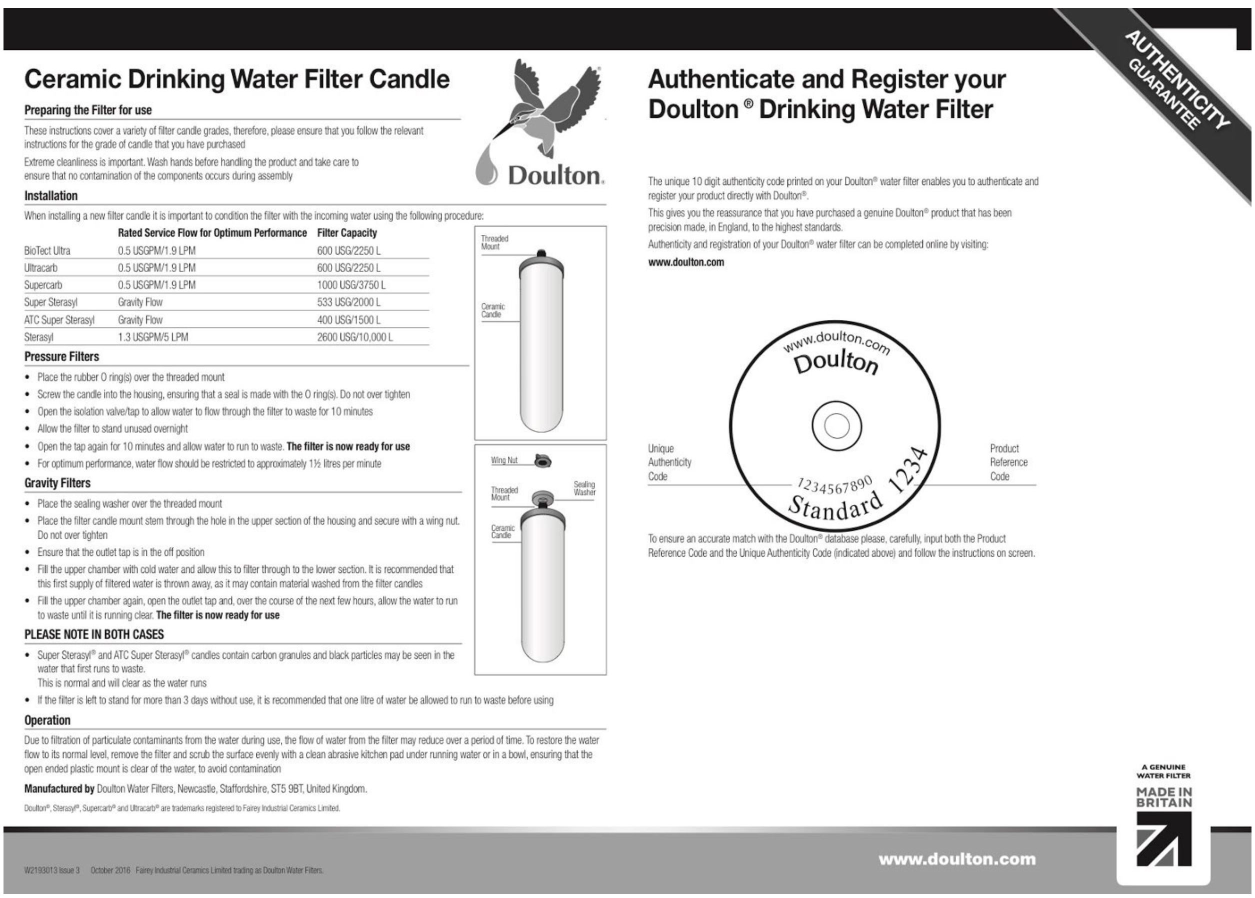
Dimensions	0.9144 x 0.9144 m
Weight	20.4 kg
Weight Capacity	70 kg
Primary Metal Base Material	Stainless Steel
Side Material	Wood
Max Speed	20 km/hr

Kickstand Product Design Specifications

Material	Stainless Steel
Weight Capacity	90 kg
Lifetime	10 years
Bike Type	Universally Attachable

Purification System Product Design Specifications

Purification Level	0.2 microns
Max Flow Rate (Single Candle)	5.0 L/min
Optimum Flow Rate (Single Candle)	1.5/min
Max Flow Rate (Multi-Candle)	25.0 L/min
Optimum Flow Rate (Multi-Candle)	7.5 L/min
Single Candle Configuration Cost	$40.00
Multi-Ceramic Candle Configuration Cost	$150.00
Filter Capacity	50,000 L
Filter Lifetime	6 months - 1 year



Ceramic Drinking Water Filter Candle

Preparing the Filter for use

These instructions cover a variety of filter candle grades, therefore, please ensure that you follow the relevant instructions for the grade of candle that you have purchased

Extreme cleanliness is important. Wash hands before handling the product and take care to ensure that no contamination of the components occurs during assembly

Installation

When installing a new filter candle it is important to condition the filter with the incoming water using the following procedure:

	Rated Service Flow for Optimum Performance	Filter Capacity
BioTect Ultra	0.5 USGPM/1.9 LPM	600 USG/2250 L
Ultracarb	0.5 USGPM/1.9 LPM	600 USG/2250 L
Supercarb	0.5 USGPM/1.9 LPM	1000 USG/3750 L
Super Sterasyl	Gravity Flow	533 USG/2000 L
ATC Super Sterasyl	Gravity Flow	400 USG/1500 L
Sterasyl	1.3 USGPM/5 LPM	2600 USG/10,000 L

Pressure Filters

- Place the rubber O ring(s) over the threaded mount
- Screw the candle into the housing, ensuring that a seal is made with the O ring(s). Do not over tighten
- Open the isolation valve/tap to allow water to flow through the filter to waste for 10 minutes
- Allow the filter to stand unused overnight
- Open the tap again for 10 minutes and allow water to run to waste. **The filter is now ready for use**
- For optimum performance, water flow should be restricted to approximately 1½ litres per minute

Gravity Filters

- Place the sealing washer over the threaded mount
- Place the filter candle mount stem through the hole in the upper section of the housing and secure with a wing nut. Do not over tighten
- Ensure that the outlet tap is in the off position
- Fill the upper chamber with cold water and allow this to filter through to the lower section. It is recommended that this first supply of filtered water is thrown away, as it may contain material washed from the filter candles
- Fill the upper chamber again, open the outlet tap and, over the course of the next few hours, allow the water to run to waste until it is running clear. **The filter is now ready for use**

PLEASE NOTE IN BOTH CASES

- Super Sterasyl® and ATC Super Sterasyl® candles contain carbon granules and black particles may be seen in the water that first runs to waste.
  This is normal and will clear as the water runs
- If the filter is left to stand for more than 3 days without use, it is recommended that one litre of water be allowed to run to waste before using

Operation

Due to filtration of particulate contaminants from the water during use, the flow of water from the filter may reduce over a period of time. To restore the water flow to its normal level, remove the filter and scrub the surface evenly with a clean abrasive kitchen pad under running water or in a bowl, ensuring that the open ended plastic mount is clear of the water, to avoid contamination

Manufactured by Doulton Water Filters, Newcastle, Staffordshire, ST5 9BT, United Kingdom.

Doulton®, Sterasyl®, Supercarb® and Ultracarb® are trademarks registered to Fairey Industrial Ceramics Limited.

W2193013 Issue 3 October 2016 Fairey Industrial Ceramics Limited trading as Doulton Water Filters.

Authenticate and Register your Doulton® Drinking Water Filter

The unique 10 digit authenticity code printed on your Doulton® water filter enables you to authenticate and register your product directly with Doulton®.

This gives you the reassurance that you have purchased a genuine Doulton® product that has been precision made, in England, to the highest standards.

Authenticity and registration of your Doulton® water filter can be completed online by visiting:

www.doulton.com

To ensure an accurate match with the Doulton® database please, carefully, input both the Product Reference Code and the Unique Authenticity Code (indicated above) and follow the instructions on screen.

Healthy water, healthy life.

Filter Performance

Doulton® British Berkefeld®

Candle Grade 49mmø		Sterasyl®	Super Sterasyl®	ATC Super Sterasyl®	Supercarb®	Chlorasyl®	Ultracarb®	BioTect Ultra®
Selection of the most appropriate grade of candle allows filter performance to be matched to the requirements of the local water conditions		Silver impregnated ceramic microfilter	Sterasyl® microfilter plus granular activated carbon	Sterasyl® microfilter plus granular activated carbon and lead removal media	Sterasyl® microfilter plus carbon block core	Sterasyl® microfilter plus carbon block core	Sterasyl® microfilter plus carbon block core and lead removal media	Sterasyl® microfilter plus carbon block core and heavy metals removal media
Filtration Rating (% particulate filtration efficiency)								
	Absolute (defined as >99.99%)	0.9 micron	0.9 micron	0.9 micron	0.9 micron	0.9 micron	0.9 micron	0.9 micron
	Nominal (defined as >99.9%)	0.5 to 0.8 micron	0.5 to 0.8 micron	0.5 to 0.8 micron	0.5 to 0.8 micron	0.5 to 0.8 micron	0.5 to 0.8 micron	0.5 to 0.8 micron
	Nominal (defined as >97%)							0.2 to 0.3 micron
Working Pressure (for pressure filter use)								
	Minimum	10 psi	10 psi	N/A	10 psi	10 psi	10 psi	10 psi
	Maximum	125 psi	125 psi	N/A	125 psi	125 psi	125 psi	125 psi
Working Parameters								
	Working temperature range	5 - 30 (°C)	5 - 30 (°C)	5 - 30 (°C)	5 – 30 (°C)	5 – 30 (°C)	5 – 30 (°C)	5 – 30 (°C)
	Working pH range	5.5 - 9.5	5.5 - 9.5	5.5 - 9.5	5.5 – 9.5	5.5 – 9.5	5.5 – 9.5	5.5 – 9.5
	Suitable for use in Gravity filters	Yes	Yes	Yes	N/A	N/A	N/A	N/A
	Recommended change frequency	12 months	6 months	6 months	6 months	6 months	6 months	6 months
Flow Rate								
Unrestricted Flow at 3 Bar Pressure up to	Litres per minute	5	4.5	N/A	3.7	3.7	3.3	3.3
	US gallons per minute	1.33	1.2	N/A	1	1	0.9	0.9
To achieve maximum performance	Litres per minute	N/A	1.2 l/hr under gravity	1.2 l/hr under gravity	1.9	1.9	1.9	1.9
	US gallons per minute	N/A	0.3 g/hr under gravity	0.3 g/hr under gravity	0.5	0.5	0.5	0.5
Capacity								
Before replacement to	Litres	10,000	2000	1500	3800	3800	2300	2300
guarantee performance	US gallons	2600	535	400	1000	1000	600	600
Quality Approval	NSF certified version available	YES⁺	NO	NO	YES	NO	YES	YES
	WRAS approved	YES	YES	NO	YES	NO	YES	‡PENDING
	Turbidity reduction to NSF std. 53	>98%	>98%	>98%	>98%	>98%	>98%	>98%
Pathogenic Organisms								
% Bacteria Removal*	E. Coli / Cholera / Shigella / Typhoid / Klebsiella Terrigena	>99.99%	>99.99%	>99.99%	>99.99%	>99.99%	>99.99%	>99.99%
% Cyst Removal	Cryptosporidium	>99.99%	>99.99%	>99.99%	>99.99%	>99.99%	>99.99%	>99.99%
	Giardia	>99.99%	>99.99%	>99.99%	>99.99%	>99.99%	>99.99%	>99.99%
Trace Organics Removal								
Insecticides	Lindane @ 0.1ppb presence	N/A	NO DATA	NO DATA	>85%	NO DATA	>85%	>85%
Herbicides	Atrazine @ 1.2ppb presence	N/A	NO DATA	NO DATA	>85%	NO DATA	>85%	>85%
Phenols	TCP @ 1.2ppb presence	N/A	NO DATA	NO DATA	>50%	NO DATA	>50%	>50%
Polyaromatic Hydrocarbons	PAHs @ 0.2ppb presence	N/A	NO DATA	NO DATA	>95%	NO DATA	>95%	>95%
Trihalomethanes	Chloroform @ 150ppb presence	N/A	NO DATA	NO DATA	>50%	NO DATA	>50%	>50%
Enhanced Organics Removal								
Lindane	2ppb presence	N/A	N/A	N/A	N/A	Ave 95%	N/A	Ave 70%
Atrazine	9ppb presence	N/A	N/A	N/A	N/A	N/A	N/A	Ave 90%
Benzene	15ppb presence	N/A	N/A	N/A	N/A	Ave 87%	N/A	Ave 87%
Inorganics Removal								
Free Chlorine Removal	2ppm presence to NSF Class 1 Std 42	N/A	Under Gravity >95% Under Pressure >50%	>95% under gravity	>97%	>97%	>96%	>96%
Monochloramine Reduction								
	3ppm presence	N/A	N/A	N/A	N/A	Ave 95% (600 USG)	N/A	N/A
	2ppm presence	N/A	N/A	N/A	N/A	N/A	N/A	Ave 64%
Heavy Metals Removal								
Lead reduction pH6.5	@ 150ppb presence to NSF Std 53	N/A	N/A	>94% under gravity	N/A	N/A	98.7%	98.7%
Lead reduction pH8.5	@ 150ppb presence to NSF Std 53	N/A	N/A	N/A	N/A	N/A	98.7%	†99.1%
Mercury reduction pH6.5	@ 6ppb presence	N/A	N/A	N/A	N/A	N/A	N/A	Ave 90%
Cadmium reduction pH 6.5	@ 30ppb presence	N/A	N/A	N/A	N/A	N/A	N/A	Ave 95%
Scale Inhibition		Slow release scale inhibition available with Ultracarb SI® and Supercarb SI® ceramic filter candles.						

State restrictions may limit the availability of certain products in California, Iowa and Wisconsin. For product availability in these States please refer to our website: www.faireyceramics.com

⁺ NSF certified replacement elements are Doulton Sterasyl®, Doulton Supercarb®, Doulton Ultracarb® and Doulton BioTect Ultra® as verified by testing in HIP Inline, and EcoFast® Inline Systems.

† Internally generated test data.

‡ Under approval process.

*Ceramics tested in HIS filter housing with a minimum of 5 log/100mls influent challenge.

A GENUINE WATER FILTER

MADE IN BRITAIN

Appendix C: Decision Matrices

Selection Criteria	Weight	Non-Priming Centrifugal Pump		Self-Priming Centrifugal Pump		Priming Hand Pump	
		Rating (0-5)	Weighted Score	Rating (0-5)	Weighted Score	Rating (0-5)	Weighted Score
Ease of Use	10%	2	0.2	4	0.4	4	0.4
Weight	10%	4	0.4	3	0.3	4	0.4
Compactability	20%	4	0.8	2	0.4	4	1
Durability	20%	4	0.8	3	0.6	3	0.6
Ease of manufacture	5%	3	0.15	3	0.15	3	0.15
Functionality	5%	4	0.2	4	0.2	3	0.15
Cost	10%	4	0.4	3	0.3	4	0.4
Flow Rate	20%	4	0.8	4	0.8	3	0.6
Total Rank Score			3.75		3.15		3.7
Ranking			1		3		2

Clear Water Pump Screening

Selection Criteria	Basic Impeller Pump	Non-Priming Centrifugal Pump	Self Priming Centrifugal Pump	Priming Hand Pump
Ease of Handling	0	0	+	+
Ease of Use	0	0	+	+
Weight	+	+	–	+
Compactability	+	+	–	0
Durability	0	+	+	0
Ease of manufacture	0	0	0	+
Functionality	0	+	+	+
Cost	+	+	0	+
Flow Rate	–	+	+	0
Sum +'s	3	6	5	6
Sum 0's	5	4	2	3
Sum -'s	1	0	2	0
Net Score	2	6	3	6
Rank	3	1	2	1
Continue?	NO	YES	YES	YES

		MCC Sterasyl		MCC Supercarb		Sterasyl w/ External Pre-Filter	
Selection Criteria	**Weight**	**Rating (0-5)**	**Weighted Score**	**Rating (0-5)**	**Weighted Score**	**Rating (0-5)**	**Weighted Score**
Ease of Handling	5%	4	0.2	4	0.2	3	0.15
Ease of Use	10%	4	0.4	4	0.4	3	0.3
Weight	10%	4	0.4	4	0.4	3	0.3
Compactability	15%	4	0.6	4	0.6	3	0.45
Durability	20%	3	0.6	3	0.6	4	0.8
Ease of manufacture	5%	3	0.15	3	0.15	3	0.15
Functionality	5%	3	0.15	3	0.15	4	0.2
Cost	10%	3	0.3	3	0.3	3	0.3
Purification	20%	3	0.6	4	0.8	5	1
Total Rank Score			3.4		3.6		3.65
Ranking			3		2		1

Water Purification Unit Screening

Selection Criteria	MCC Sterasyl	MCC Supercarb	Sterasyl w/ External Pre-Filter	Sterasyl w/ Secondary Gravity Purifying Stage	Sterasyl w/ Iodine/Chlorine Stage
Ease of Handling	+	+	0	–	0
Ease of Use	+	+	0	–	0
Weight	0	0	0	–	0
Compactability	0	0	0	0	0
Durability	–	–	+	–	0
Ease of manufacture	0	0	0	–	0
Portability	0	0	–	–	0
Functionality	0	0	+	–	–
Cost	+	+	+	–	0
Purification	0	0	+	+	+
Sum +'s	3	2	4	1	1
Sum 0's	6	7	5	0	8
Sum -'s	1	1	1	8	1
Net Score	2	1	3	-7	0
Rank	2	3	1	4	3
Continue?	YES	YES	YES	NO	NO

MCC = Multi-Candle Ceramic*

		Adjustable Pin-Angle Hinge		Stationary Screw Pump Adjustment		Adjustable Pump Locking System	
Selection Criteria	**Weight**	**Rating (0-5)**	**Weighted Score**	**Rating (0-5)**	**Weighted Score**	**Rating (0-5)**	**Weighted Score**
Ease of Handling	5%	3	0.15	4	0.2	4	0.2
Ease of Use	10%	3	0.3	4	0.4	4	0.4
Weight	10%	3	0.3	3	0.3	3	0.3
Compactability	25%	3	0.75	3	0.75	3	0.75
Durability	20%	3	0.6	3	0.6	3	0.6
Ease of manufacture	5%	4	0.2	3	0.15	3	0.15
Functionality	5%	3	0.15	4	0.2	4	0.2
Cost	10%	3	0.3	3	0.3	3	0.3
Availability	10%	3	0.3	3	0.3	3	0.3
Total Rank Score			3.05		3.2		3.2
Ranking			2		1 (TIED)		1 (TIED)

Rear Wheel Kickstand Screening

Selection Criteria	Twist Friction Vertical Adjustment	Pin-Lock Vertical Adjustment	Adjustable Pin-Angle Hinge	Stationary Screw Pump Adjustment	Adjustable Pump Locking System
Ease of Handling	–	–	+	+	+
Ease of Use	–	–	+	+	+
Weight	0	0	0	0	0
Compactability	+	+	0	0	0
Durability	–	–	0	+	+
Ease of manufacture	0	0	0	+	+
Portability	+	+	0	0	0
Functionality	0	0	0	+	+
Cost	0	0	0	0	0
Availability	–	–	+	+	+
Sum +'s	2	2	3	6	6
Sum 0's	4	4	7	4	4
Sum -'s	4	4	0	0	0
Net Score	-2	-2	3	6	6
Rank	3 (TIED)	3 (TIED)	2	1 (TIED)	1 (TIED)
Continue?	NO	NO	YES	YES	YES

		Metal Frame w/ Wooden Brace		Metal Truss Frame		Lateral Water Tricycle Storage	
Selection Criteria	**Weight**	**Rating (0-5)**	**Weighted Score**	**Rating (0-5)**	**Weighted Score**	**Rating (0-5)**	**Weighted Score**
Ease of Handling	5%	3	0.15	3	0.15	3	0.15
Ease of Use	10%	4	0.4	4	0.4	3	0.3
Weight	10%	3	0.3	2	0.2	4	0.4
Compactability	25%	3	0.75	3	0.45	3	0.75
Durability	20%	4	0.8	5	1	3	0.6
Ease of manufacture	5%	3	0.15	2	0.1	4	0.2
Functionality	5%	4	0.2	4	0.2	4	0.2
Cost	10%	3	0.3	2	0.2	3	0.3
Availability	10%	3	0.3	2	0.2	3	0.3
Total Rank Score			3.35		2.9		3.2
Ranking			1		3		2

Cart Screening

Selection Criteria	Metal Frame w/ Wooden Braces	Metal Truss Frame	Purification Falcon	Leading Push-Cart Design	Lateral Water Tricycle Storage
Ease of Handling	0	0	+	–	+
Ease of Use	+	+	0	–	–
Weight	0	–	0	0	+
Compactability	+	+	+	0	+
Durability	0	+	0	0	0
Ease of Manufacture	+	0	–	0	+
Portability	–	–	–	0	0
Functionality	0	0	0	0	0
Costs	+	0	–	0	0
Avalability	+	–	–	0	0
Sum +'s	5	3	2	0	4
Sum 0's	4	4	4	8	5
Sum -'s	1	4	4	2	1
Net Score	4	-1	-2	-2	3
Rank	1	3	4 (TIED)	4 (TIED)	2
Continue?	YES	YES	NO	NO	YES

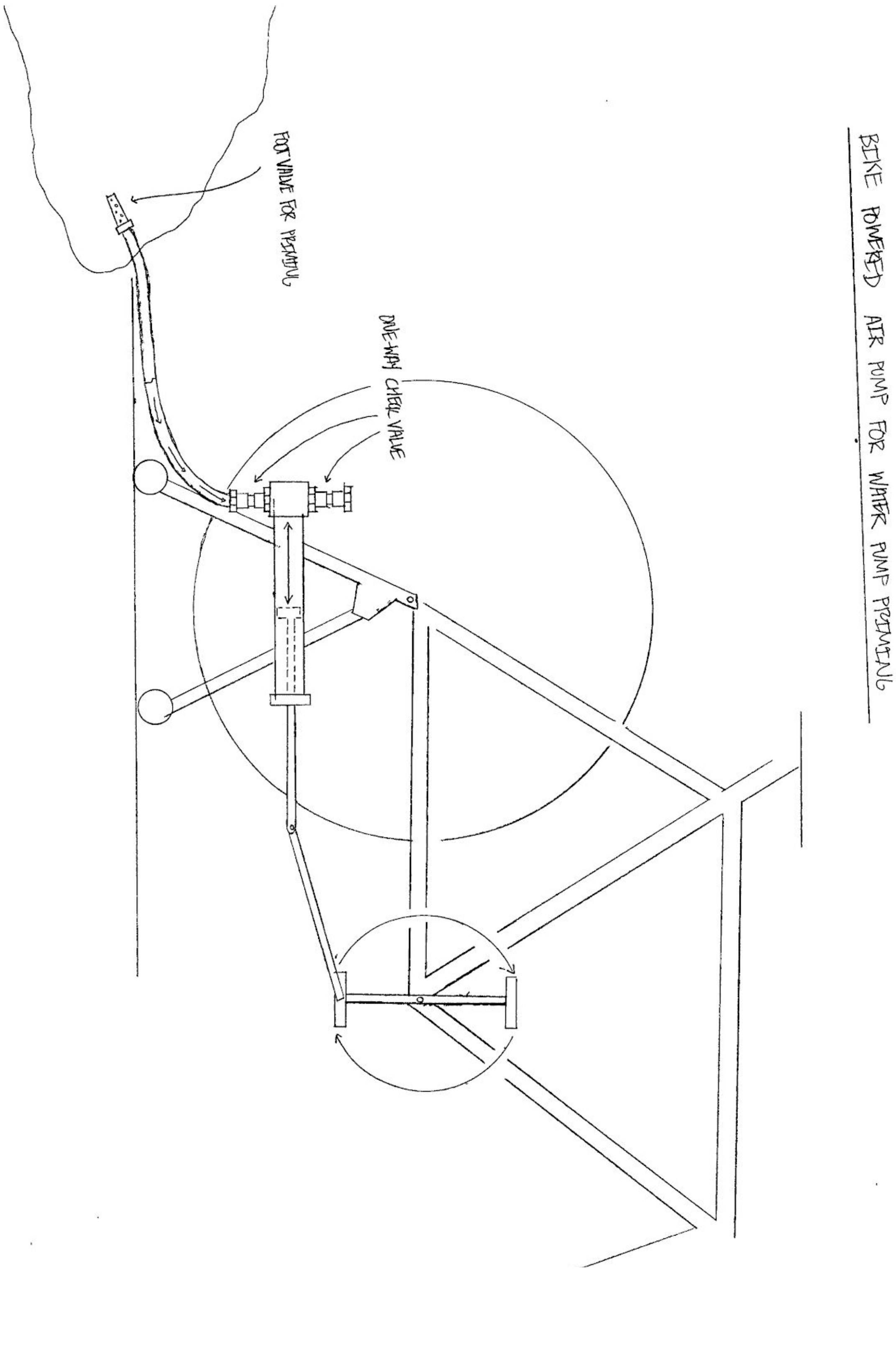
		Single Point Axle Pin Adapter		Dual Bar Frame w/ Pin Attachment		Dual Bar Frame w/ Ball Mount	
Selection Criteria	**Weight**	**Rating (0-5)**	**Weighted Score**	**Rating (0-5)**	**Weighted Score**	**Rating (0-5)**	**Weighted Score**
Ease of Handling	5%	5	0.25	4	0.2	4	0.2
Ease of Use	10%	5	0.5	4	0.4	3	0.3
Weight	10%	4	0.4	3	0.3	3	0.3
Compactability	25%	4	1	3	0.45	3	0.75
Durability	20%	3	0.6	5	1	5	1
Ease of manufacture	5%	3	0.15	5	0.25	4	0.2
Functionality	5%	4	0.2	4	0.2	4	0.2
Cost	10%	4	0.4	4	0.4	3	0.3
Availability	10%	3	0.3	4	0.4	3	0.3
Total Rank Score			3.8		3.6		3.55
Ranking			1		2		3

Cart Hitch & Attachment Screening

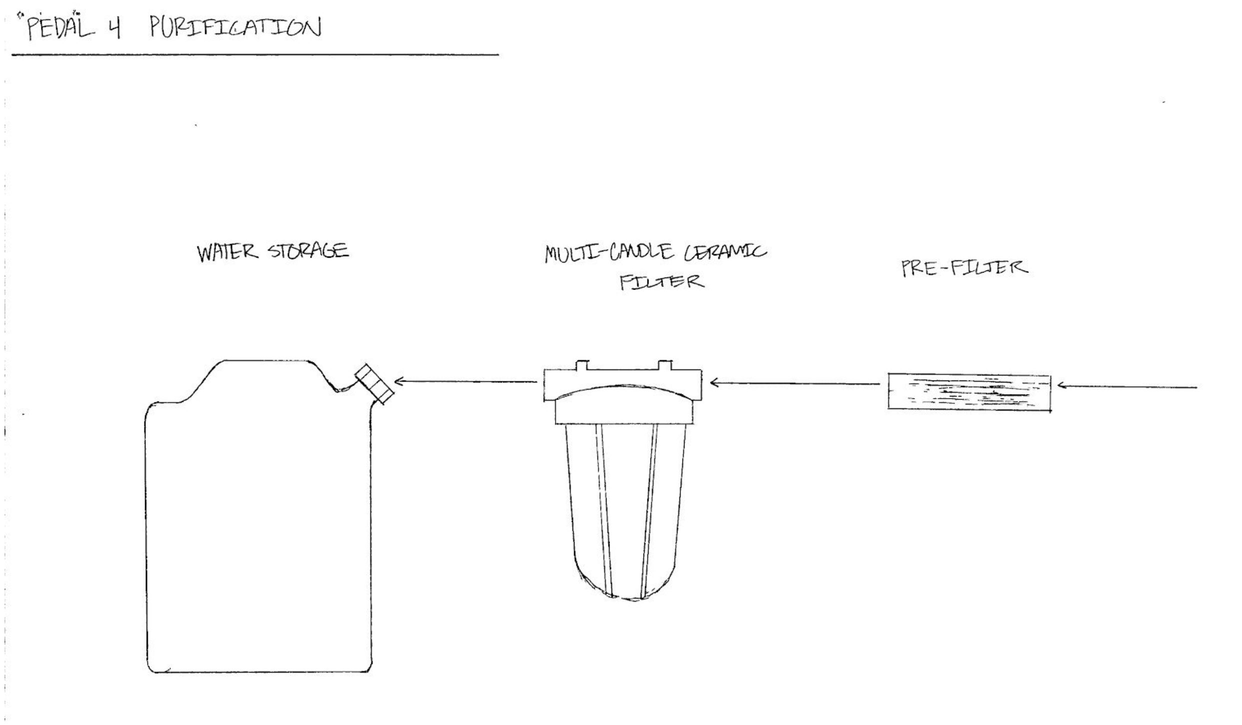
Selection Criteria	Single Point Axle Pin Adapter	Single Point Axel w/ Ball Mount	Dual Bar Frame w/ Pin Attachment	Dual Bar Frame w/ Ball Mount	Rear Bike Rack Pin Attachment
Ease of Handling	+	+	0	0	0
Ease of Use	+	+	+	+	+
Weight	0	–	0	–	–
Compactability	+	0	0	–	–
Durability	–	+	+	+	+
Ease of Manufacture	–	–	+	0	–
Portability	+	0	0	0	–
Functionality	0	0	0	0	+
Costs	+	–	+	0	–
Avalability	0	–	+	0	0
Sum +'s	5	3	5	2	3
Sum 0's	3	3	4	7	1
Sum -'s	2	3	0	0	5
Net Score	3	0	5	2	-2
Rank	2	4	1	3	5
Continue?	YES	NO	YES	YES	NO

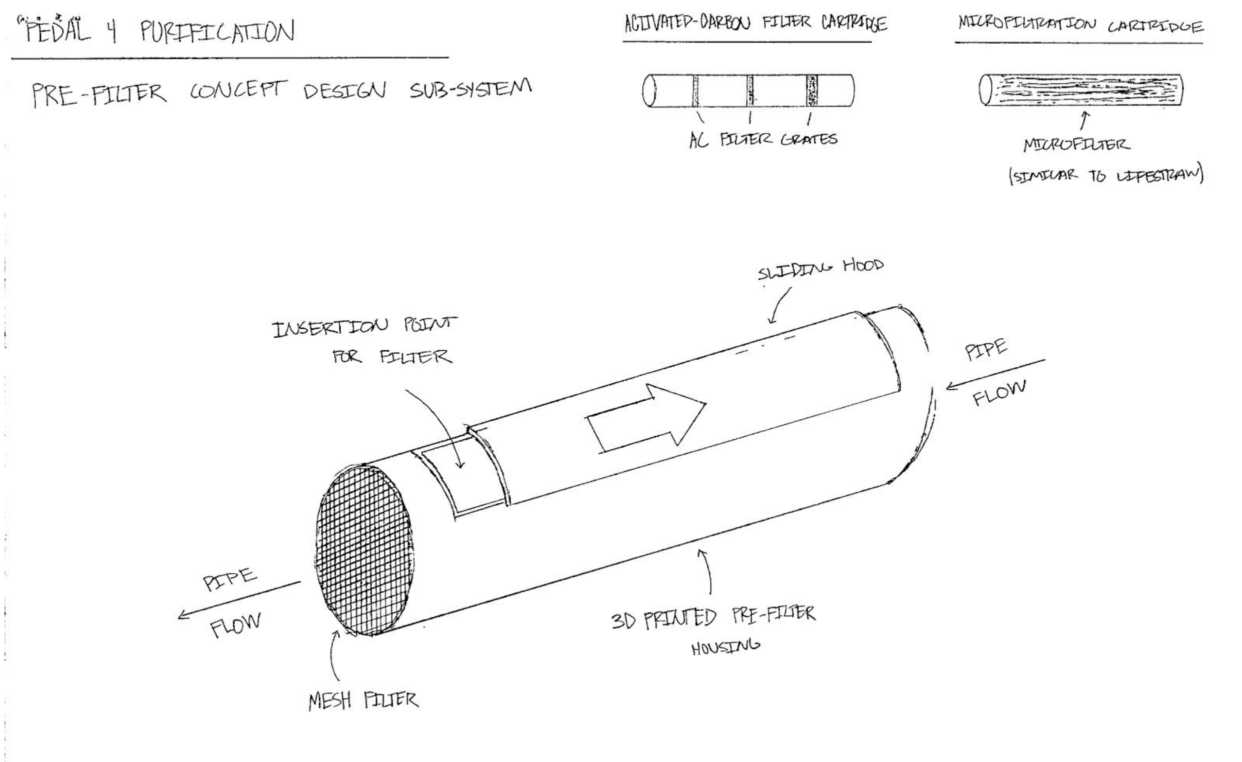
Appendix D: Design Sketches

Pump Sketches

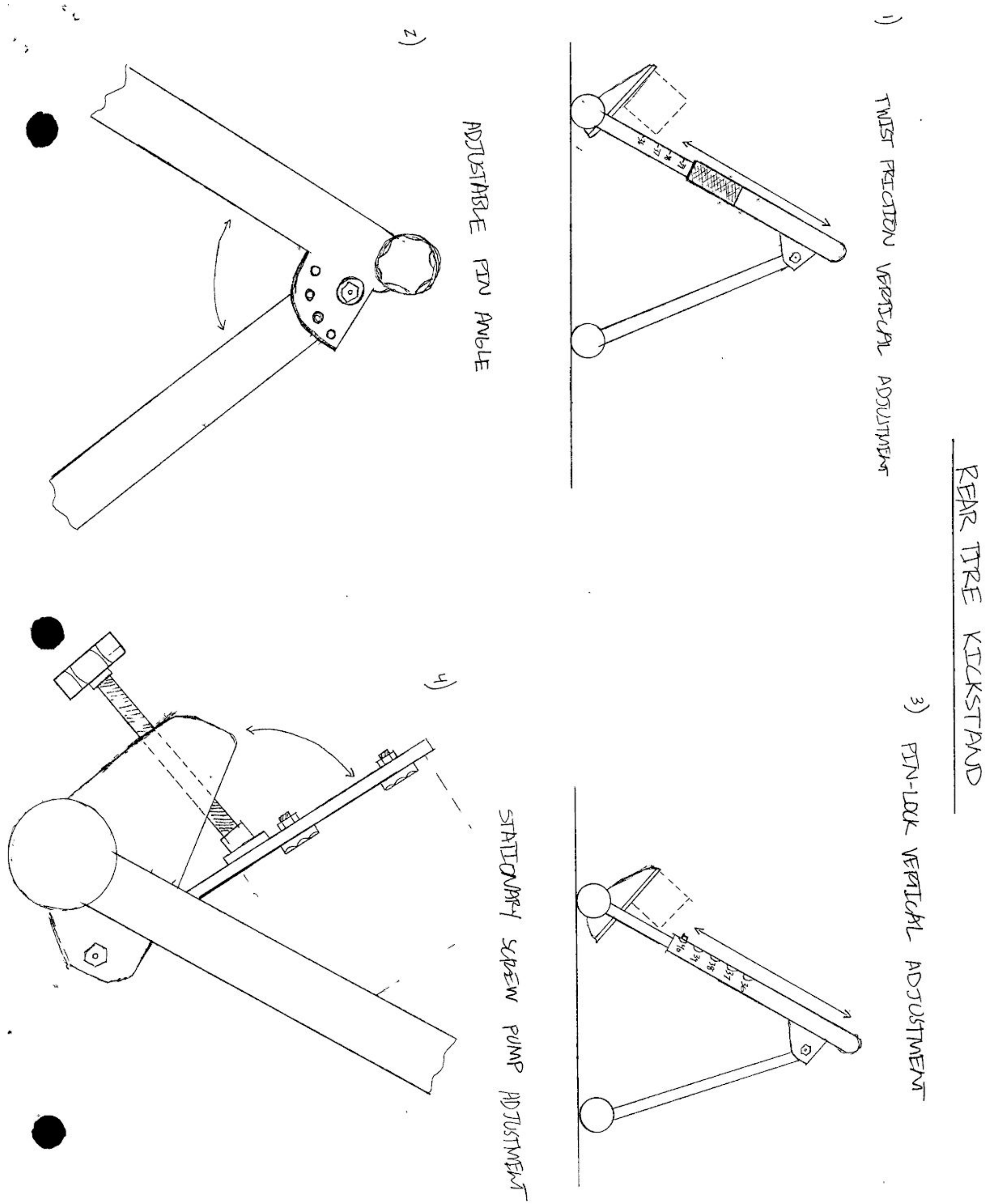


Purification Sketches

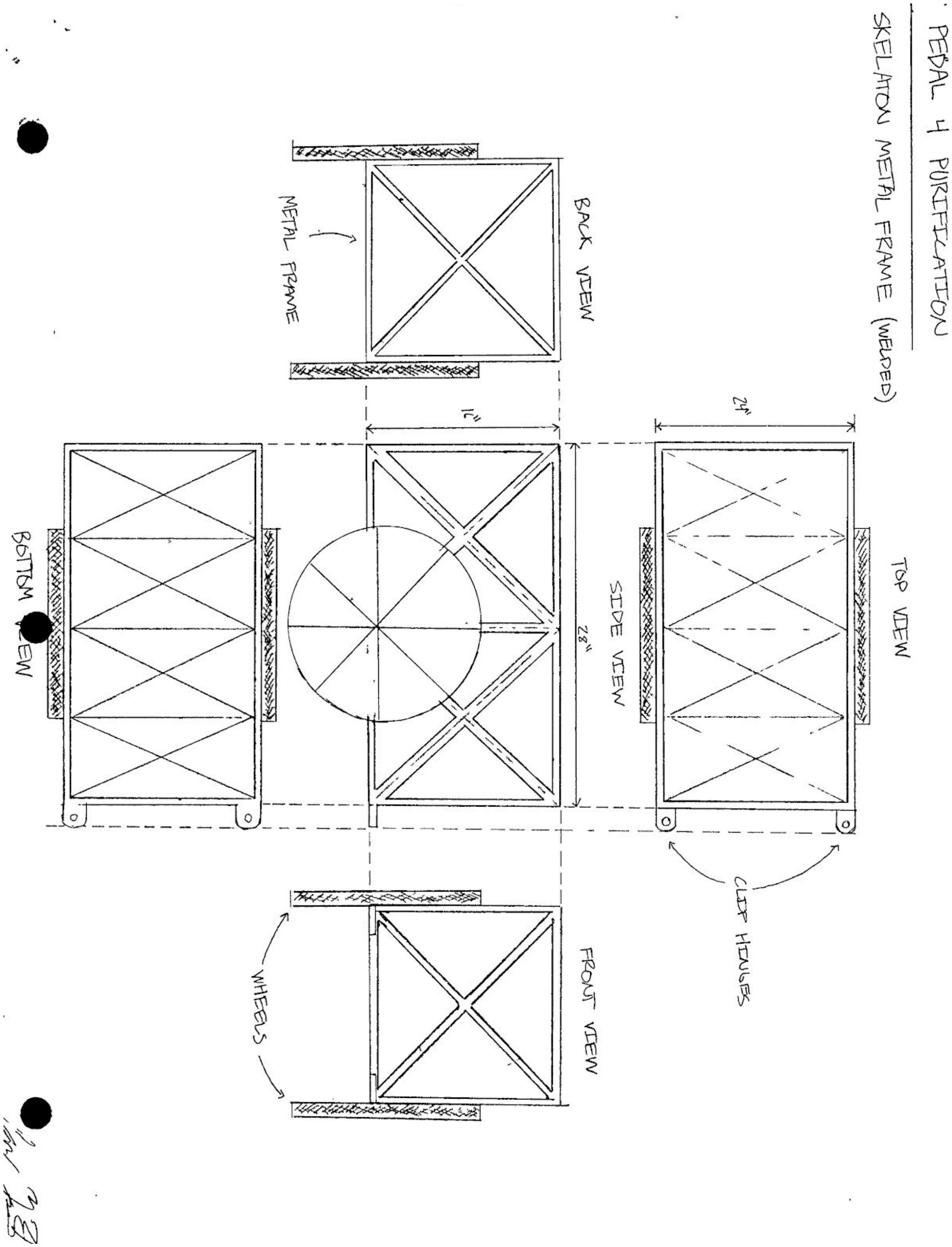


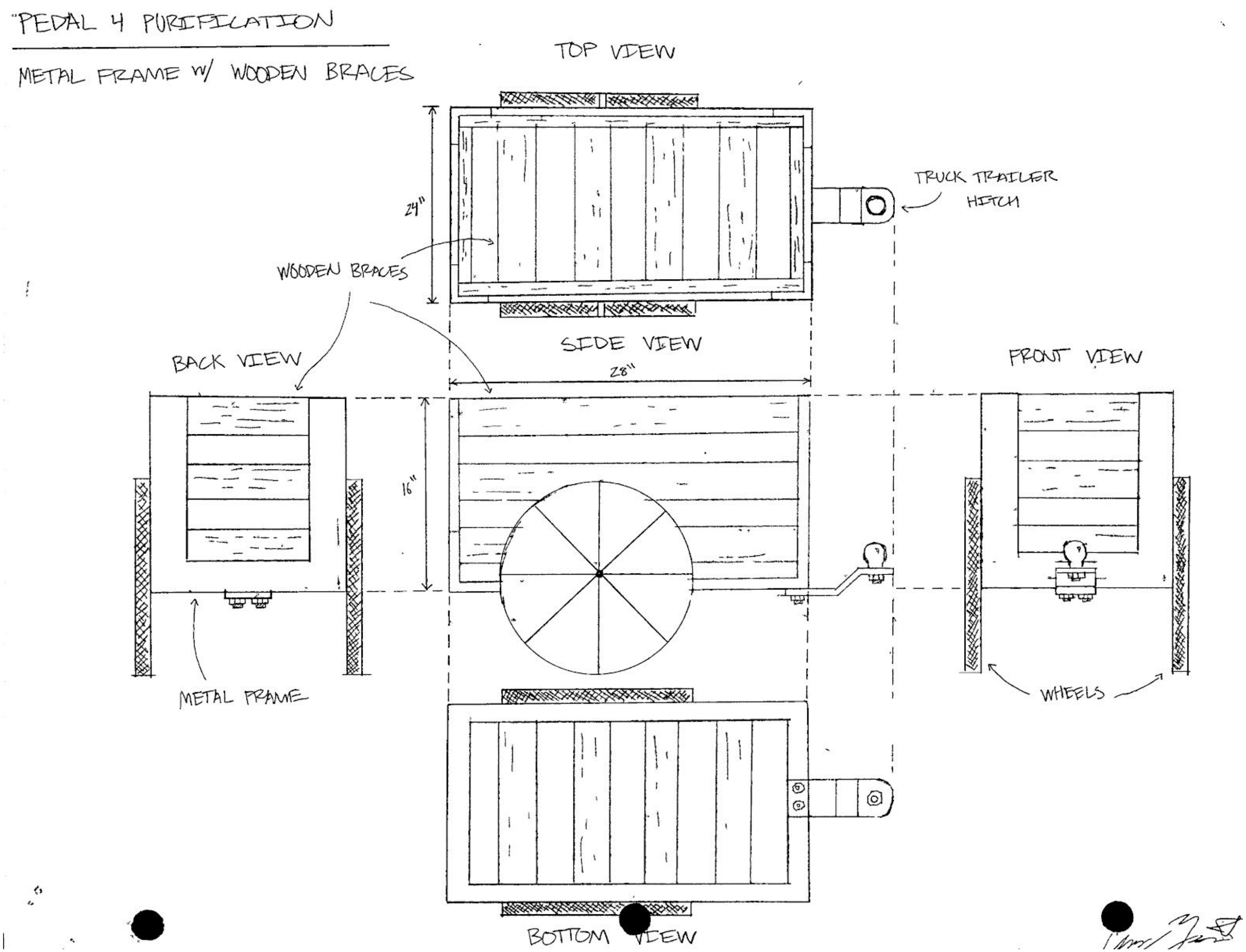


Rear Kickstand Sketches



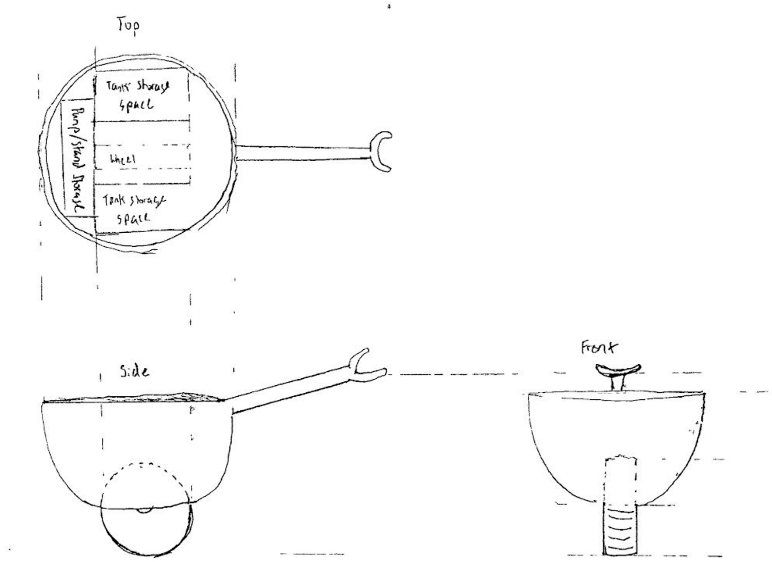
Cart Sketches




"PEDAL 4 PURIFICATION
METAL FRAME W/ WOODEN BRACES
TOP VIEW
24"
TRUCK TRAILER HITCH
WOODEN BRACES
SIDE VIEW
28"
BACK VIEW
FRONT VIEW
16"
METAL FRAME
WHEELS
BOTTOM VIEW

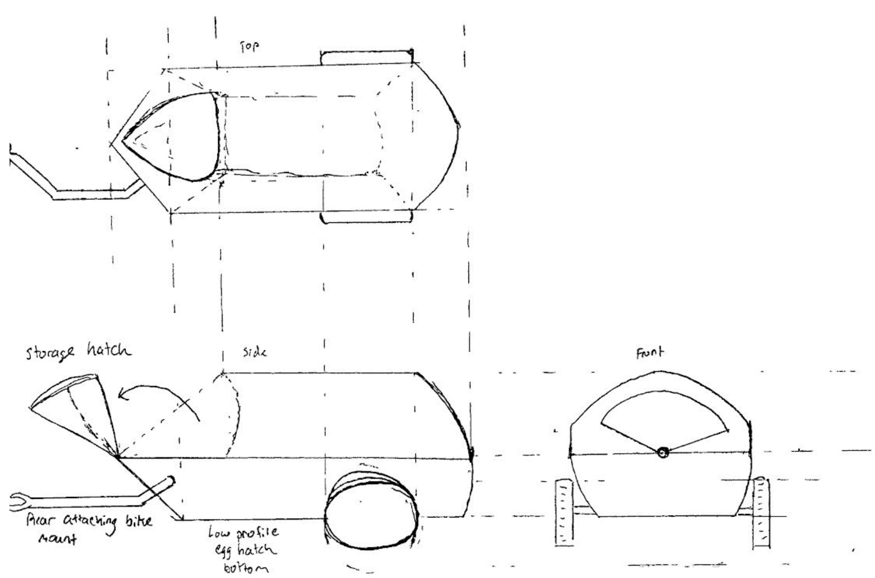
Uni-Wheel Front Push

Front attaching cart design

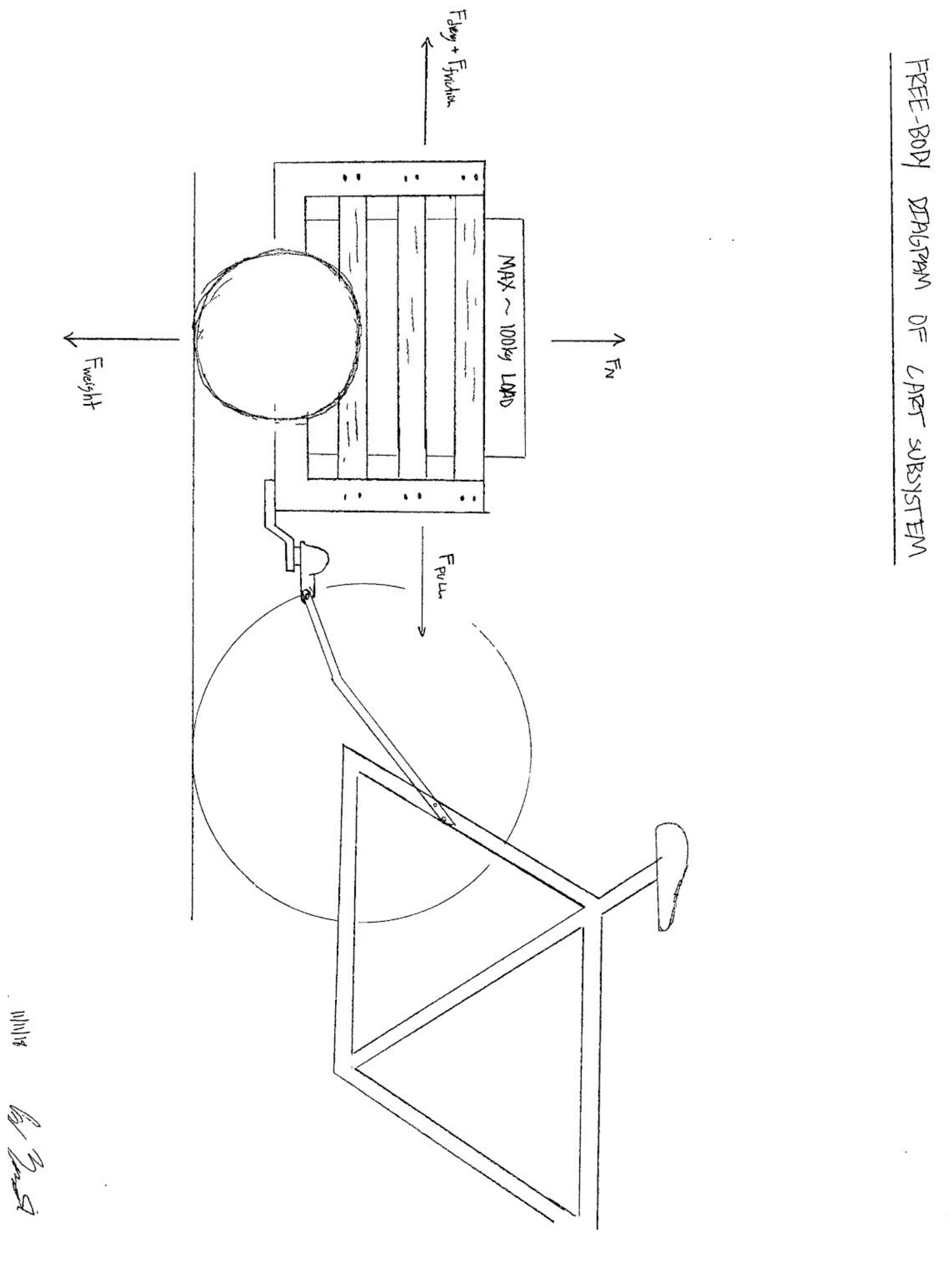


"Purification Falcon 1.0

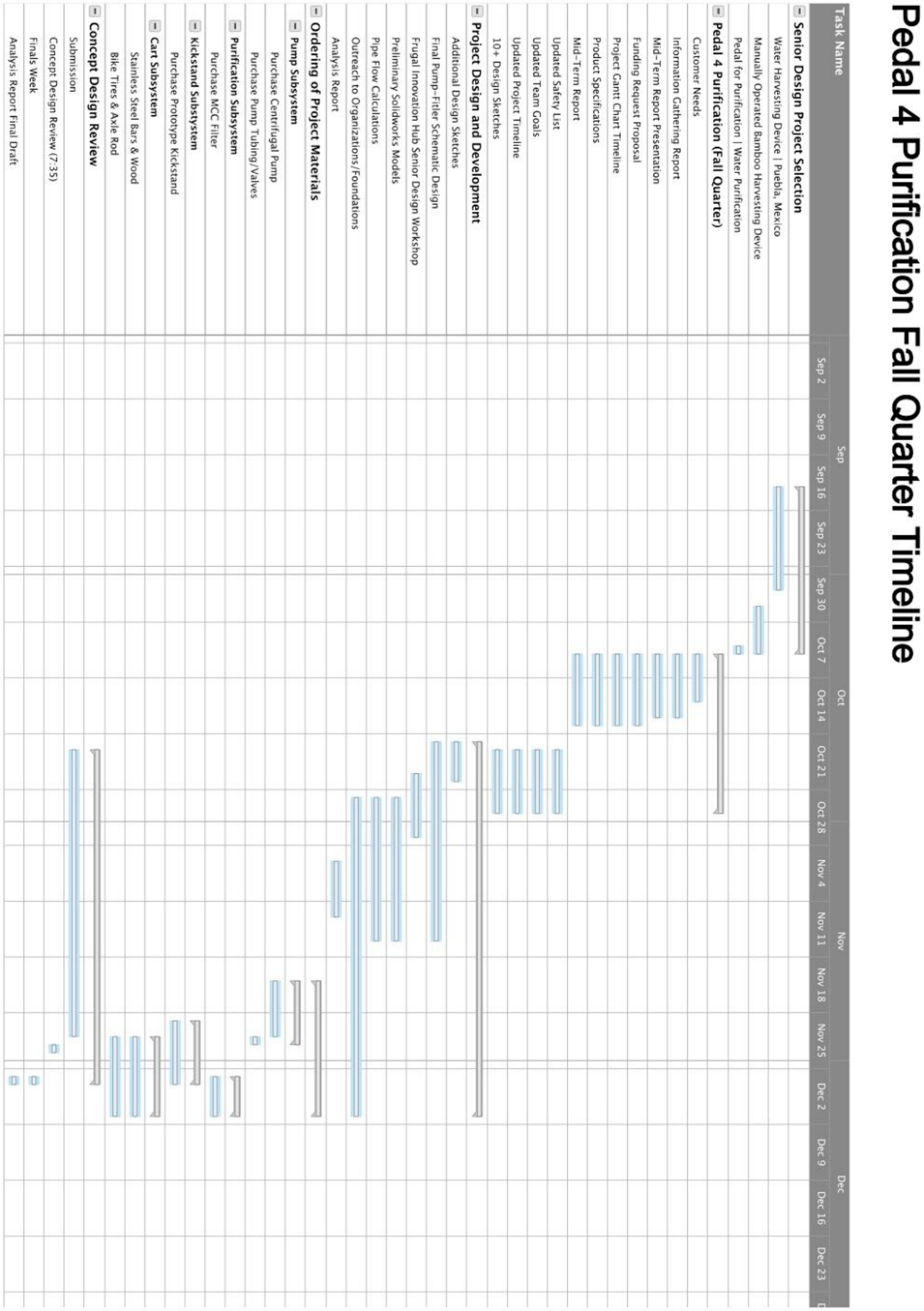
Cart-Purification System



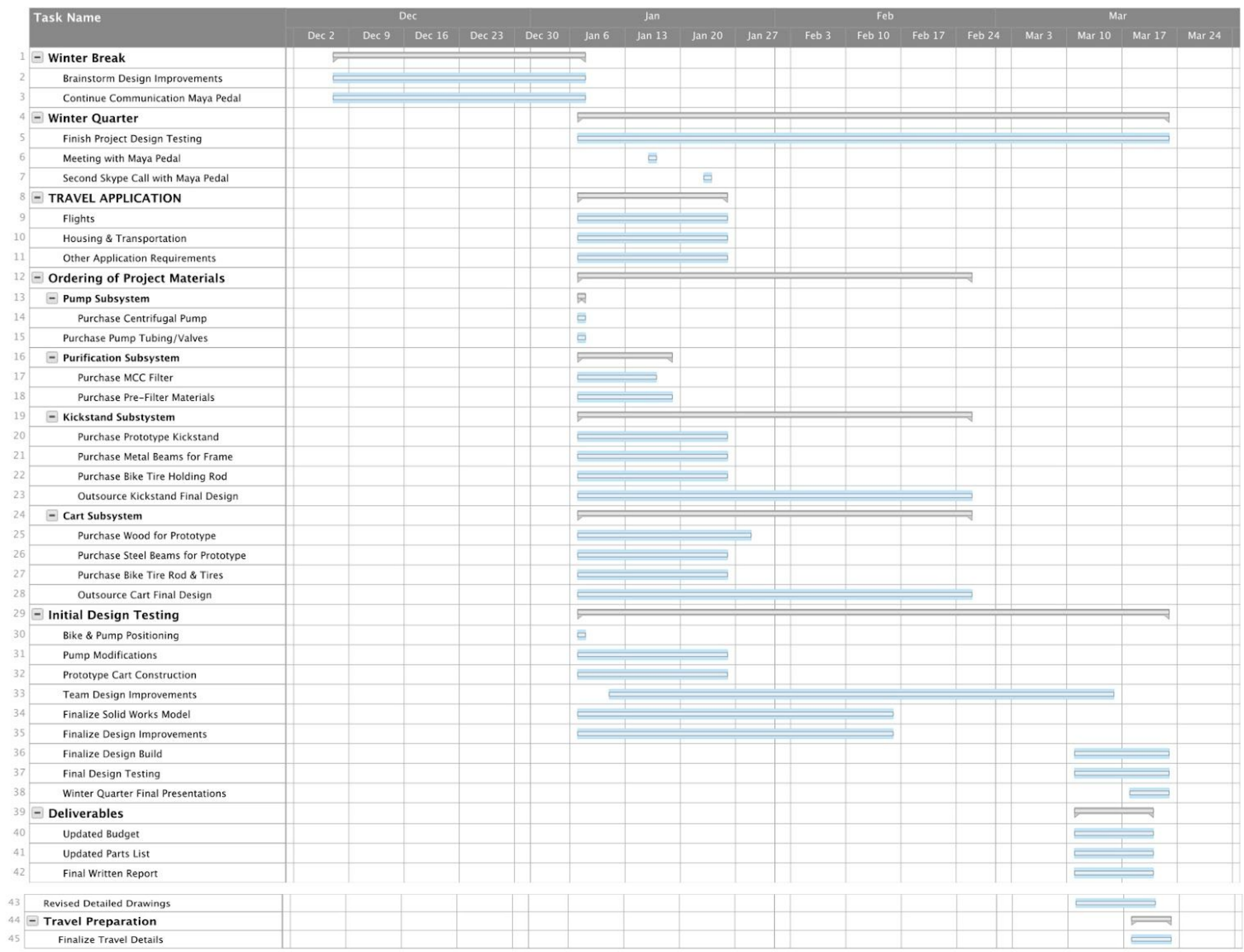
Cart Hitch & Attachment Sketches



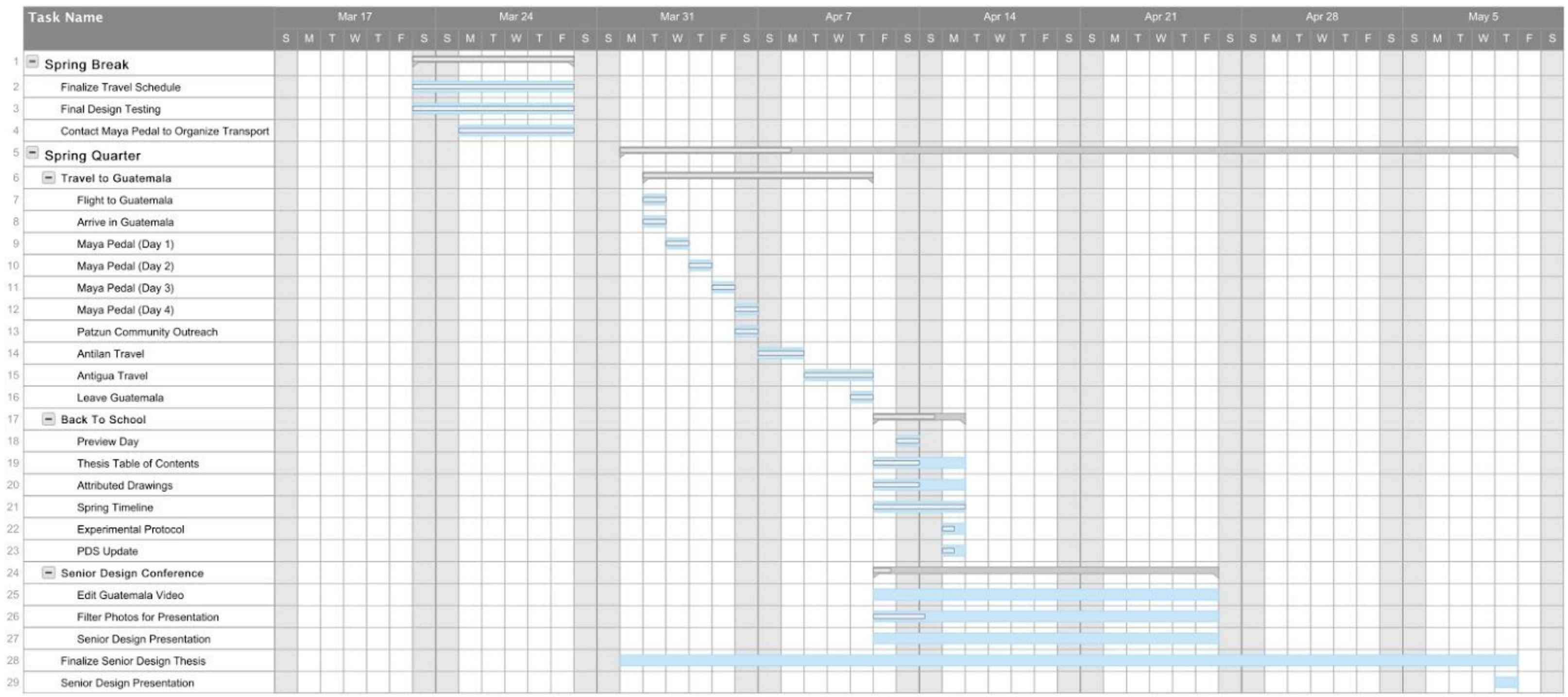
Appendix E: Project Timeline



Pedal 4 Purification Winter Quarter Timeline



Pedal 4 Purification Spring Quarter Timeline



Appendix F: Project Budget

Category	INCOME	Sought	Committed	Pending
Grant	Santa Clara University	$2,800.00	$2,000.00	$0
Travel Grant	Dean of School of Engineering	$2,000.00	$2,000.00	$0
Donation	Presbetyrian Women's Church	$500.00	$500.00	$0
	TOTAL	$5,300.00	$4,500.00	

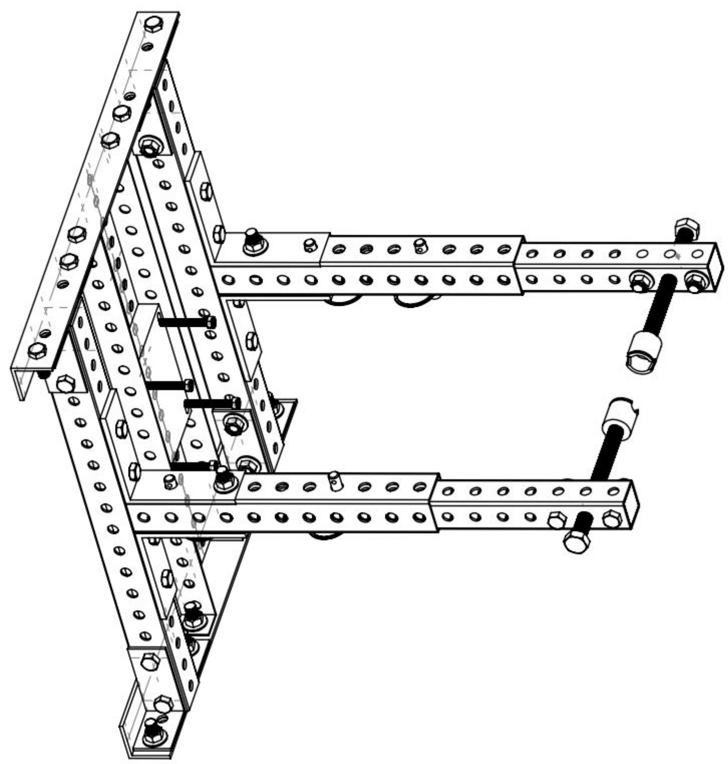
Category	EXPENSES	Estimated	Spent	Pending
PUMP				
	Friction Contact Powered Pump (x2)	$97.65	$97.65	$0.00
	Water Pump Outlet to 3/4 Pex pipe	$35.00	$35.00	$0.00
	Pump Foot Valve	$12.00	$12.00	$0.00
	Z-Flex Stainless Steel Gear Clamps for Hose-to-Pump Connection	$18.91	$18.91	$0.00
	PVC Bushing	$2.88	$2.88	$0.00
	Nylon Barb	$10.08	$10.08	$0.00
PURIFICATION				
	Multi Candle Ceramic Filter (x2)	$249.16	$249.16	$0.00
	1" D PVC Pressure Hose Tubing	$30.00	$30.00	$0.00
	Stainless Steel Wire mesh	$20.00	$20.00	$0.00
	Purification Testing Kit	$10.00	$10.00	$0.00
	0.5 Micron Pre-Filter	$20.00	$20.00	$0.00
	Filter Housing (x2)	$50.00	$50.00	$0.00
	Housing Bracket (x2)	$20.00	$20.00	$0.00
KICKSTAND				
	Conquer Indoor Bike Trainer Portable Exercise Bicycle Magnetic Stand	$59.95	$59.95	$0.00
	Flat Washers, Stainless Steel, 1/2"	$0.50	$0.50	$0.00
	Flat Washers, Stainless Steel, 3/8"	$5.00	$5.00	$0.00
	HEX Nuts - USS 1/2"	$0.65	$0.65	$0.00
	HEX Nuts - USS 3/8"	$2.00	$2.00	$0.00
	HEX Nuts - USS 1/4"	$0.50	$0.50	$0.00
	HEX Bolts, Stainless Steel 1/2x6.0"	$2.00	$2.00	$0.00
	HEX Bolts, Stainless Steel 3/8x2.0"	$4.00	$4.00	$0.00
	HEX Bolts, Stainless Steel 3/8x2.5"	$4.00	$4.00	$0.00
	HEX Bolts, Stainless Steel 3/8x1.0"	$10.00	$10.00	$0.00
	HEX Bolts, Stainless Steel 1/4x2.5"	$1.00	$1.00	$0.00
	1.5" x 1/8" Angle Beam 72"	$87.92	$87.92	$0.00
	1-1/4 in. x 36 in. Zinc-Plated Punched Square Tube	$35.92	$35.92	$0.00
	1 in. x 36 in. Zinc-Plated Punched Square Tube	$16.98	$16.98	$0.00

CART				
	BrightLight Welding	$330.56	$330.56	$0.00
	Aluminum Square Tubing and Angle Bracket for Cart Erame	$167.83	$167.83	$0.00
	Premium Kiln Dried Square Edged Whitewood 1"x4"x10" (x5)	$50.00	$50.00	$0.00
	Aluminum Square Tubing 3/4" x 3/4", 0.0625" Wall	$205.67	$205.67	$0.00
	Sta-Tru 25x1.5 in Silver St1 36H Rim Front Wheel (x2)	$90.28	$90.28	$0.00
	Schwin All-Terain Bicycle Tire with Puncture-Proof 26 in (x2)	$50.00	$50.00	$0.00
	Bell Standard Bicycle Tire Tube (x2)	$20.38	$20.38	$0.00
	Hex bolts, Stainless steel 18-8, 1/4"-20 x 3/8" (50 pack) (x2)	$20.00	$20.00	$0.00
	1"x3'x1/16" Flat Stainless Steel Plate	$15.23	$15.23	$0.00
	Hex HD SMS Self-Drilling Screws	$9.16	$9.16	$0.00
	3/8"-24 Fine Thread Grade C All Metal Locknut Medium (50 pack) (x2)	$20.00	$20.00	$0.00
	3 inch Corner Brace	$58.83	$58.83	$0.00
	Steel Angle Bracket and Square Tubing for Second /Third Cart Frame	$75.86	$75.86	$0.00
	Flat Beam of Aluminum (1/8" thick and 3' long)	$10.00	$10.00	$0.00
	1"x1" Aluminum Tubing	$67.89	$67.89	$0.00
	Kickstand for Cart (x2)	$50.00	$50.00	$0.00
	Angle Bracket for Gripping the Wheel	$15.44	$15.44	$0.00

HITCH				
	1 in. x 36 in. 16-Gauge Thick Round Tube	$18.32	$18.32	$0.00
	Punched SQ Tube ZP 1-1/2x36	$20.98	$20.98	$0.00
	Square Tube Aluminum 96x1x1/20	$29.92	$29.92	$0.00
	1 in. Rigid Conduit 2-Hole Strap 4-Pack	$1.79	$1.79	$0.00
	1-inch Pillow Bearing	$27.98	$27.98	$0.00
	Crown Bolt 7/16 in. 4 in. Grade 8 External Hex Hex-Head Cap Screws	$6.72	$6.72	$0.00
	1-1/4 in. x 36 in. Plain Steel Flat Bar with 1/4 in. Thick	$12.72	$12.72	$0.00
	Sheet Metal	$0.00	$0.00	$0.00
	1/4 in. x 2 in. Zinc-Plated Round Head Wire Lock Pin	$5.88	$5.88	$0.00
	1 in. x 3 in. Yellow Zinc Grade 8 Hex Bolt	$11.43	$11.43	$0.00
TOTAL		**$2,198.97**	**$2,198.97**	**0**
		Estimated Surplus	Current Surplus	
		$301.03	$301.03	

Category	EXPENSES	Estimated	Spent	Pending
TRAVEL				
	Plane Tickets to Guatemala	$2,500.00	$2,000.00	$0.00
	Maya Pedal Hostel Housing	$250.00	$160.00	$0.00
	Food	$640.00	$240.00	$0.00
	Transportation	$80.00	$150.00	$0.00
	Materials	$100.00	$87.00	$0.00
	Misc.	$150.00	$0.00	$0.00
TOTAL		**$3,720.00**	**$2,637.00**	**$0.00**
		Estimated Surplus	Current Surplus	
		-$1,720.00	-$637.00	

Appendix G: Kickstand Subsystem Detailed Drawings



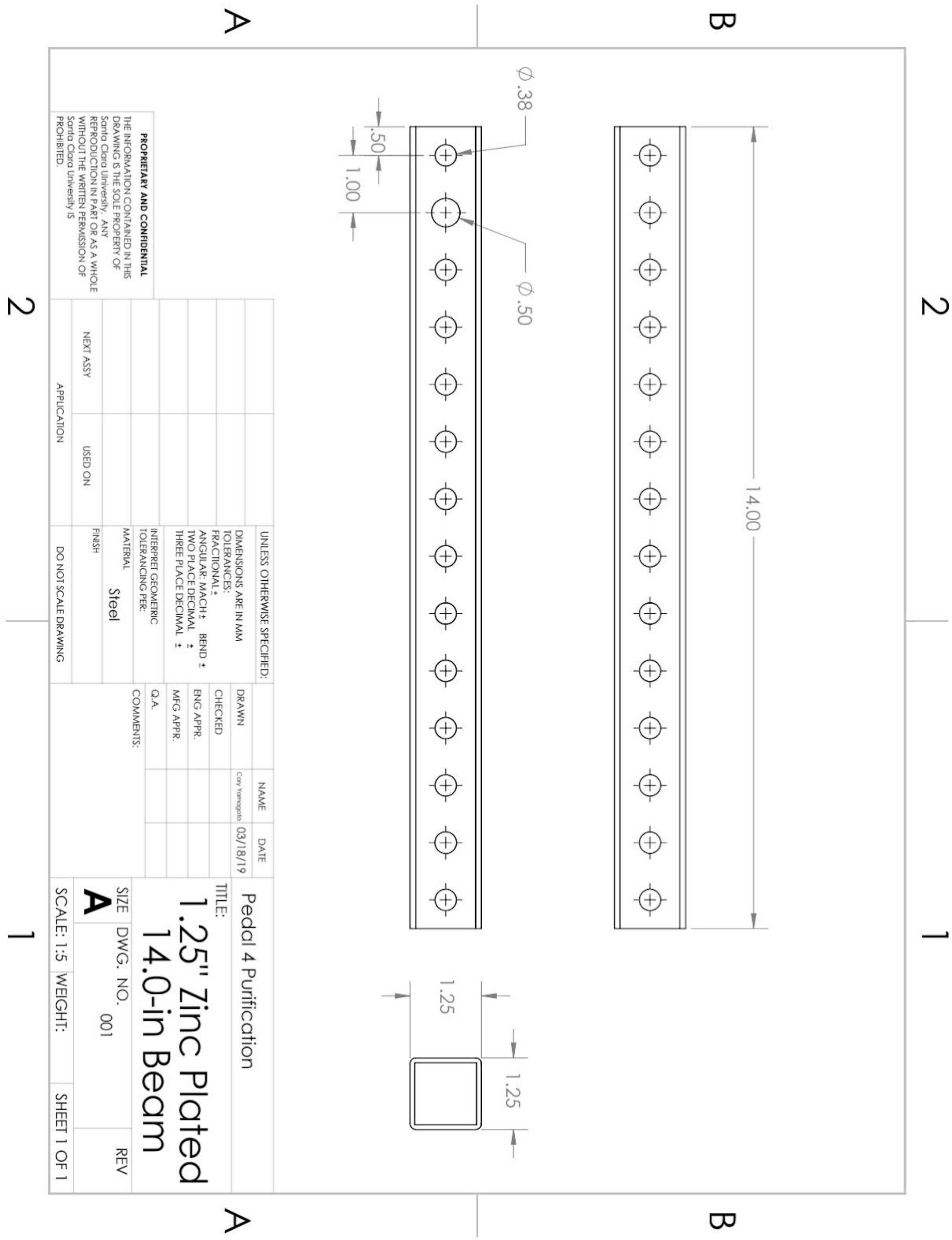
ITEM NO.	PART NUMBER	QTY.
1	Aluminum Angle Beam	2
2	Part2^Kickstand Base Assembly	1
3	1.5 - Zinc Plated 18-inch beam	2
4	L-bracket base brace-right	4
5	L-bracket base brace-left	4
6	11inch-1.5 beam-right	1
7	11inch-1.5beam-left	1
8	L-bracket bottom brace	4
9	Washer	26
10	1 inch bolt	20
11	2.5 inch bolt	2
12	Small Nut	26
13	Pin Ring	4
14	Post Pin	4
15	2.0 inch bolt	8
16	14inch-1.25 beam	2
17	Inner Rectangle Support	2
18	Big Bolt	2
19	1.75 top post bolt	4
20	Rear Axle Cap	2
21	Plastic Rear Axle Cap	2
22	Center Pump Beam Left	1
23	Center Pump Beam Right	1
24	Wooden Pump Base Platec	1
25	Pump Bolts	4
26	Pump Hex Nut .25	4

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL Multiple
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Cory Yamagata	03/18/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

Pedal 4 Purification
TITLE: Kickstand Final Assembly
SIZE A DWG. NO. 003 REV
SCALE: 1:10 WEIGHT: SHEET 1 OF 1

NEXT ASSY | USED ON
APPLICATION


Pedal 4 Purification
TITLE:
1.25" Zinc Plated 14.0-in Beam
SIZE
A
DWG. NO.
001
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Steel
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
Cory Yamagata
03/18/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NEXT ASSY
USED ON
APPLICATION
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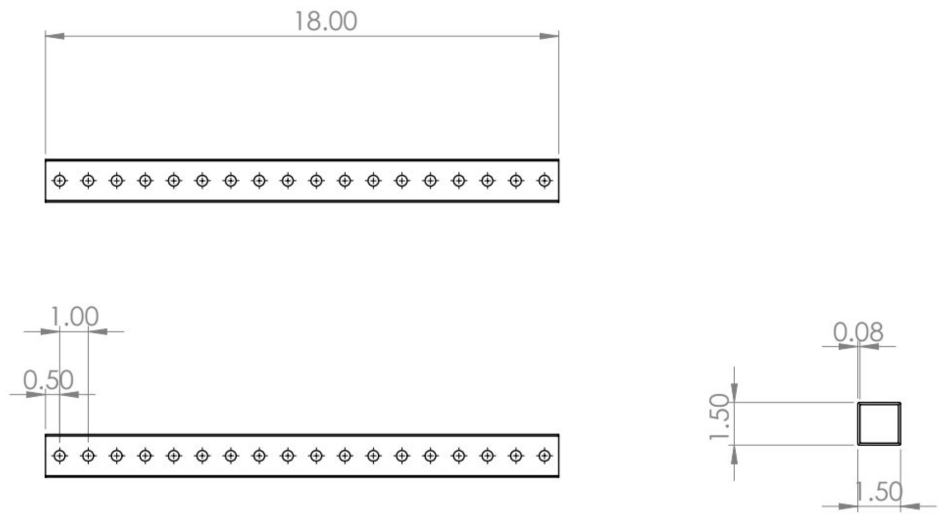
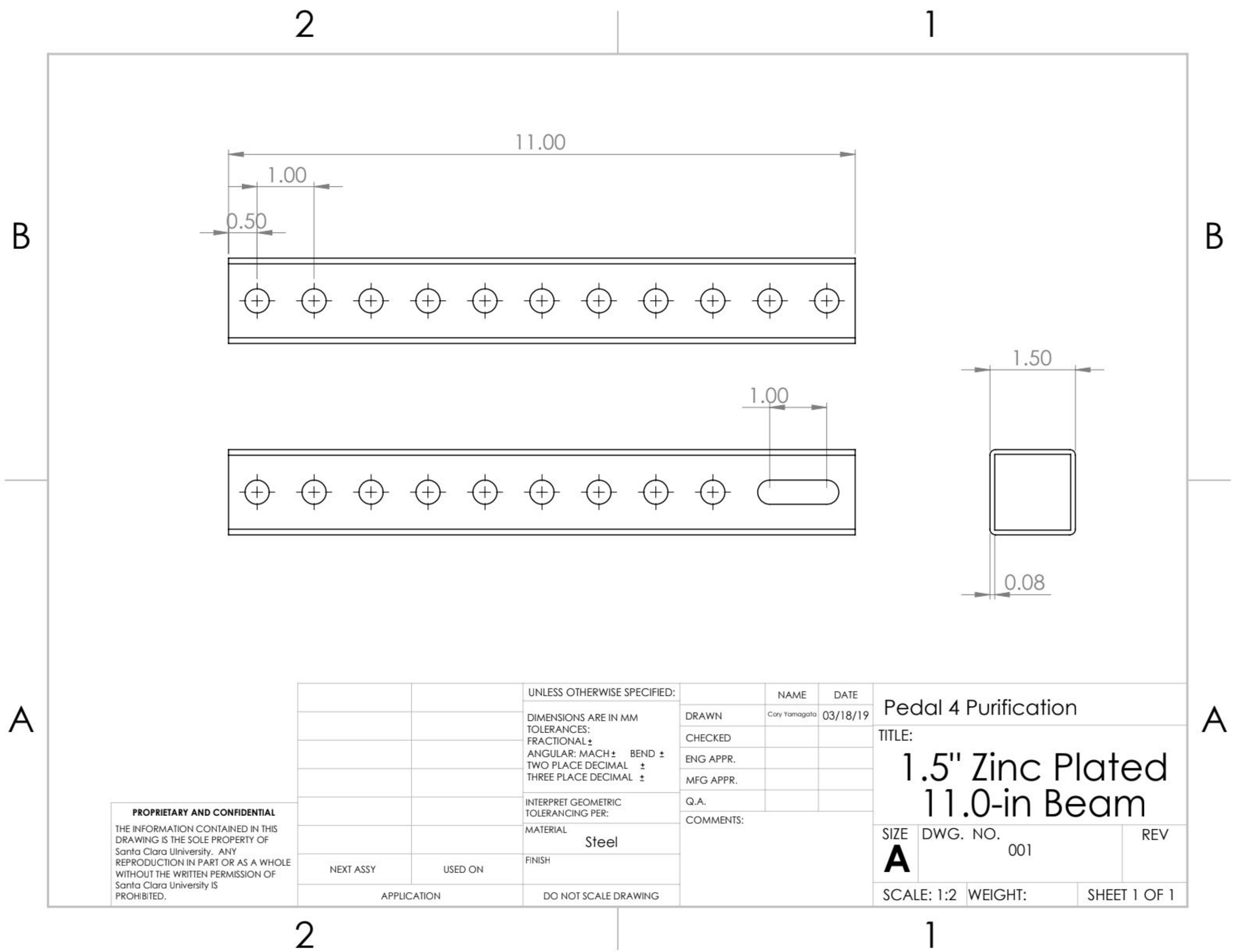
Ø .38
Ø .50
.50
1.00
14.00
1.25
1.25
A
B
1
2



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Pedal 4 Purification
		DIMENSIONS ARE IN MM TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	Cory Yamagata	03/18/19	TITLE: 1.5" Zinc Plated 18-in Beam
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL Steel	COMMENTS:			SIZE A · DWG. NO. 001 · REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:5 · WEIGHT: · SHEET 1 OF 1


11.00
1.00
0.50
1.00
1.50
0.08
B
A
2
1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Steel
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
Cory Yamagata
03/18/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pedal 4 Purification
TITLE:
1.5" Zinc Plated 11.0-in Beam
SIZE
A
DWG. NO.
001
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
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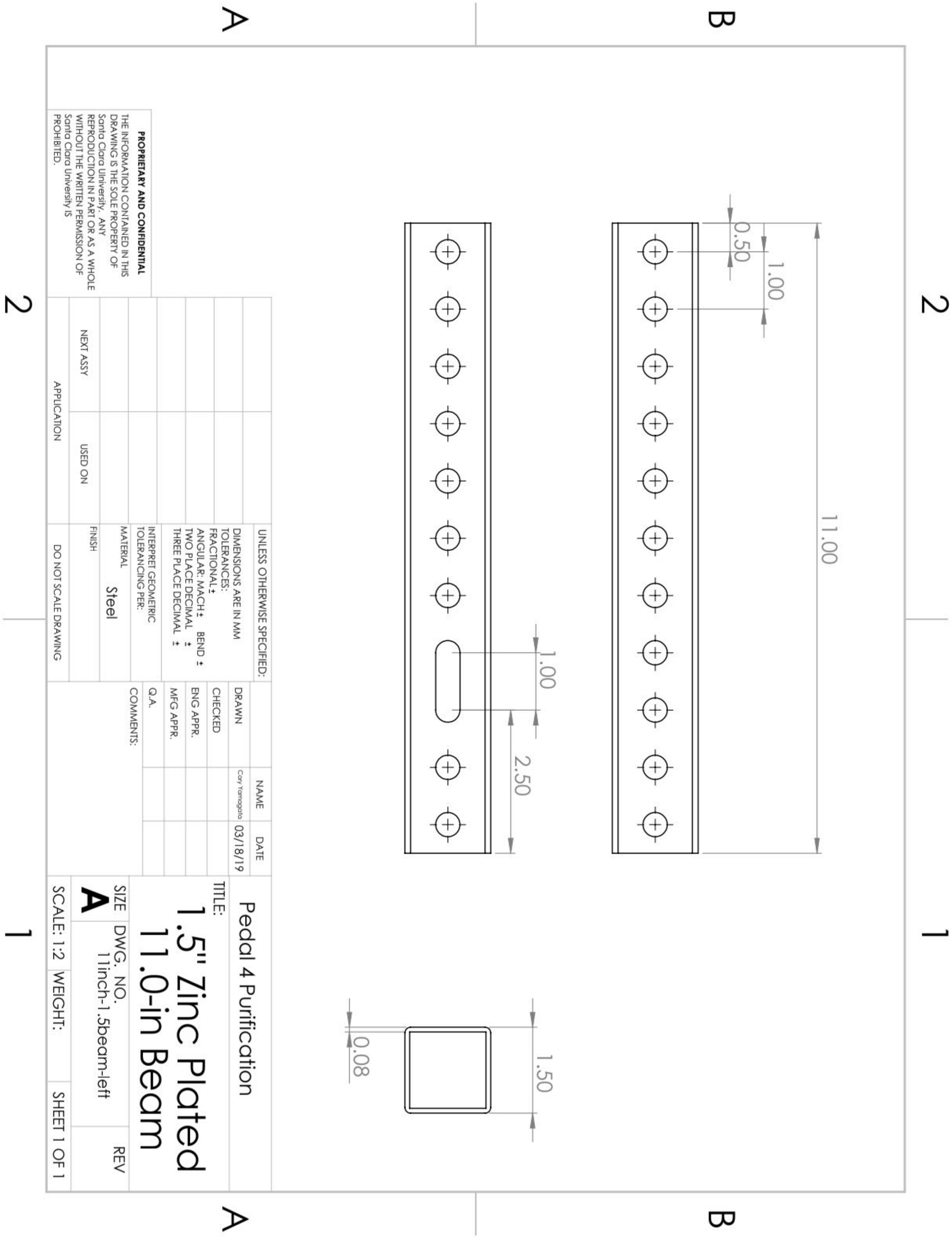

0.50
1.00
11.00
1.00
2.50
0.08
1.50
PROPRIETARY AND CONFIDENTIAL
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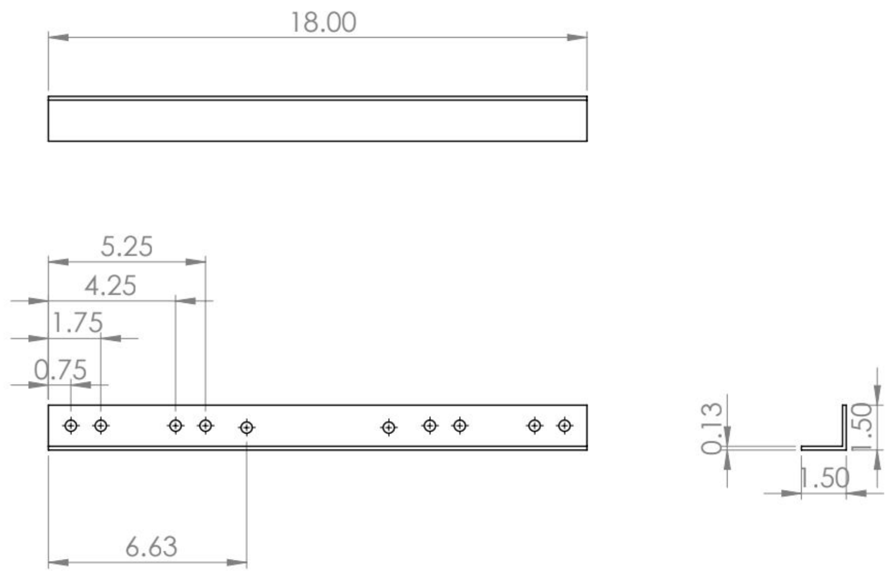
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Steel
FINISH
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
Cory Yamagata
03/18/19
Pedal 4 Purification
TITLE:
1.5" Zinc Plated 11.0-in Beam
SIZE
A
DWG. NO.
11inch-1.5beam-left
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN MM TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	Cory Yamagata	03/18/19
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL Aluminum	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

NEXT ASSY	USED ON
APPLICATION	

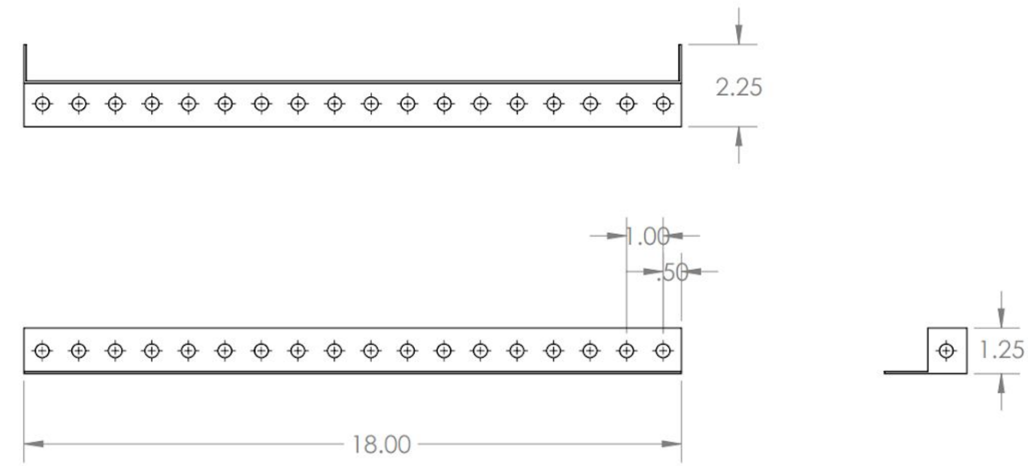
Pedal 4 Purification

TITLE:

Aluminum Angle Base Beam

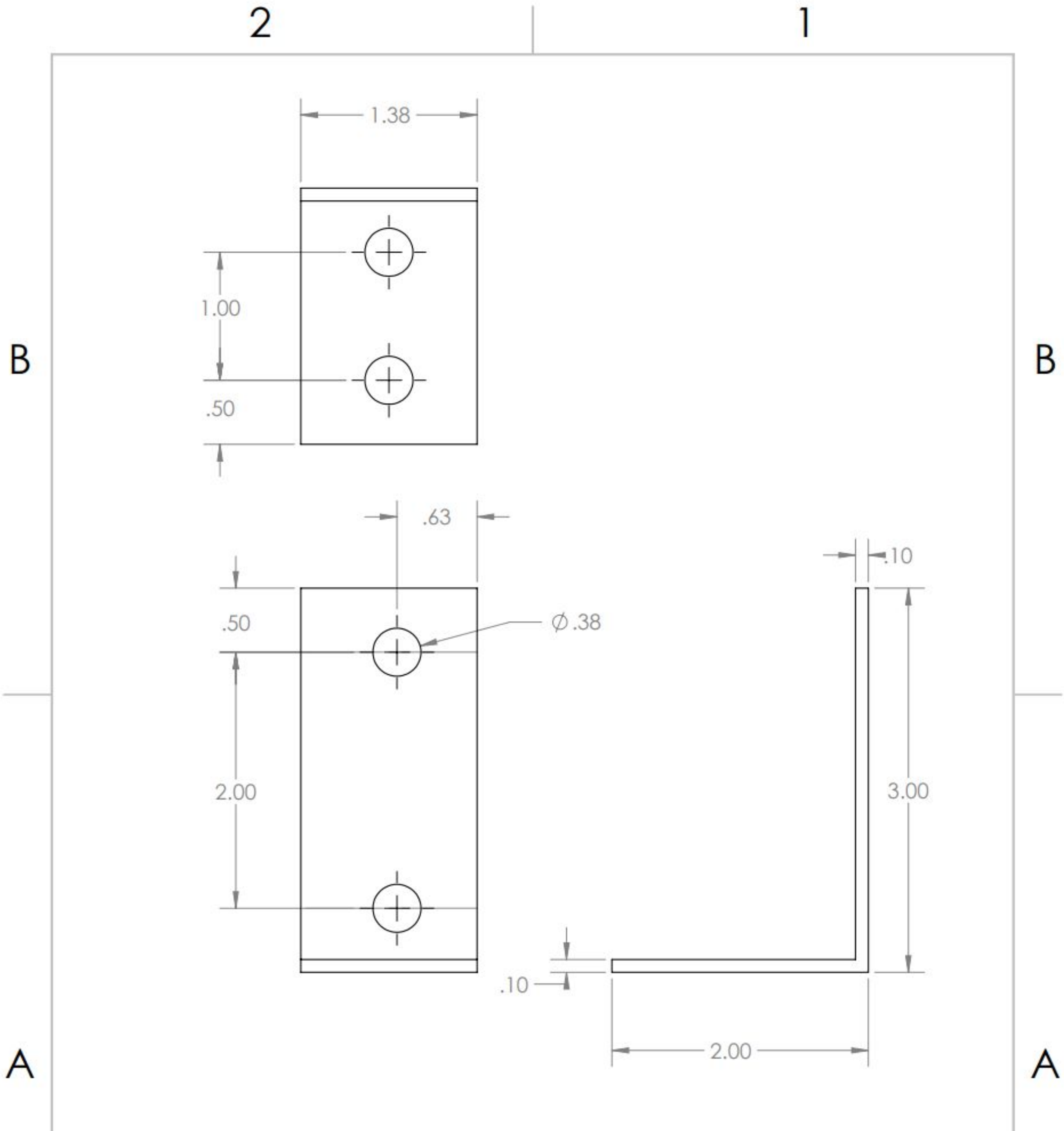
SIZE A | DWG. NO. 001 | REV

SCALE: 1:5 | WEIGHT: | SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	Pedal 4 Purification	
DIMENSIONS ARE IN MM TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	Cory Yamagata	03/18/19	TITLE: Center Pump Support Beam	
	CHECKED				
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL Steel	COMMENTS:			SIZE A DWG. NO. 001	REV
FINISH					
DO NOT SCALE DRAWING				SCALE: 1:5 WEIGHT:	SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	



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NEXT ASSY	USED ON
APPLICATION	

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL
Steel

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Cory Yamagata	03/18/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

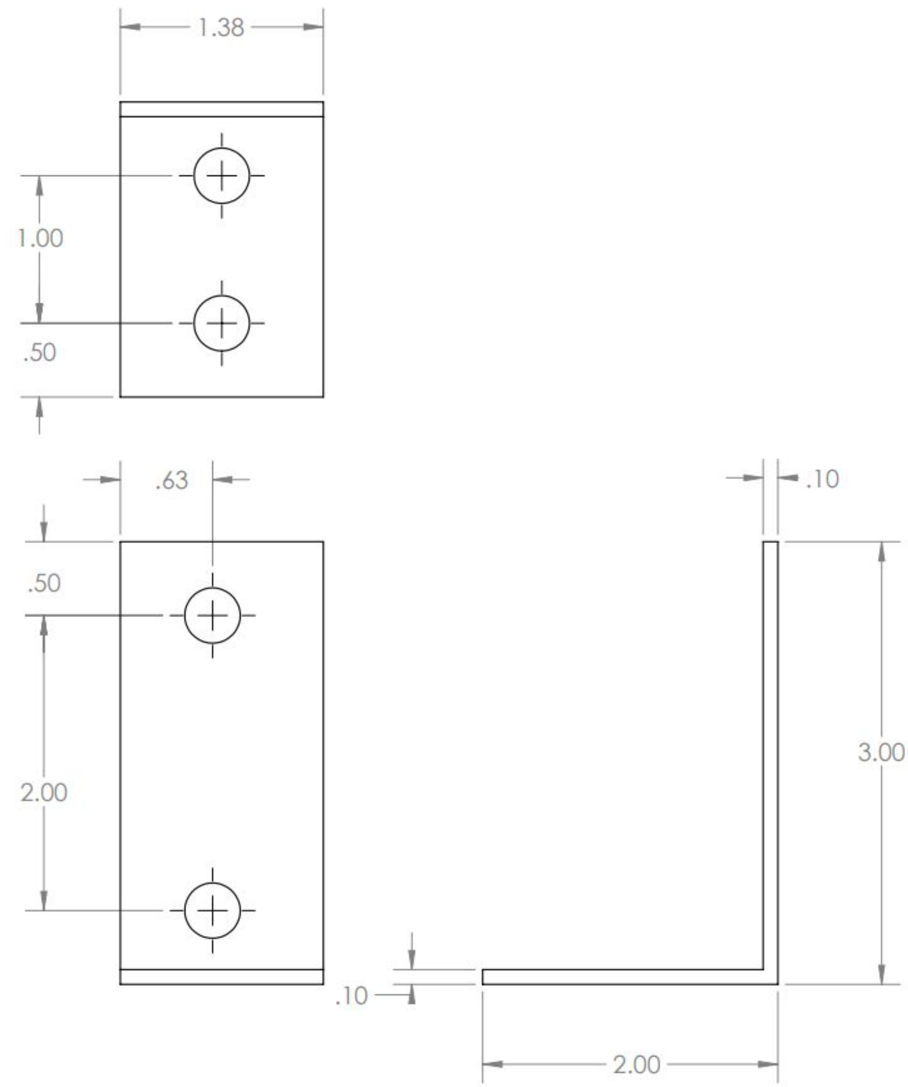
Pedal 4 Purification

Base L-Bracket

SIZE A DWG. NO. 001 REV.

SCALE:1:1 WEIGHT: SHEET 1 OF 1

2 1



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APPLICATION	

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL
Steel

FINISH

DO NOT SCALE DRAWING

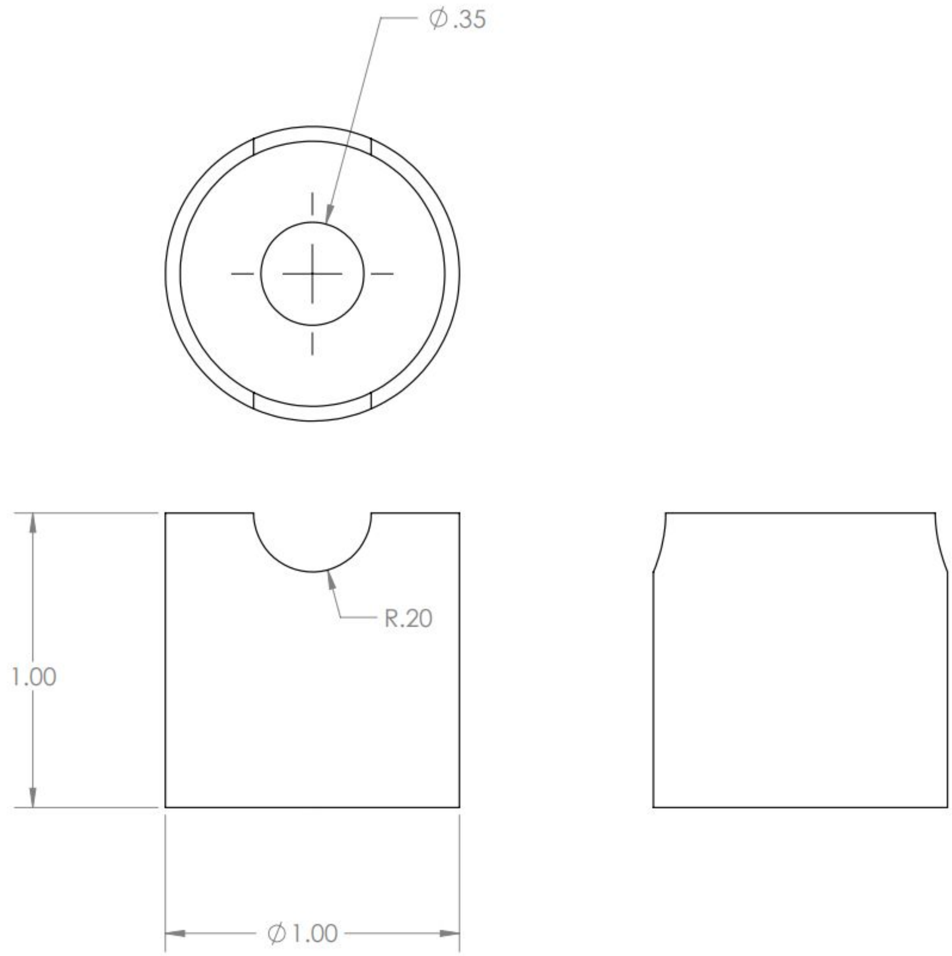
	NAME	DATE
DRAWN	Cory Yamagata	03/18/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

Pedal 4 Purification

Bottom Cross L-Bracket Left

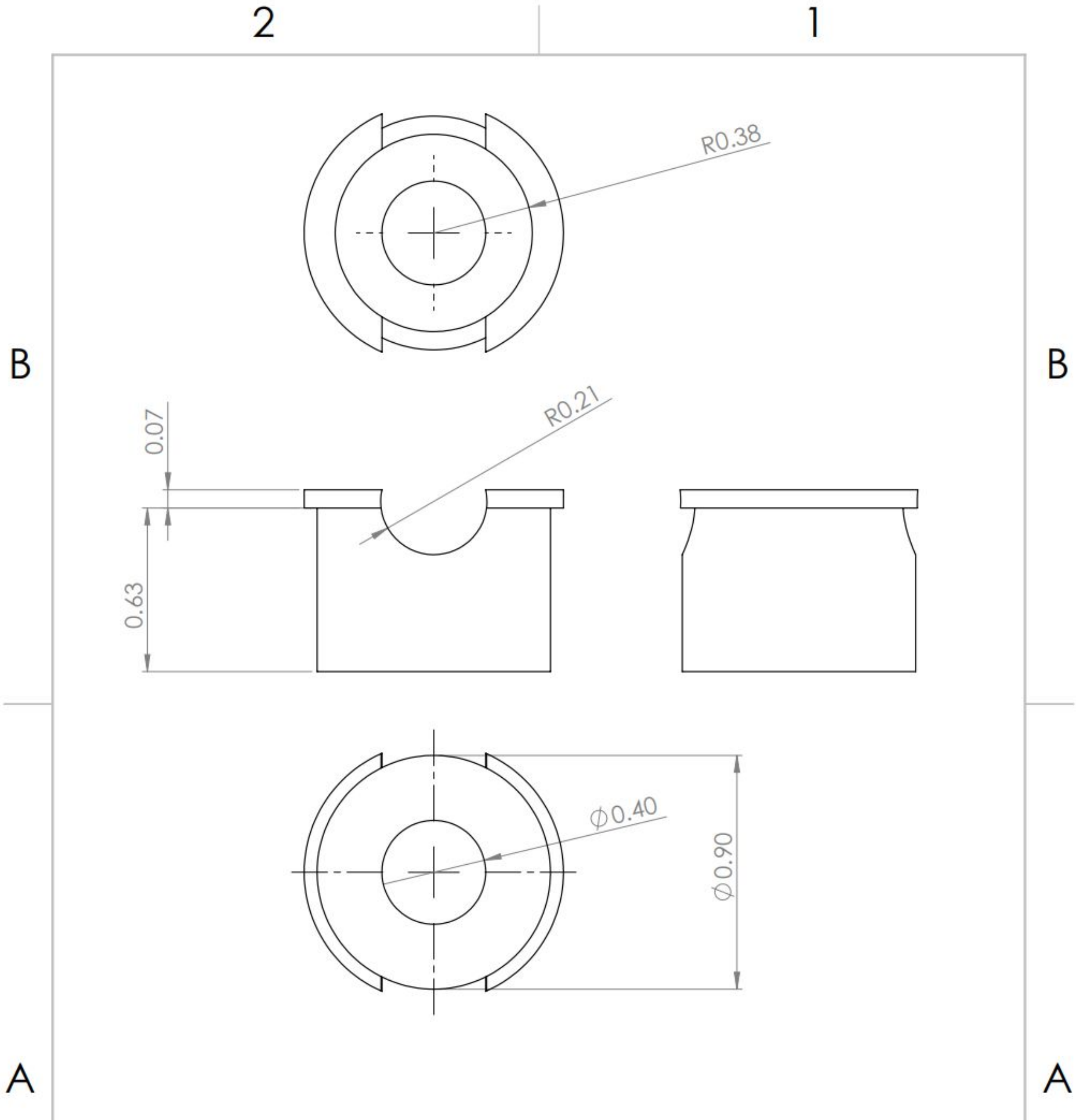
SIZE A | DWG. NO. 001 | REV.

SCALE:1:1 | WEIGHT: | SHEET 1 OF 1



DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±		NAME	DATE	Pedal 4 Purification	
	DRAWN	Cory Yamagata	03/18/19		
	CHECKED			Rear Support Axle Cap	
	ENG APPR.				
	MFG APPR.				
MATERIAL Steel	Q.A.				
FINISH	COMMENTS:			SIZE A DWG. NO. 001	REV.
DO NOT SCALE DRAWING				SCALE:2:1 WEIGHT:	SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	



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NEXT ASSY	USED ON
APPLICATION	

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL
PVC

FINISH

DO NOT SCALE DRAWING

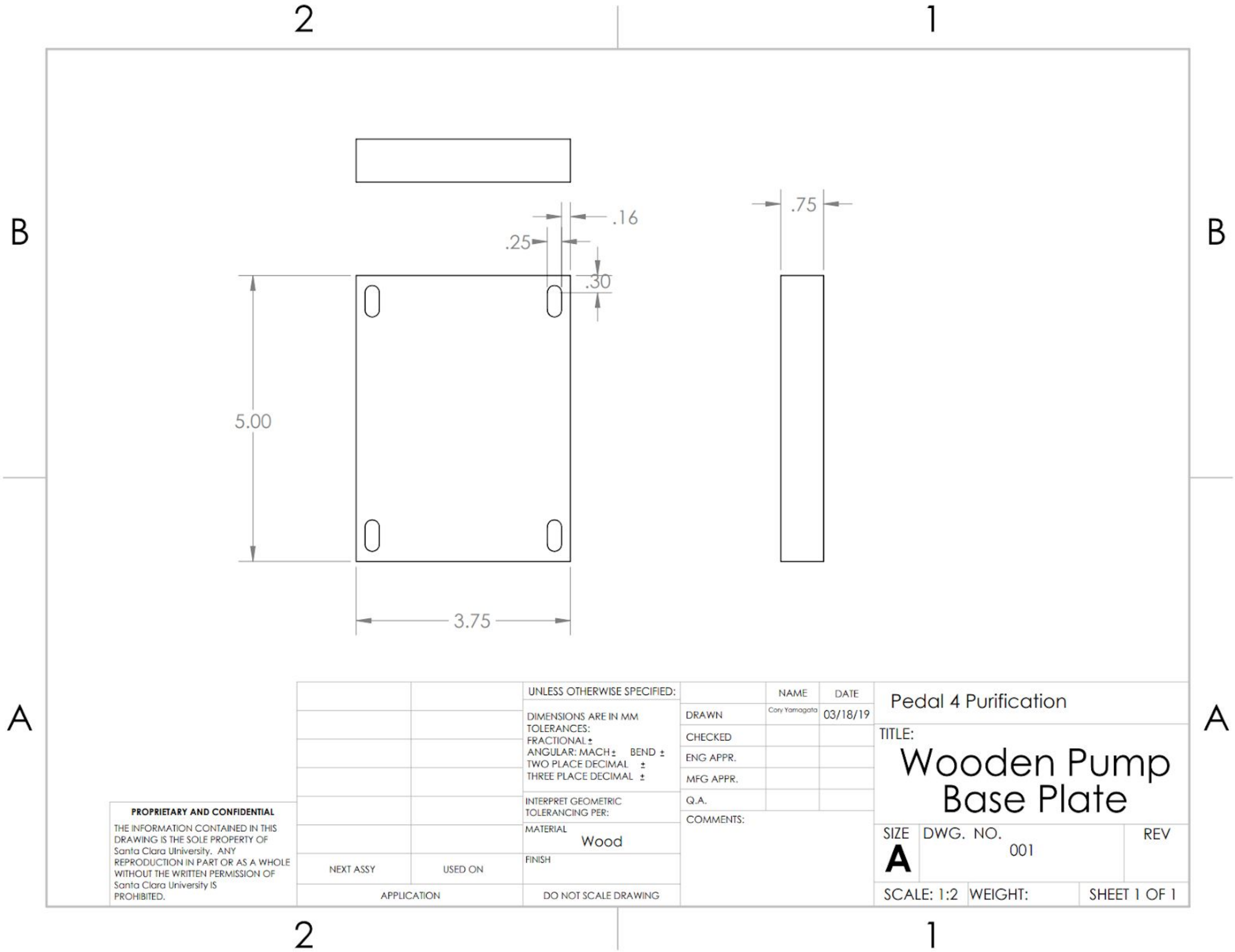
	NAME	DATE
DRAWN	Cary Yamagata	03/18/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

Pedal 4 Purification

Plastic Rear Axle Joint Cap

SIZE A DWG. NO. 001 REV.

SCALE:2:1 WEIGHT: SHEET 1 OF 1


.16
.25
.30
.75
5.00
3.75
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Wood
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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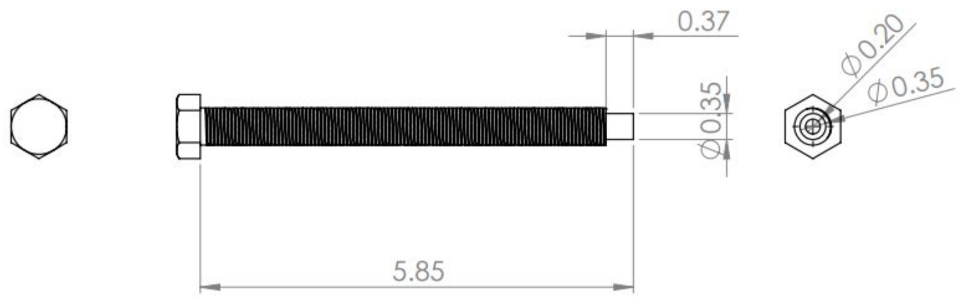
NAME
DATE
DRAWN
Cory Yamagata
03/18/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pedal 4 Purification
TITLE:
Wooden Pump Base Plate
SIZE
A
DWG. NO.
001
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

2 1

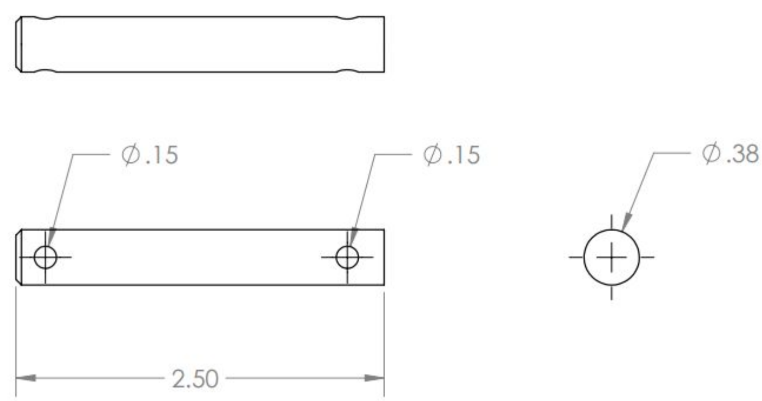
B B



A A

		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±		NAME	DATE	Pedal 4 Purification
			DRAWN	Cary Yamagata	03/18/19	
			CHECKED			Rear Axle Support Bolt
			ENG APPR.			
			MFG APPR.			
		MATERIAL Galvanized Steel	Q.A.			
			COMMENTS:			
NEXT ASSY	USED ON	FINISH				SIZE A DWG. NO. 001 REV.
APPLICATION		DO NOT SCALE DRAWING				SCALE:1:2 WEIGHT: SHEET 1 OF 1

2 1



		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±		NAME	DATE
			DRAWN	Cory Yamagata	03/18/19
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		MATERIAL Steel	Q.A.		
NEXT ASSY	USED ON	FINISH	COMMENTS:		
APPLICATION		DO NOT SCALE DRAWING			

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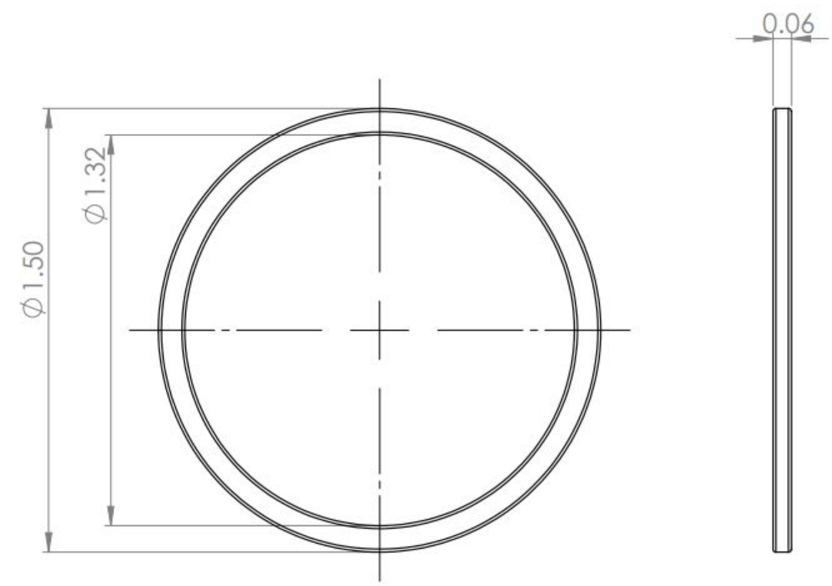
Pedal 4 Purification

Locking Support Post Pin

SIZE A | DWG. NO. 001 | REV.

SCALE:1:1 | WEIGHT: | SHEET 1 OF 1



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NEXT ASSY | USED ON

APPLICATION

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL
Steel

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Cory Yamagata	03/18/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

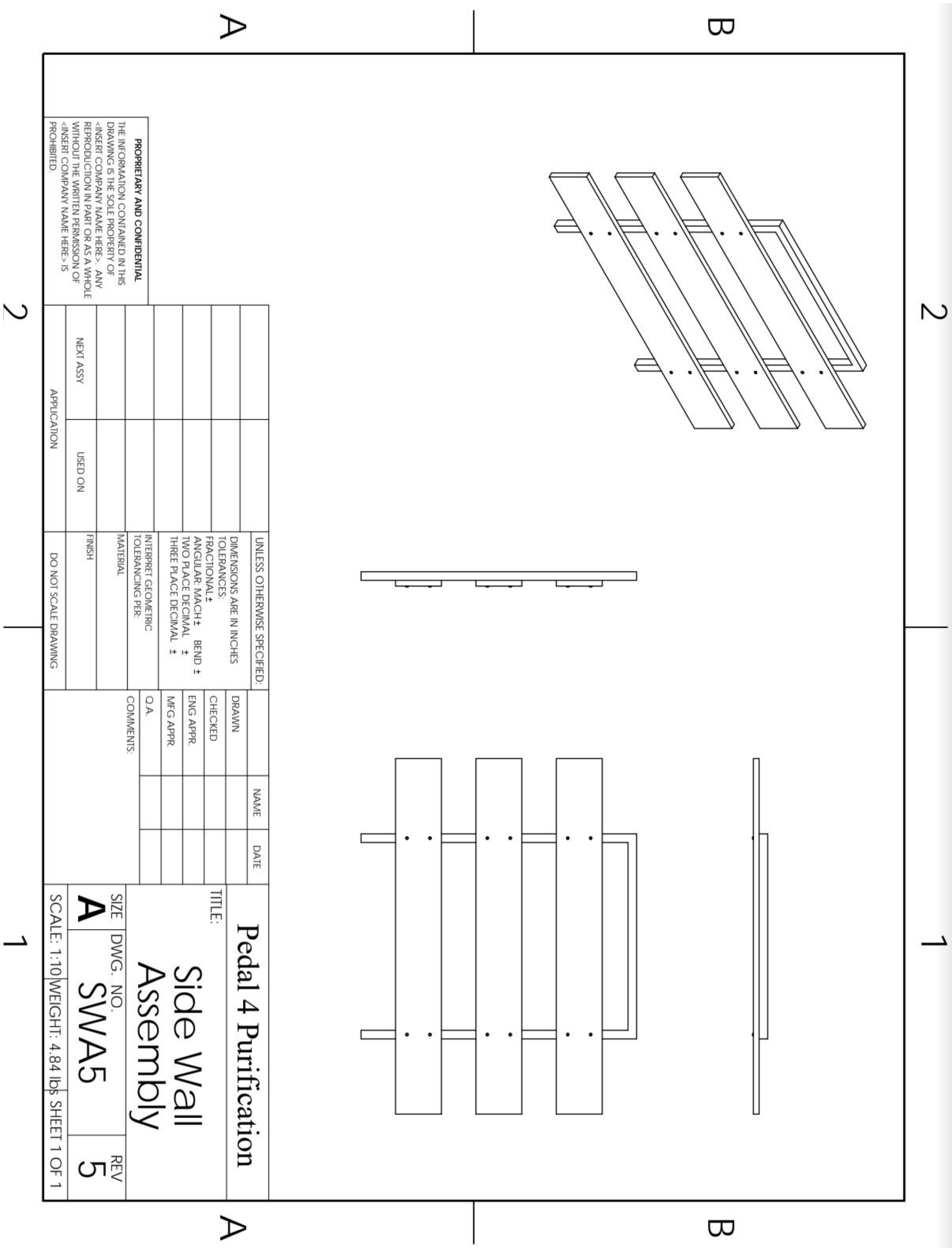
Pedal 4 Purification

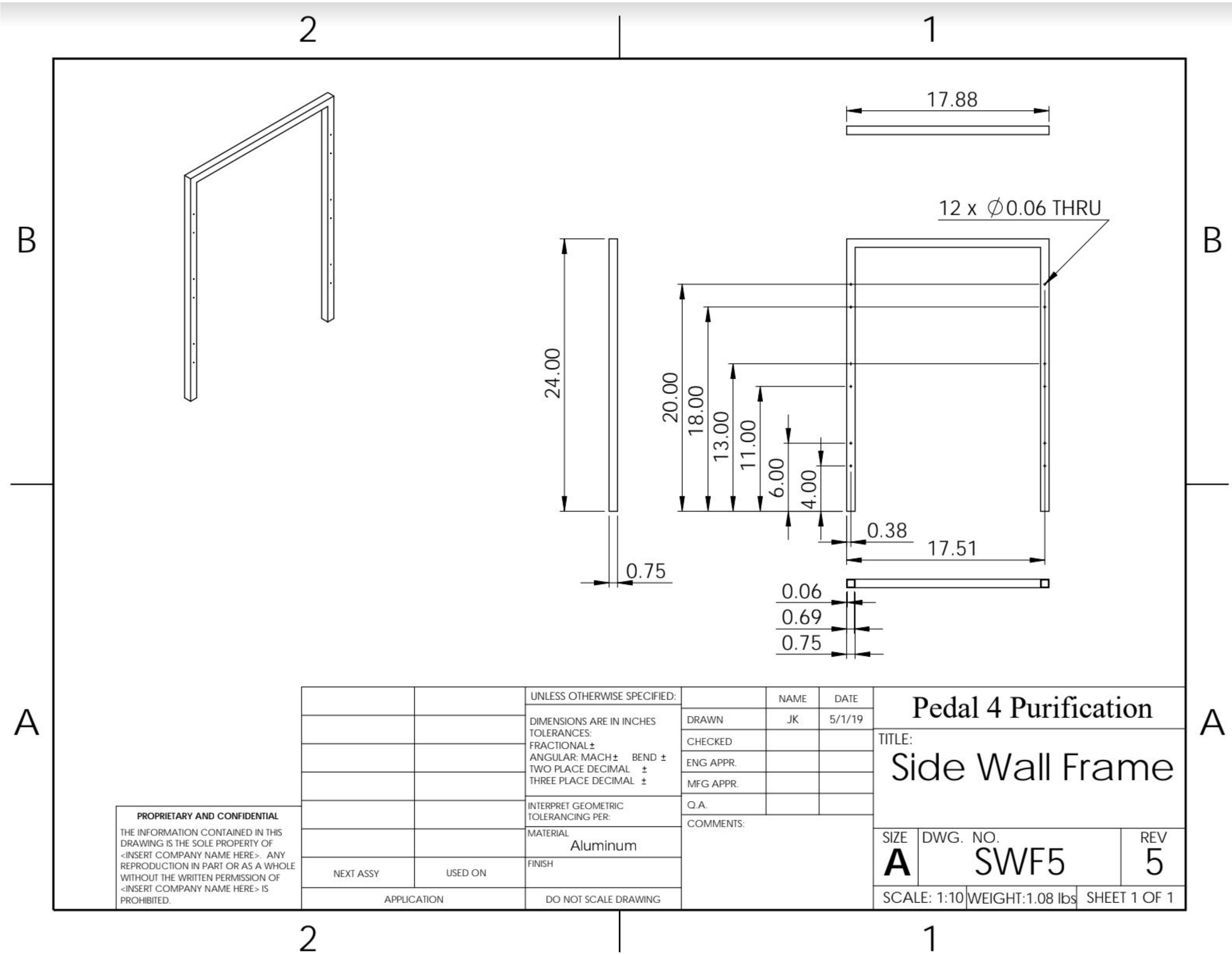
Pin Pull Ring

SIZE A | DWG. NO. 001 | REV.

SCALE:2:1 | WEIGHT: | SHEET 1 OF 1

Appendix H: Cart Subsystem Detailed Drawings (Jonathan)




2
1
B
A
17.88
12 x ∅0.06 THRU
24.00
20.00
18.00
13.00
11.00
6.00
4.00
0.38
17.51
0.75
0.06
0.69
0.75
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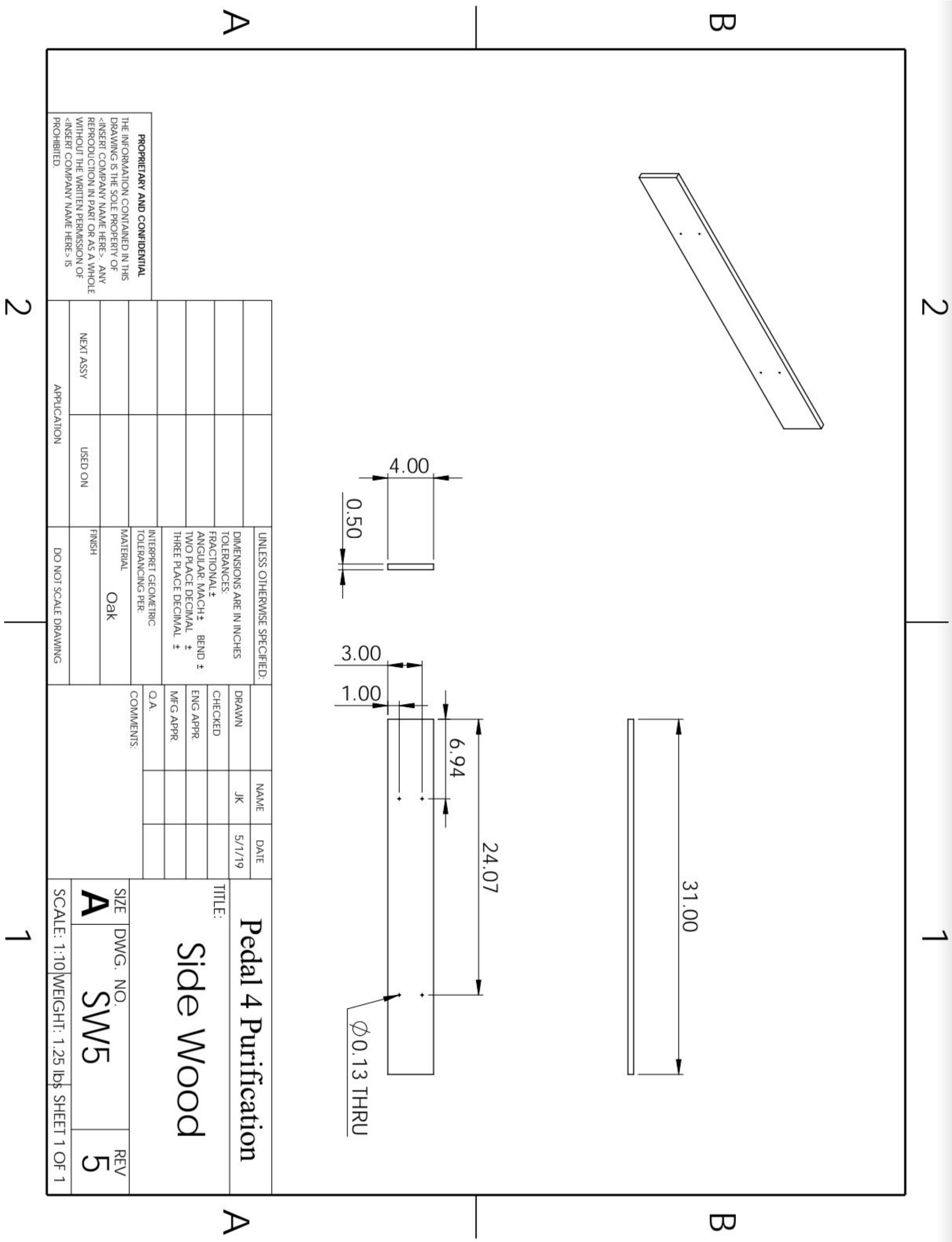
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
JK
5/1/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pedal 4 Purification
TITLE:
Side Wall Frame
SIZE
A
DWG. NO.
SWF5
REV
5
SCALE: 1:10
WEIGHT:1.08 lbs
SHEET 1 OF 1



Pedal 4 Purification
TITLE:
Side Wood
SIZE
A
DWG. NO.
SW5
REV
5
SCALE: 1:10
WEIGHT: 1.25 lbs
SHEET 1 OF 1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Oak
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
JK
5/1/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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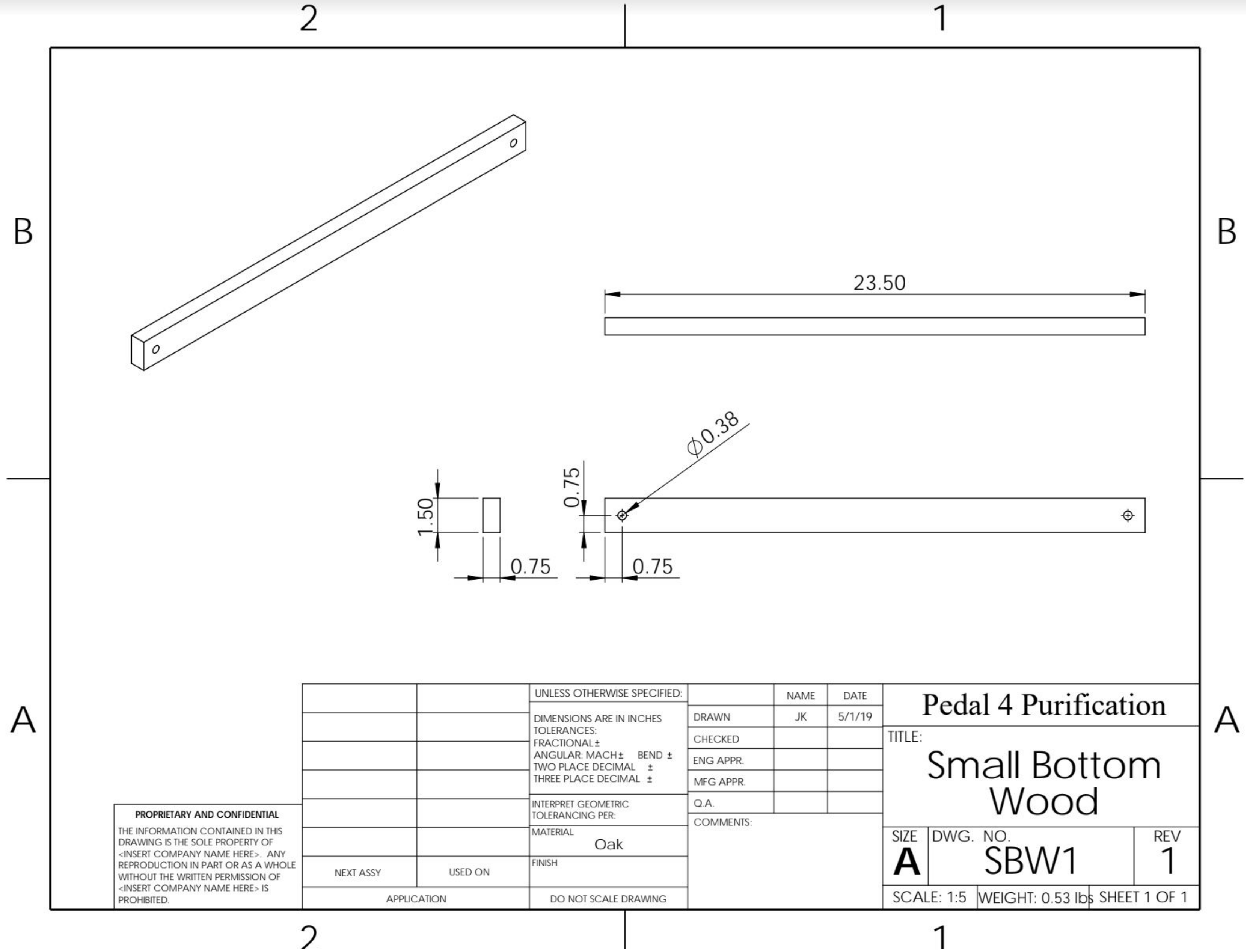
4.00
0.50
3.00
1.00
6.94
24.07
31.00
∅0.13 THRU
A
B
1
2


2
1
B
A
23.50
⌀0.38
1.50
0.75
0.75
0.75
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Oak
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
JK
5/1/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pedal 4 Purification
TITLE:
Small Bottom Wood
SIZE
A
DWG. NO.
SBW1
REV
1
SCALE: 1:5
WEIGHT: 0.53 lbs
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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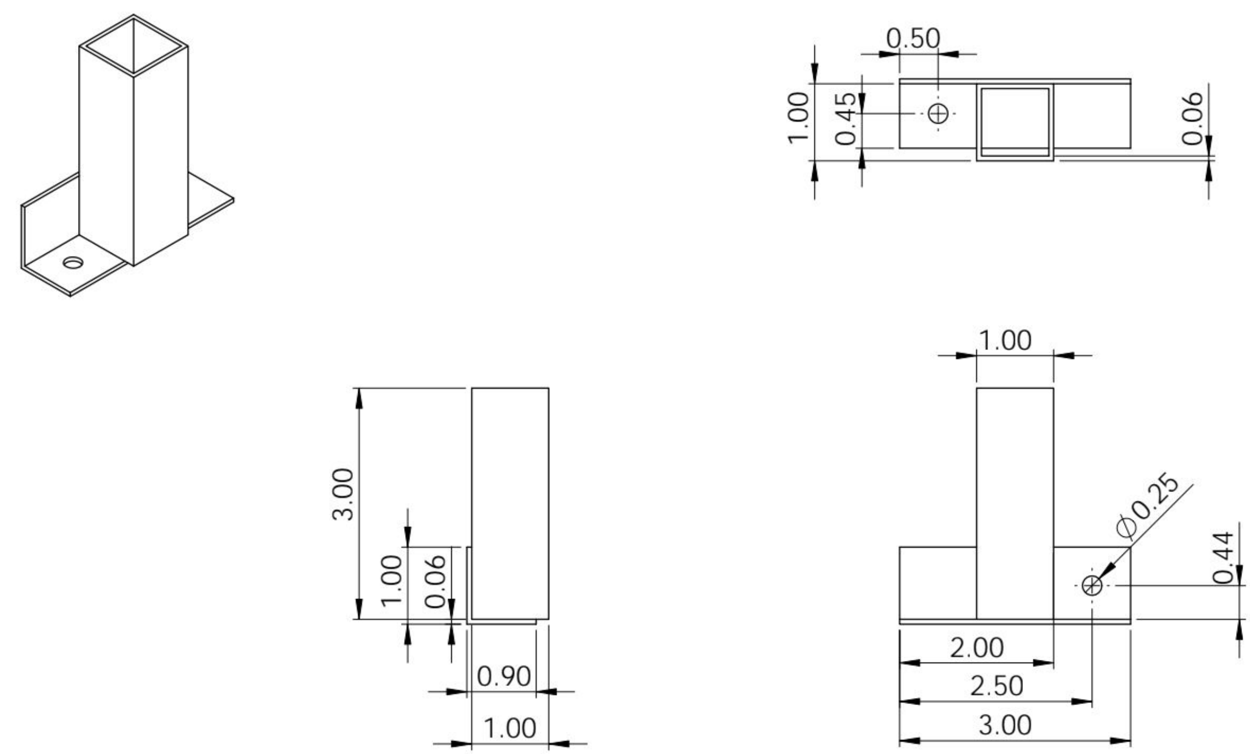

PROPRIETARY AND CONFIDENTIAL

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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: Steel

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	JK	5/1/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

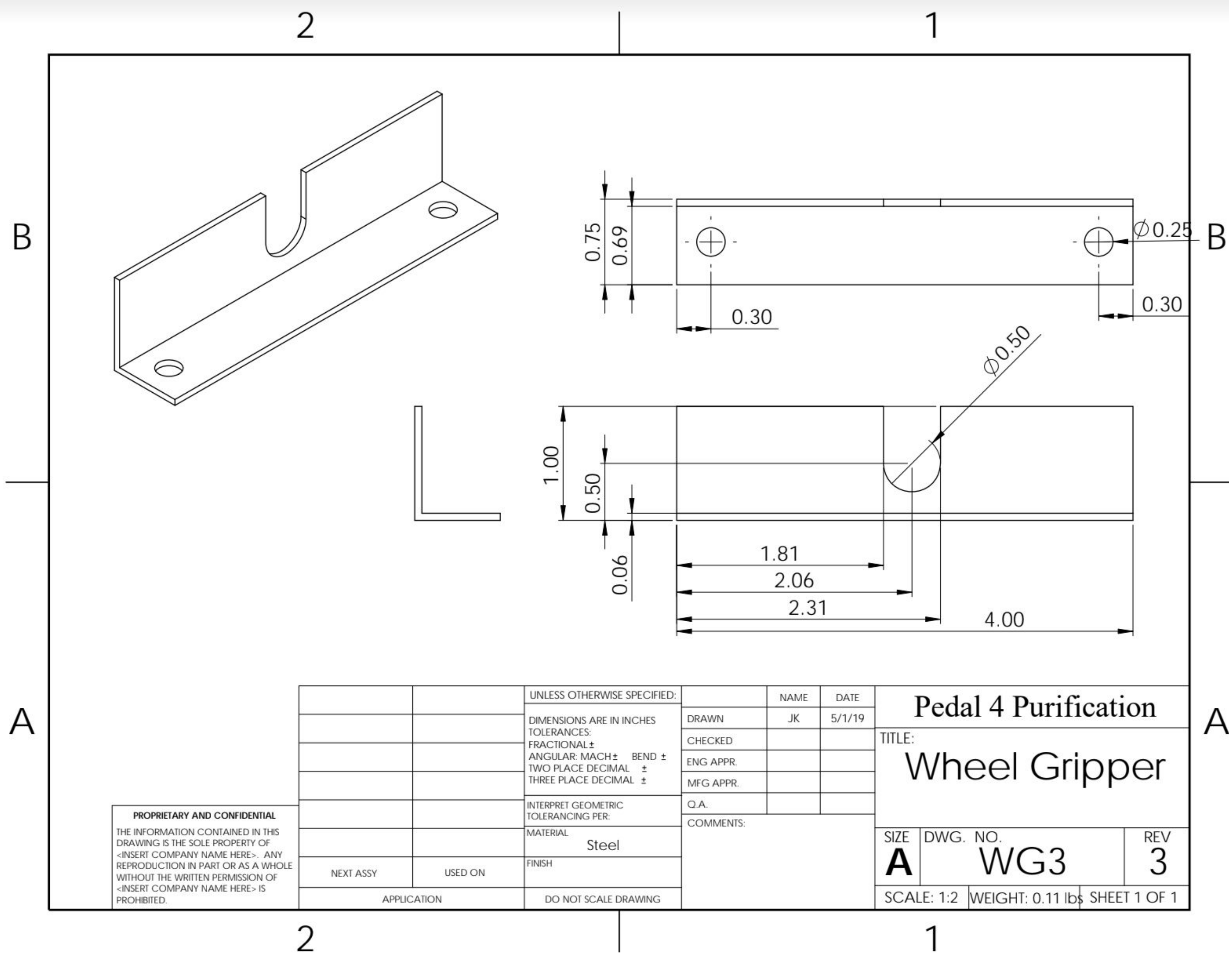
COMMENTS:

Pedal 4 Purification

TITLE: Wall Post

SIZE: A DWG. NO.: WP2 REV: 2

SCALE: 1:1 WEIGHT: 0.3 lbs SHEET 1 OF 1



2
1
B
A
0.75
0.69
0.30
0.30
⌀0.25
⌀0.50
1.00
0.50
0.06
1.81
2.06
2.31
4.00
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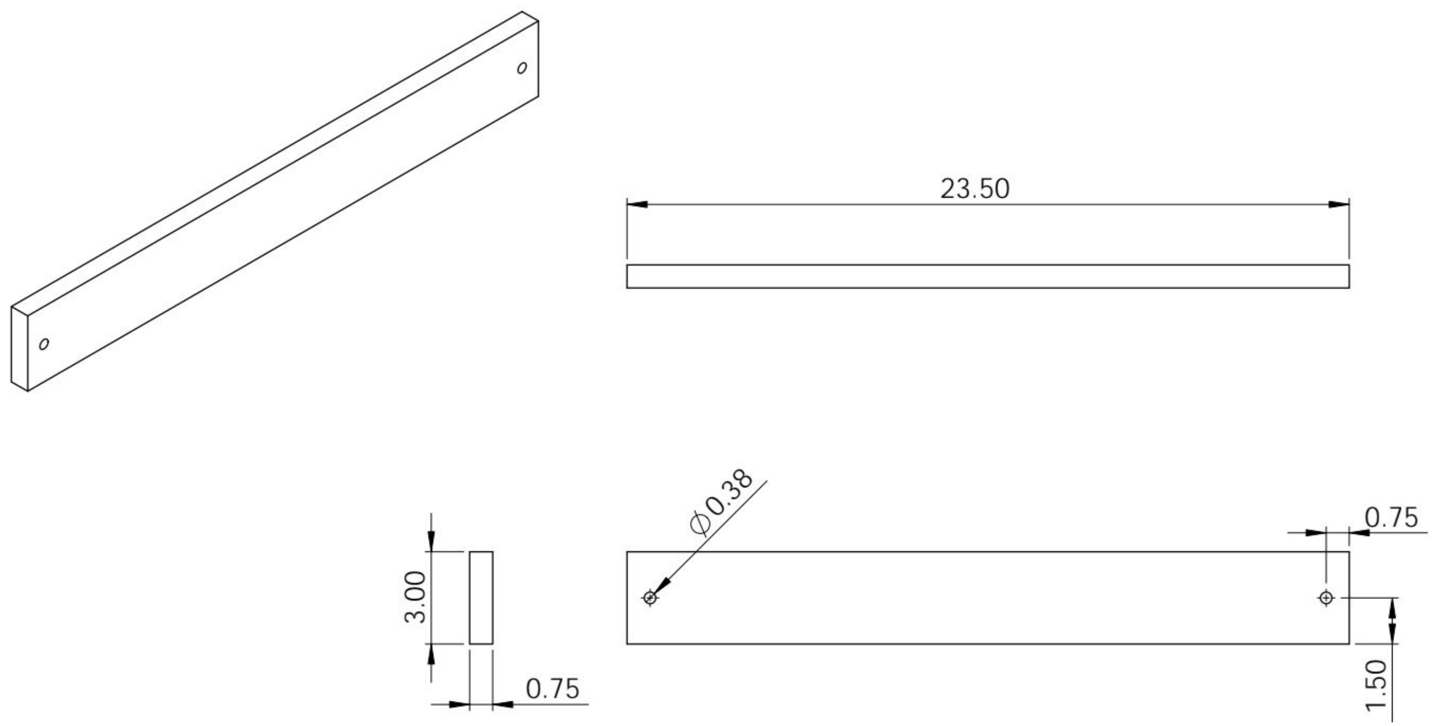
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Steel
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
JK
5/1/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pedal 4 Purification
TITLE:
Wheel Gripper
SIZE
A
DWG. NO.
WG3
REV
3
SCALE: 1:2
WEIGHT: 0.11 lbs
SHEET 1 OF 1



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APPLICATION	

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DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: Oak

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	JK	5/1/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

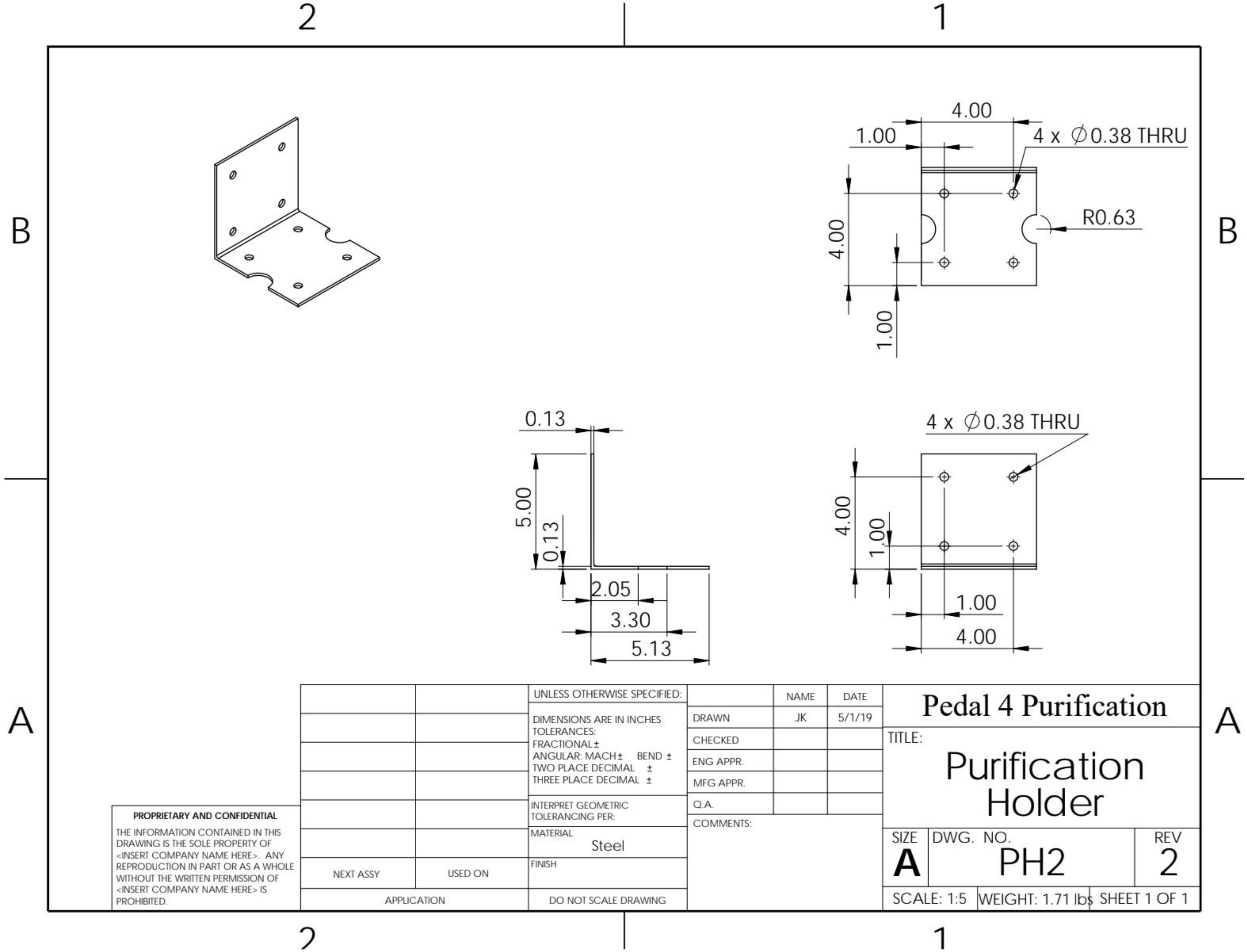
COMMENTS:

Pedal 4 Purification

TITLE: Medium Bottom Wood

SIZE: A | DWG. NO.: MBW1 | REV: 1

SCALE: 1:5 | WEIGHT:1.07 lbs | SHEET 1 OF 1



4.00
1.00
4 x ∅0.38 THRU
R0.63
4.00
1.00
0.13
5.00
0.13
2.05
3.30
5.13
4 x ∅0.38 THRU
4.00
1.00
1.00
4.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL Steel
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN JK 5/1/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pedal 4 Purification
TITLE:
Purification Holder
SIZE A
DWG. NO. PH2
REV 2
SCALE: 1:5
WEIGHT: 1.71 lbs
SHEET 1 OF 1
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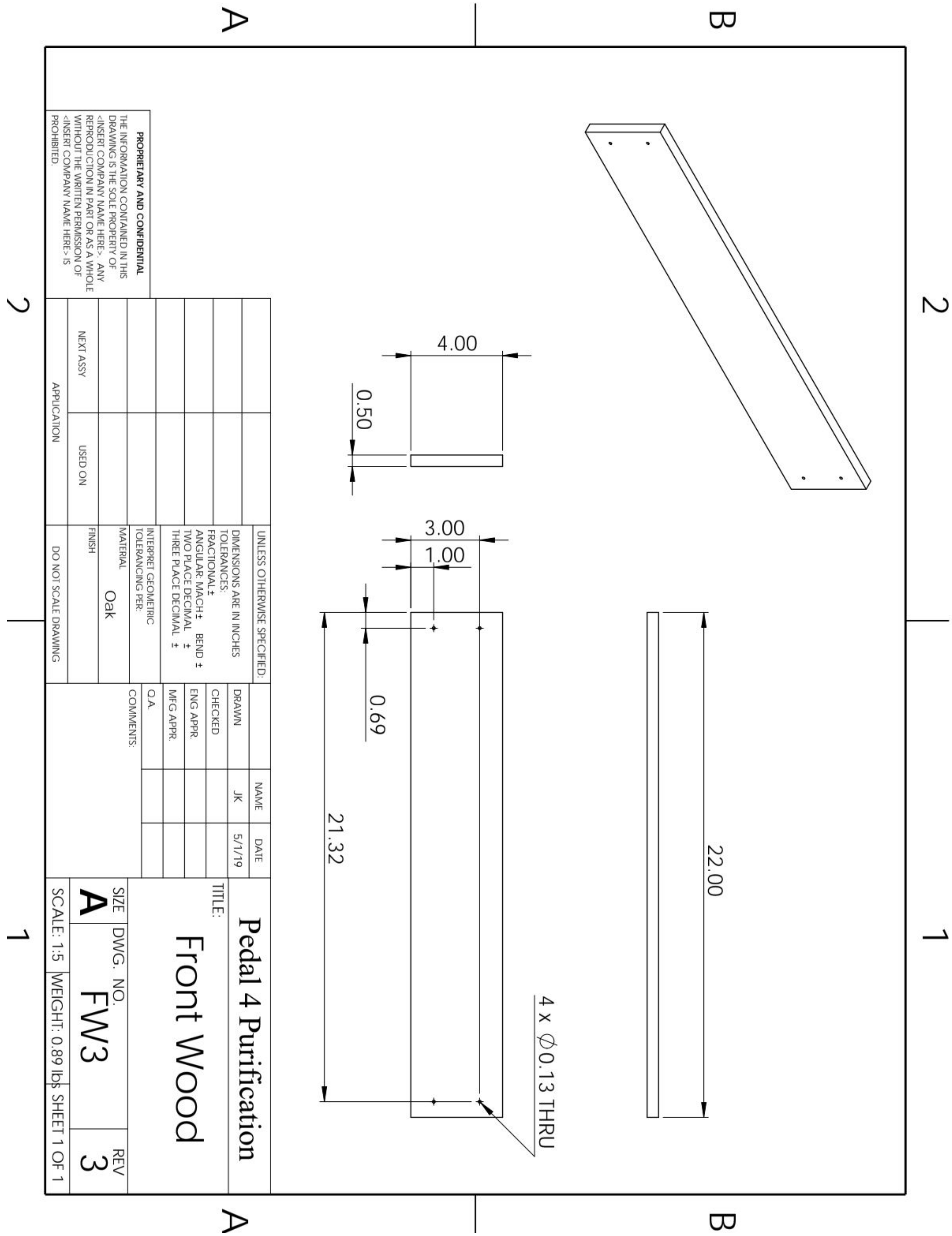
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USED ON
APPLICATION
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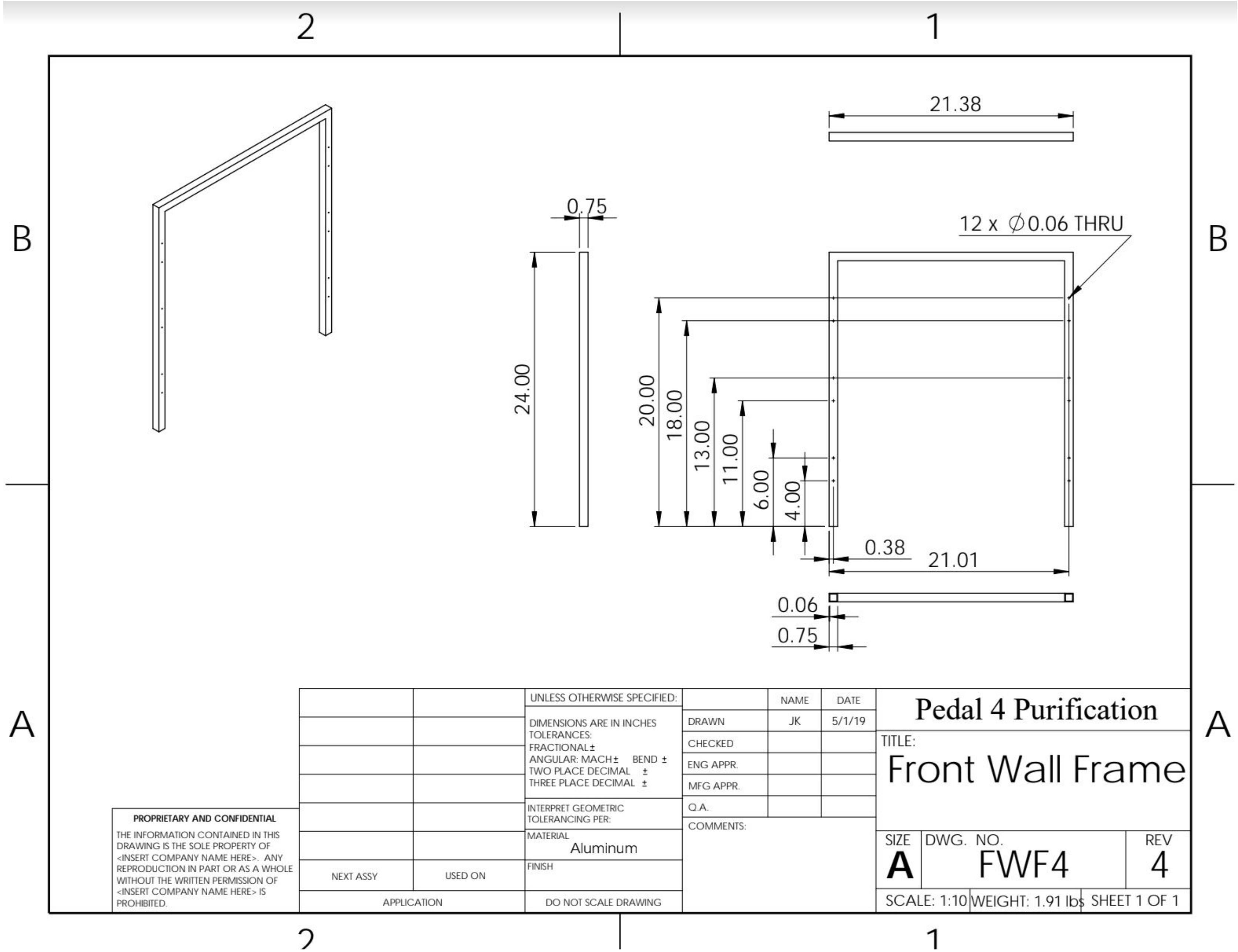
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Oak
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
JK
5/1/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pedal 4 Purification
TITLE:
Front Wood
SIZE
A
DWG. NO.
FW3
REV
3
SCALE: 1:5
WEIGHT: 0.89 lbs
SHEET 1 OF 1
4.00
0.50
3.00
1.00
0.69
21.32
22.00
4 x ∅0.13 THRU
A
B
1
2



21.38
0.75
12 x ∅0.06 THRU
24.00
20.00
18.00
13.00
11.00
6.00
4.00
0.38
21.01
0.06
0.75
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
JK
5/1/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pedal 4 Purification
TITLE:
Front Wall Frame
SIZE
A
DWG. NO.
FWF4
REV
4
SCALE: 1:10
WEIGHT: 1.91 lbs
SHEET 1 OF 1
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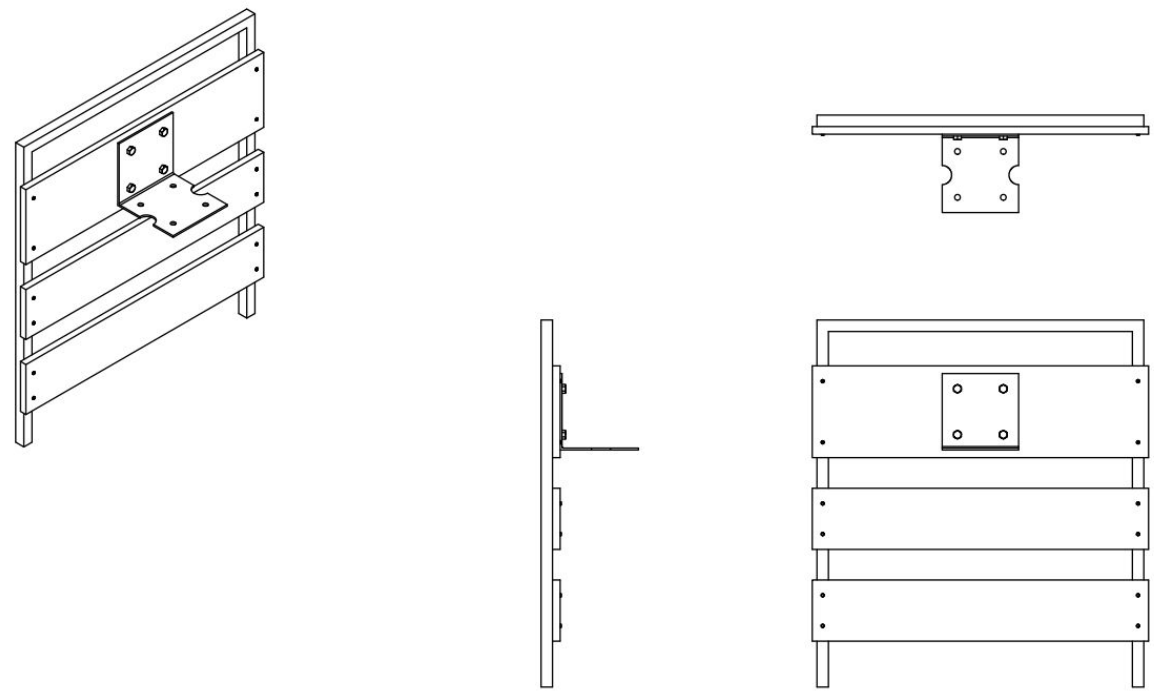


Pedal 4 Purification

TITLE: Front Wall Assembly

SIZE	DWG. NO.	REV
A	FWA5	5

SCALE: 1:10 | WEIGHT: 5.99 lbs | SHEET 1 OF 1

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

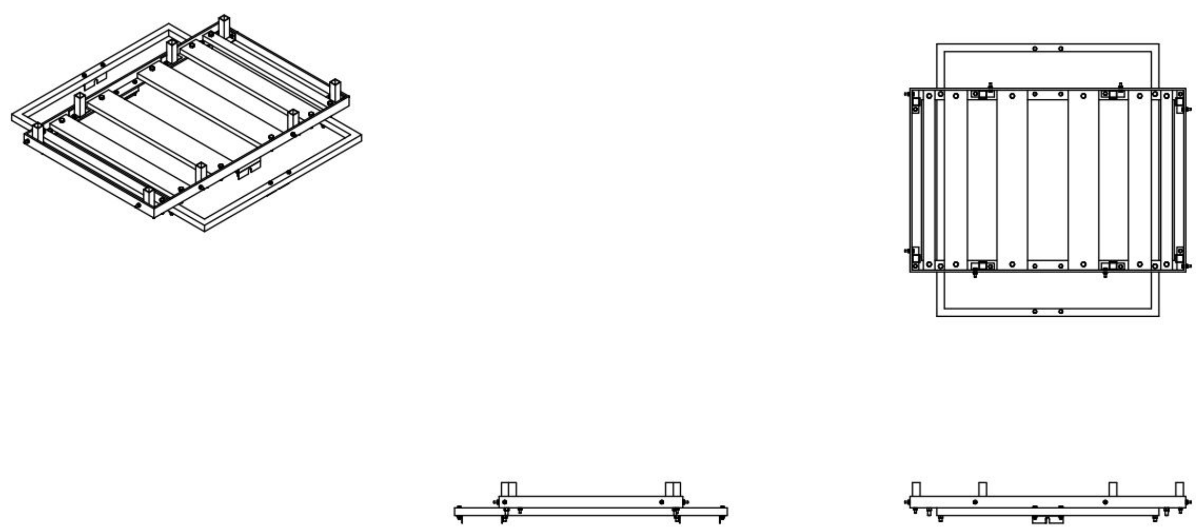
INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

NEXT ASSY	USED ON
APPLICATION	



		UNLESS OTHERWISE SPECIFIED:
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±
		INTERPRET GEOMETRIC TOLERANCING PER:
		MATERIAL
NEXT ASSY	USED ON	FINISH
APPLICATION		DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

PROPRIETARY AND CONFIDENTIAL

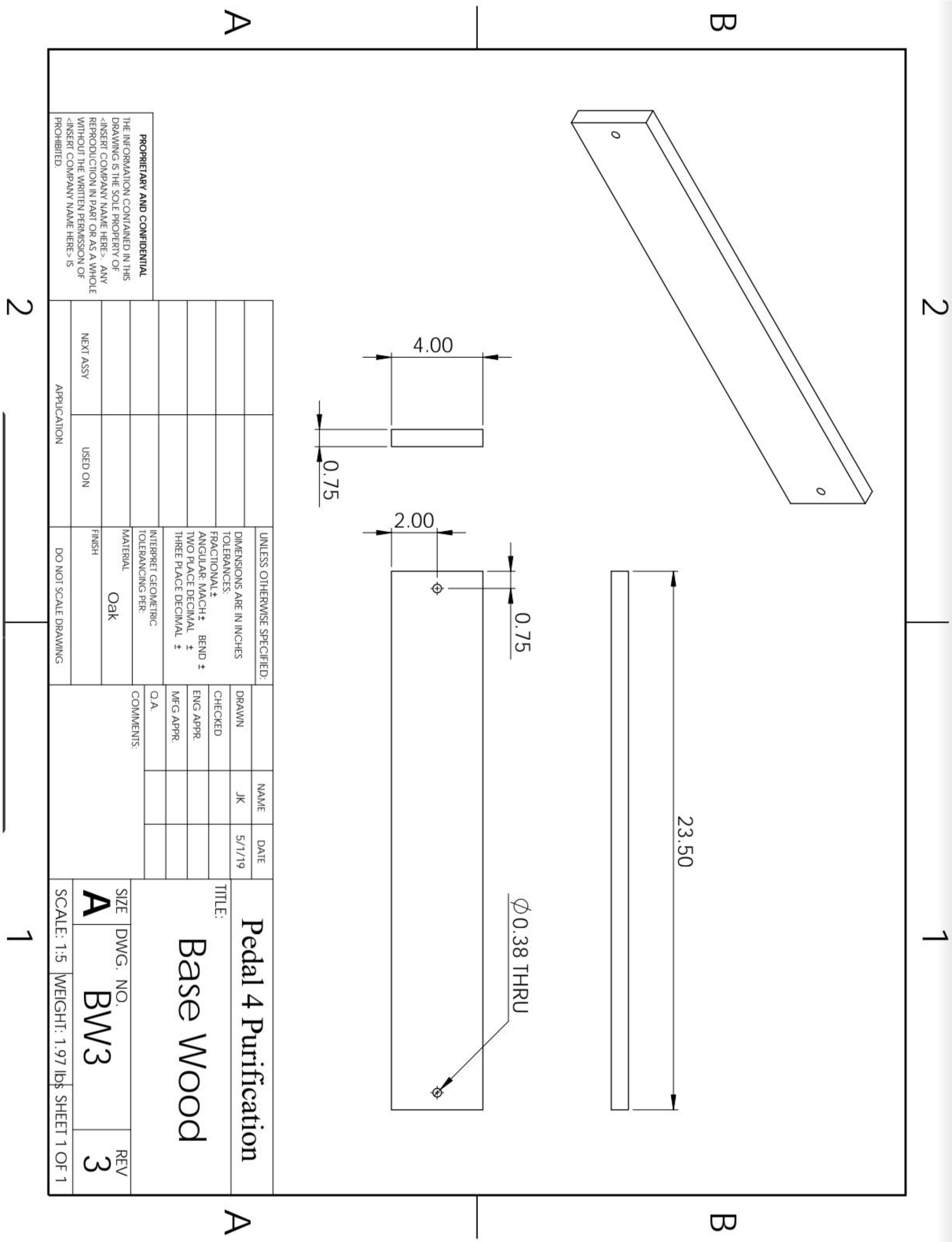
Pedal 4 Purification

TITLE:

Base Assembly

SIZE	DWG. NO.	REV
A	BA6	6

SCALE: 1:20 | WEIGHT: 20.28 lbs | SHEET 1 OF 1


A
B
1
2
4.00
0.75
2.00
0.75
23.50
∅0.38 THRU
PROPRIETARY AND CONFIDENTIAL
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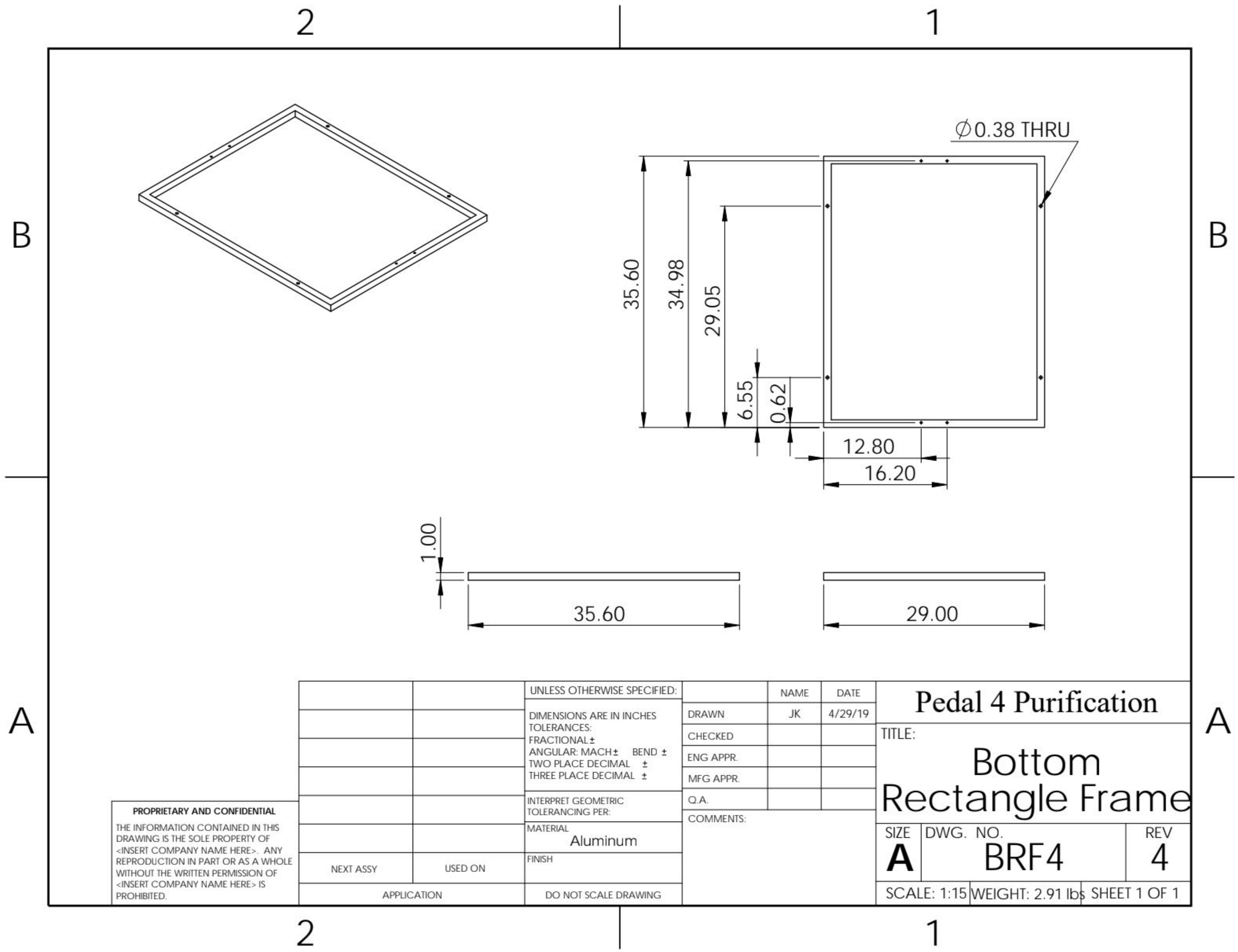
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Oak
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
JK
5/1/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pedal 4 Purification
TITLE:
Base Wood
SIZE
A
DWG. NO.
BW3
REV
3
SCALE: 1:5
WEIGHT: 1.97 lbs
SHEET 1 OF 1


∅0.38 THRU
35.60
34.98
29.05
6.55
0.62
12.80
16.20
1.00
35.60
29.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
JK
4/29/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pedal 4 Purification
TITLE:
Bottom Rectangle Frame
SIZE
A
DWG. NO.
BRF4
REV
4
SCALE: 1:15
WEIGHT: 2.91 lbs
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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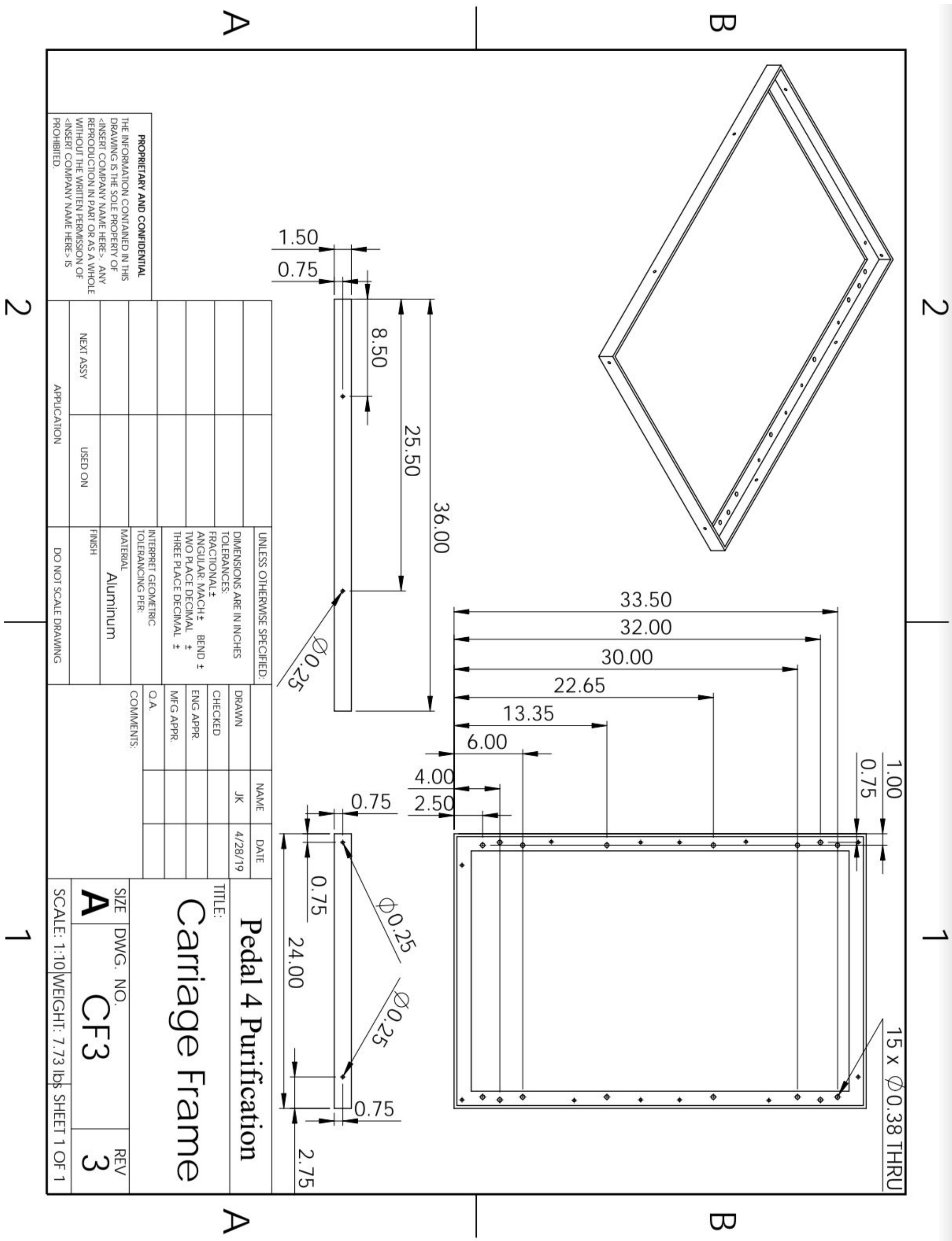
A
B
2
1
1.50
0.75
8.50
25.50
36.00
⌀0.25
33.50
32.00
30.00
22.65
13.35
6.00
4.00
2.50
1.00
0.75
0.75
0.75
24.00
⌀0.25
⌀0.25
0.75
2.75
15 X ⌀0.38 THRU
PROPRIETARY AND CONFIDENTIAL
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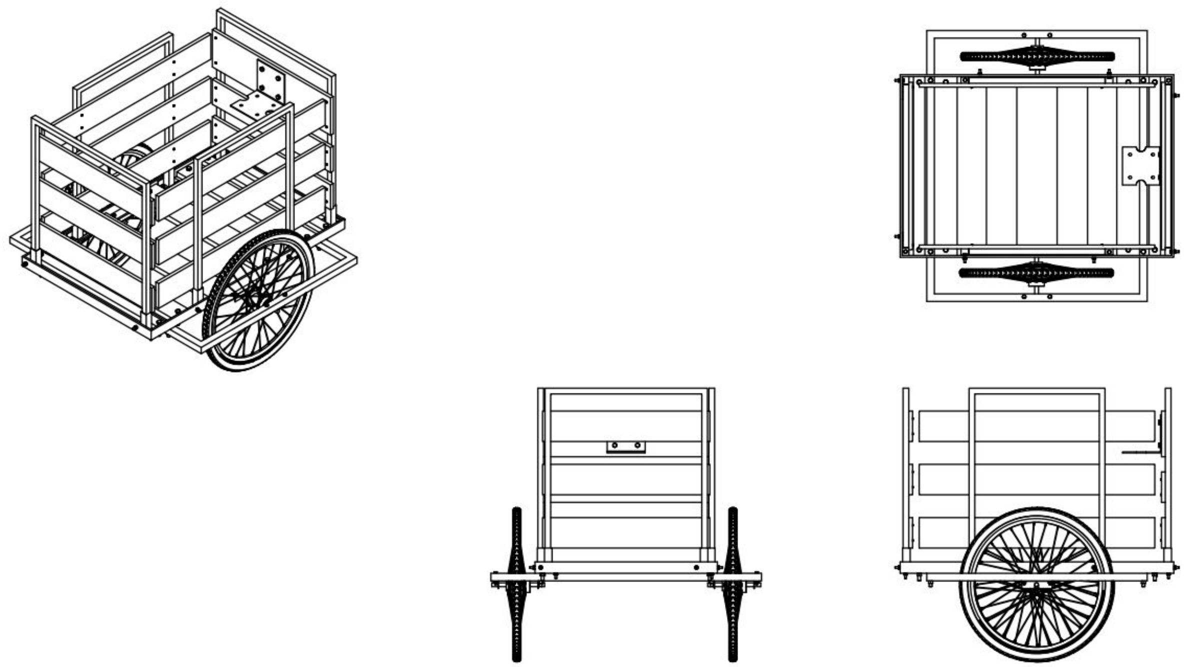
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
JK
4/28/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pedal 4 Purification
TITLE:
Carriage Frame
SIZE
A
DWG. NO.
CF3
REV
3
SCALE: 1:10
WEIGHT: 7.73 lbs
SHEET 1 OF 1



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APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: Multiple

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	JK	5/1/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

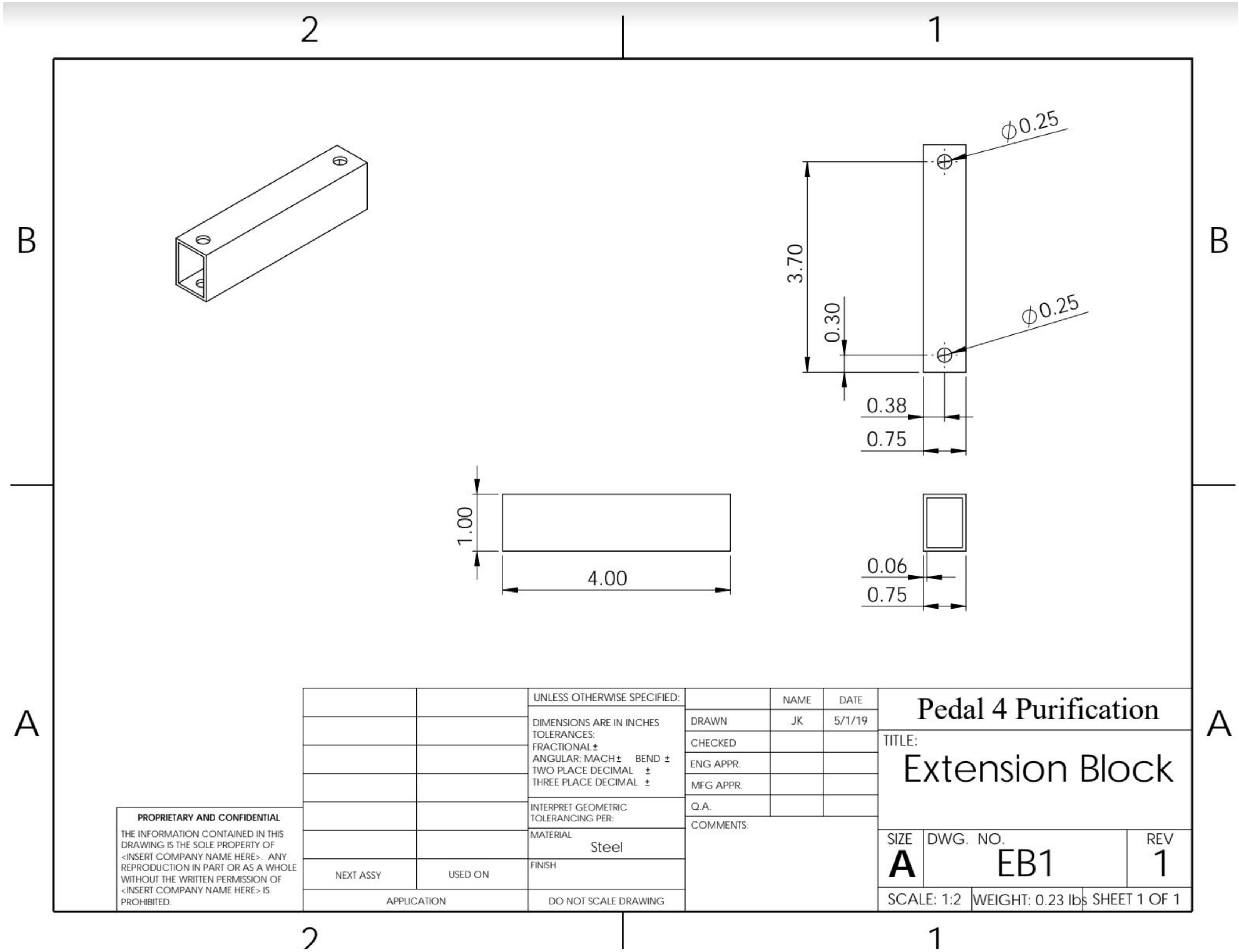
COMMENTS:

Pedal 4 Purification

TITLE: Cart Assembly

SIZE: A | DWG. NO.: Cart5 | REV: 5

SCALE: 1:20 | WEIGHT: 43 lbs | SHEET 1 OF 1



2
1
B
A
⌀0.25
⌀0.25
3.70
0.30
0.38
0.75
1.00
4.00
0.06
0.75
PROPRIETARY AND CONFIDENTIAL
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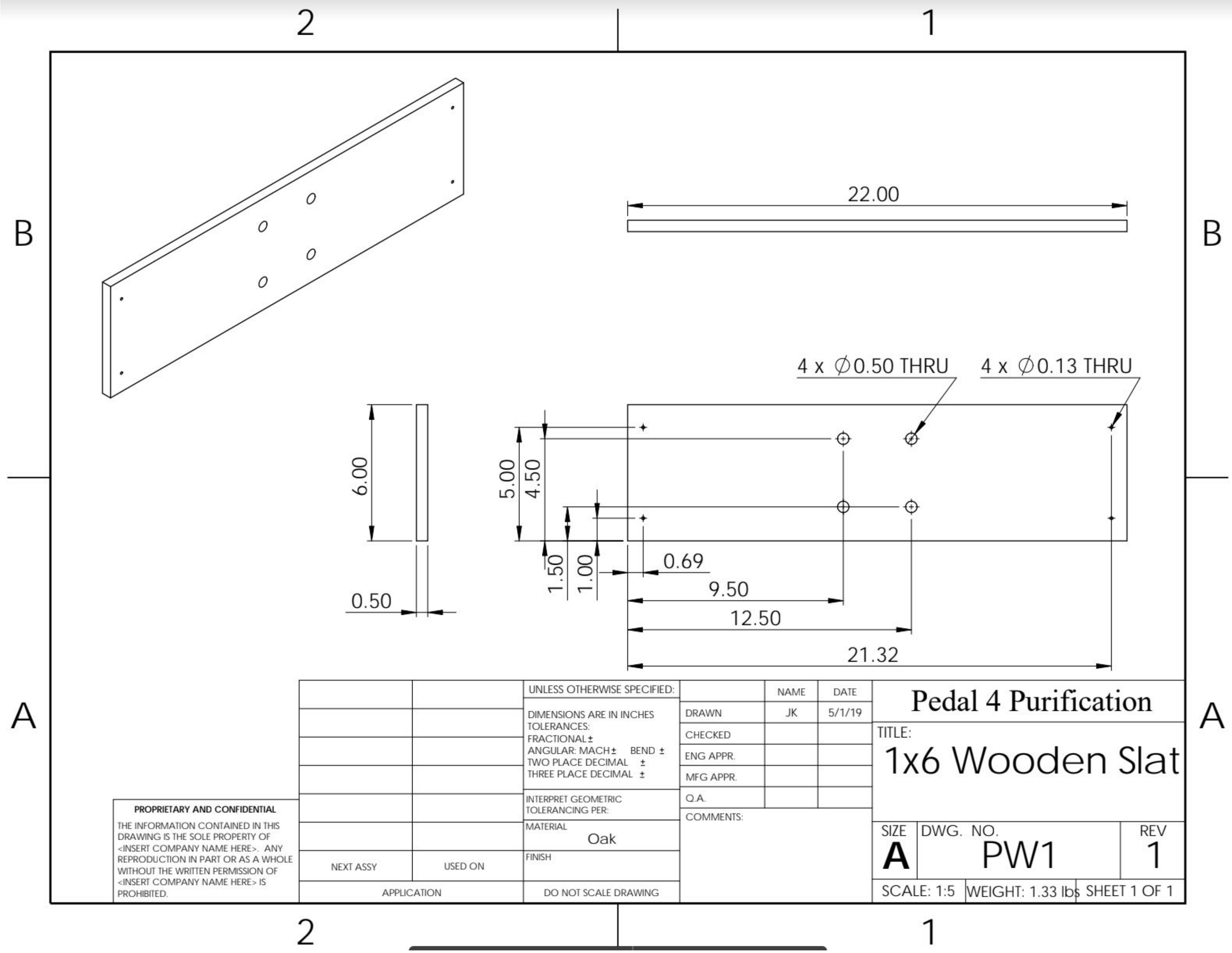
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Steel
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
JK
5/1/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pedal 4 Purification
TITLE:
Extension Block
SIZE
A
DWG. NO.
EB1
REV
1
SCALE: 1:2
WEIGHT: 0.23 lbs
SHEET 1 OF 1


2
1
B
A
22.00
4 x ∅0.50 THRU
4 x ∅0.13 THRU
6.00
0.50
5.00
4.50
1.50
1.00
0.69
9.50
12.50
21.32
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Oak
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
JK
5/1/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pedal 4 Purification
TITLE:
1x6 Wooden Slat
SIZE
A
DWG. NO.
PW1
REV
1
SCALE: 1:5
WEIGHT: 1.33 lbs
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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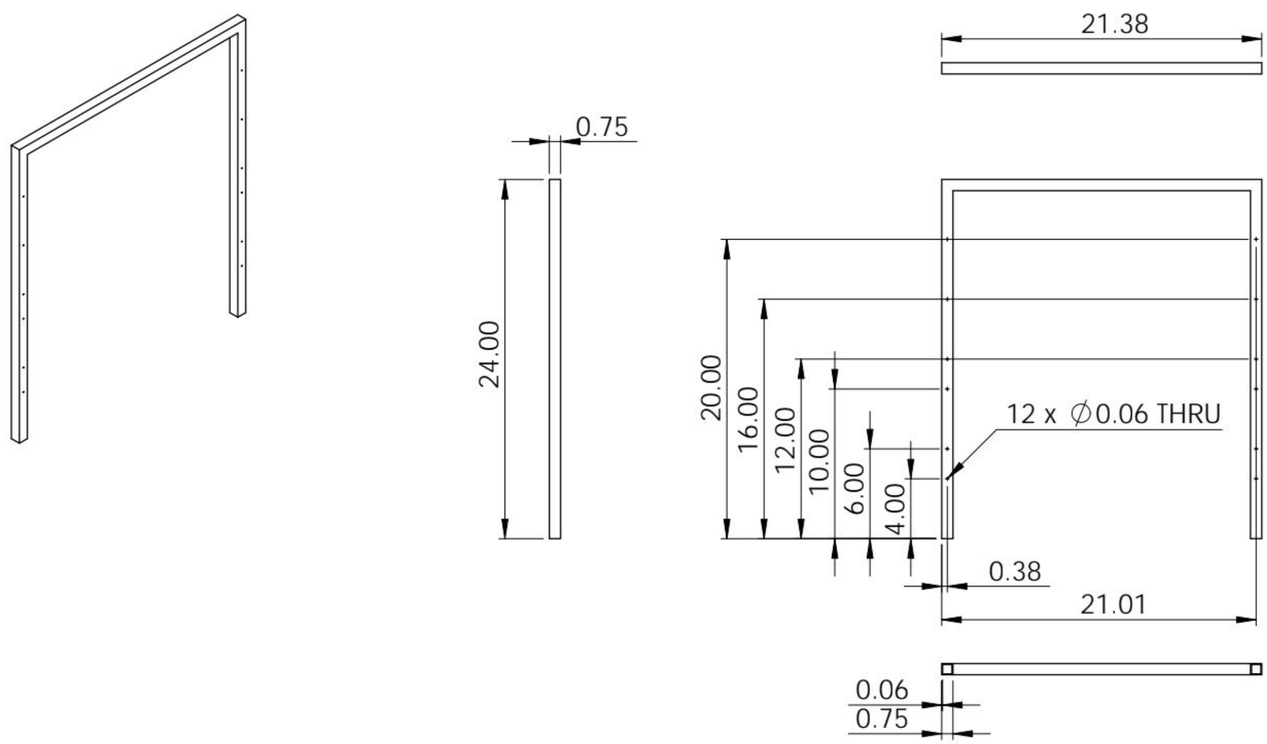

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	JK	5/1/19
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL Aluminum	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

NEXT ASSY	USED ON
APPLICATION	

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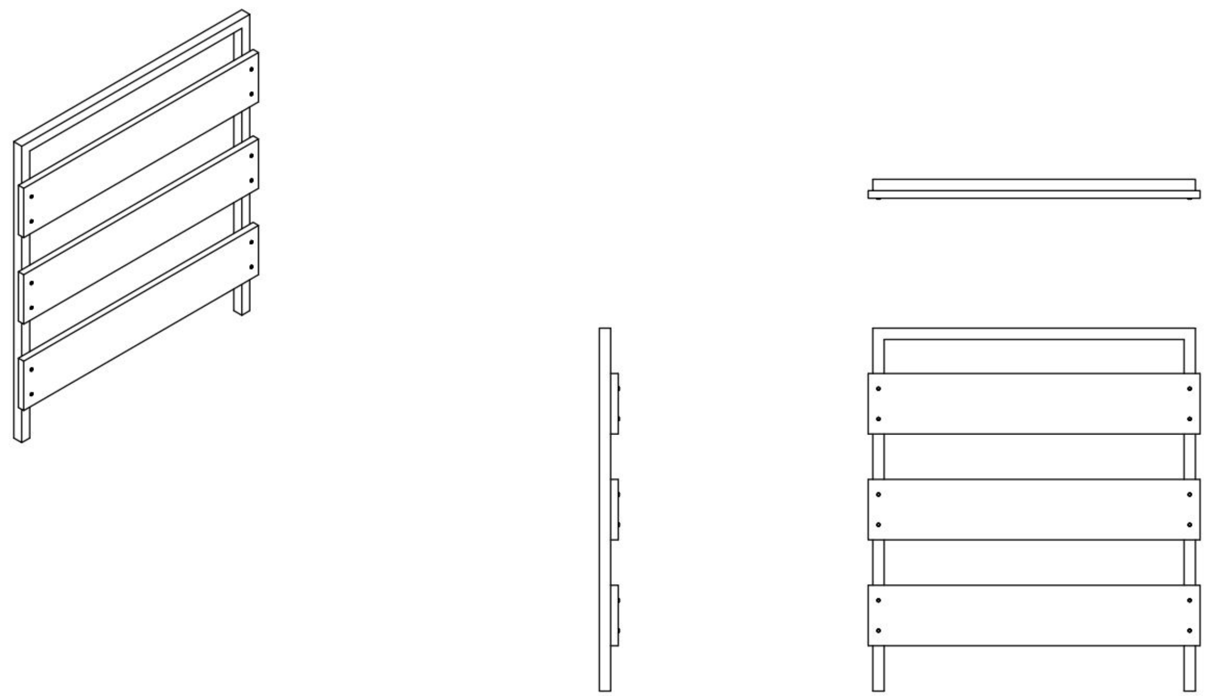
Pedal 4 Purification

TITLE: Back Wall Frame

SIZE A | DWG. NO. BWF3 | REV 3

SCALE: 1:10 | WEIGHT: 1.91 lbs | SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

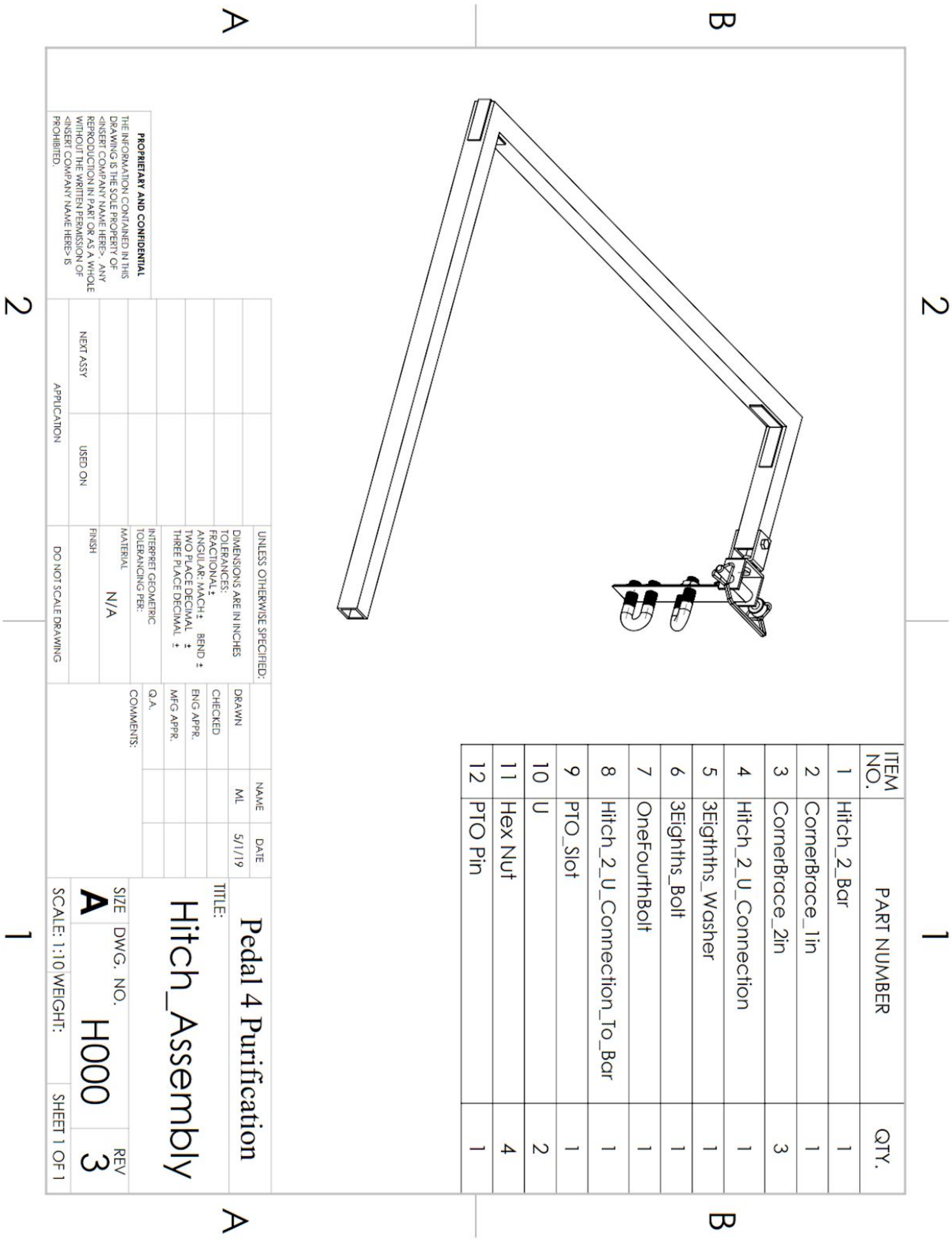
Pedal 4 Purification

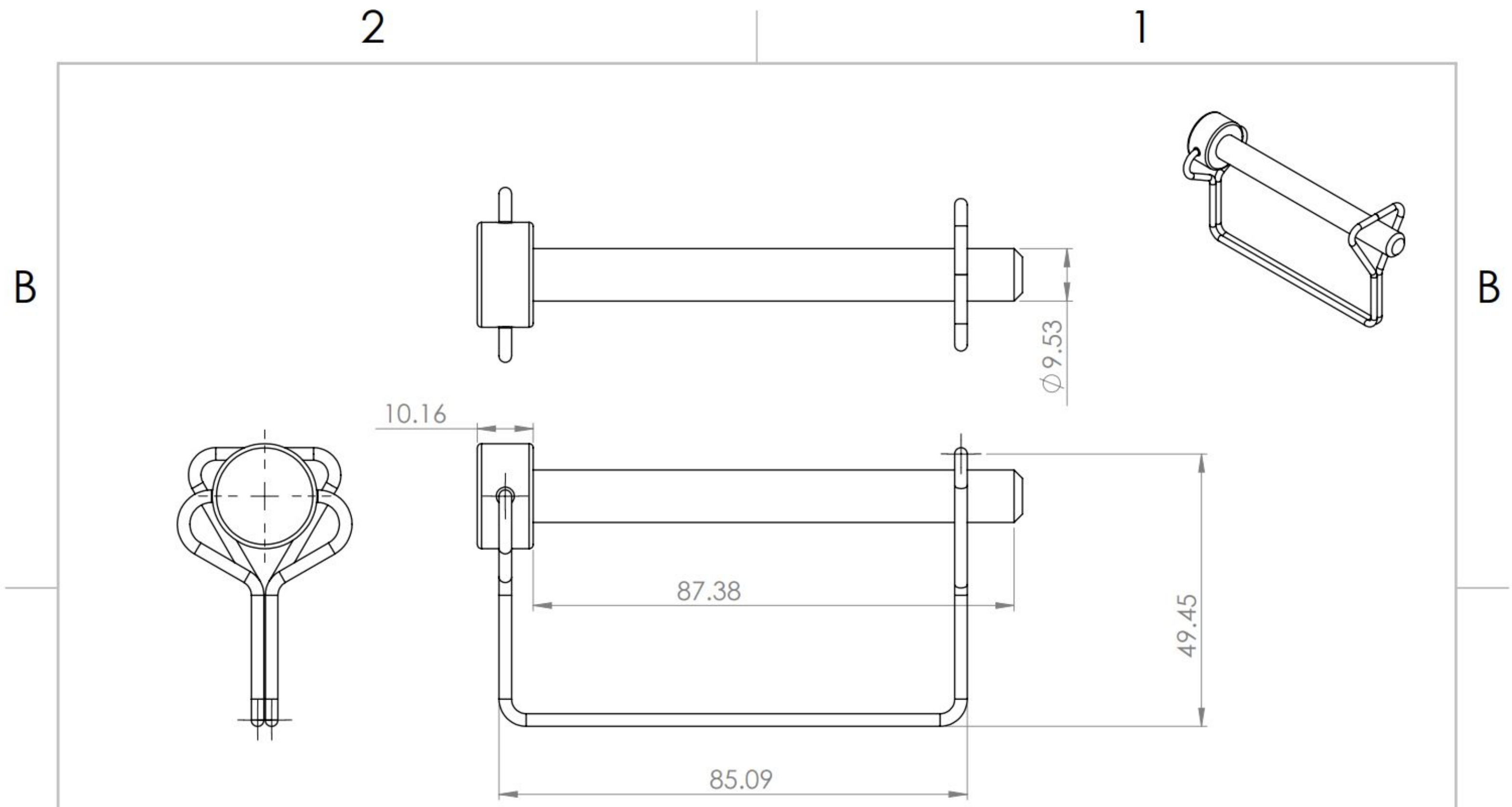
TITLE: Back Wall Assembly

SIZE	DWG. NO.	REV
A	BWA5	5

SCALE: 1:10 WEIGHT: 3.81 lbs SHEET 1 OF 1

Appendix I: Hitch Subsystem Detailed Drawings





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APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL: Steel
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	ML	5/1/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

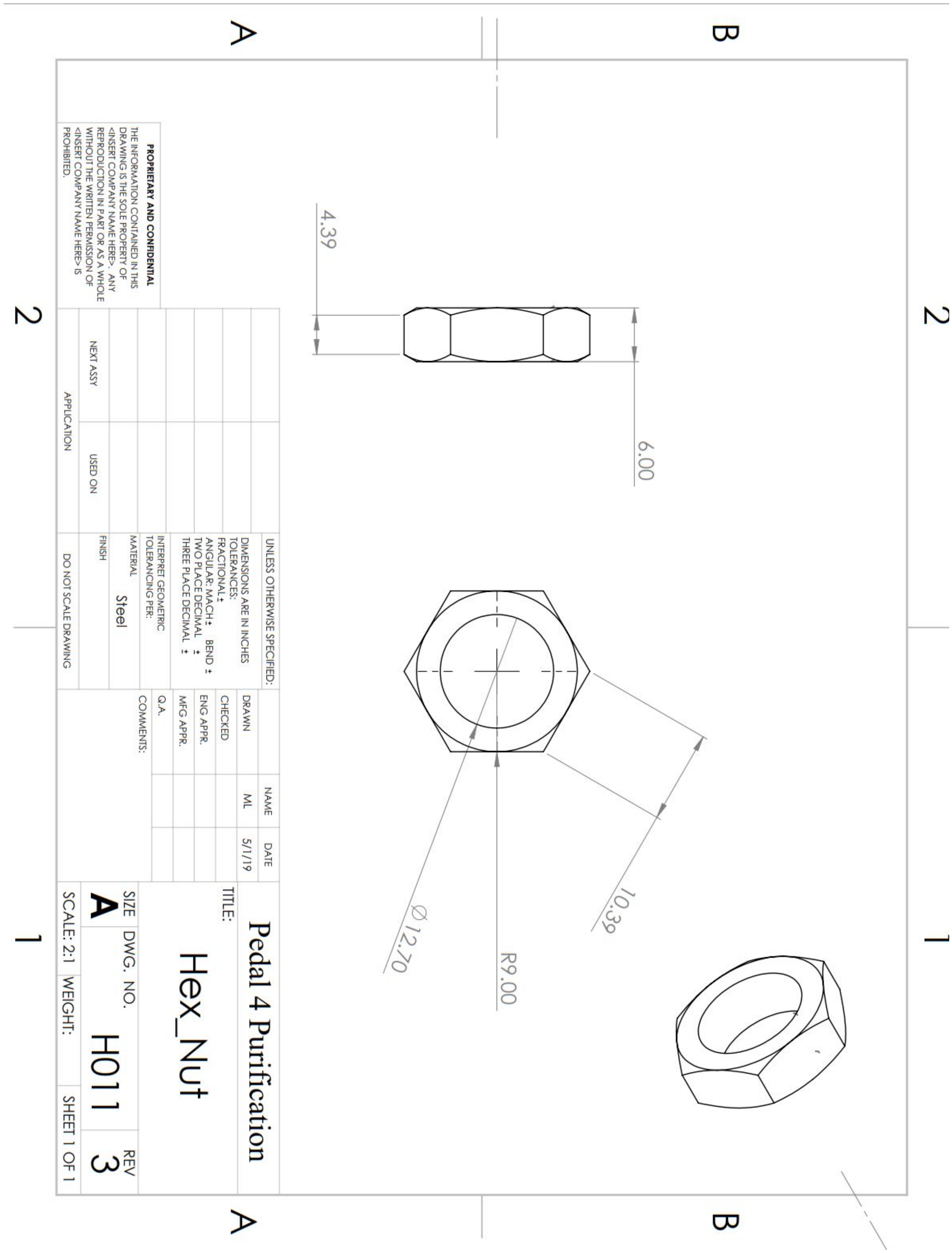
COMMENTS:

Pedal 4 Purification

TITLE: PTO_Pin

SIZE: A | DWG. NO.: H012 | REV: 3

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1



Pedal 4 Purification
TITLE:
Hex_Nut
SIZE
A
DWG. NO.
H011
REV
3
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
4.39
6.00
10.39
R9.00
Ø12.70
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
Steel
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
ML
5/1/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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A
B
2
1


Pedal 4 Purification
TITLE:
U
SIZE
A
DWG. NO.
H010
REV
3
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
NAME
DATE
DRAWN
ML
5/1/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Steel
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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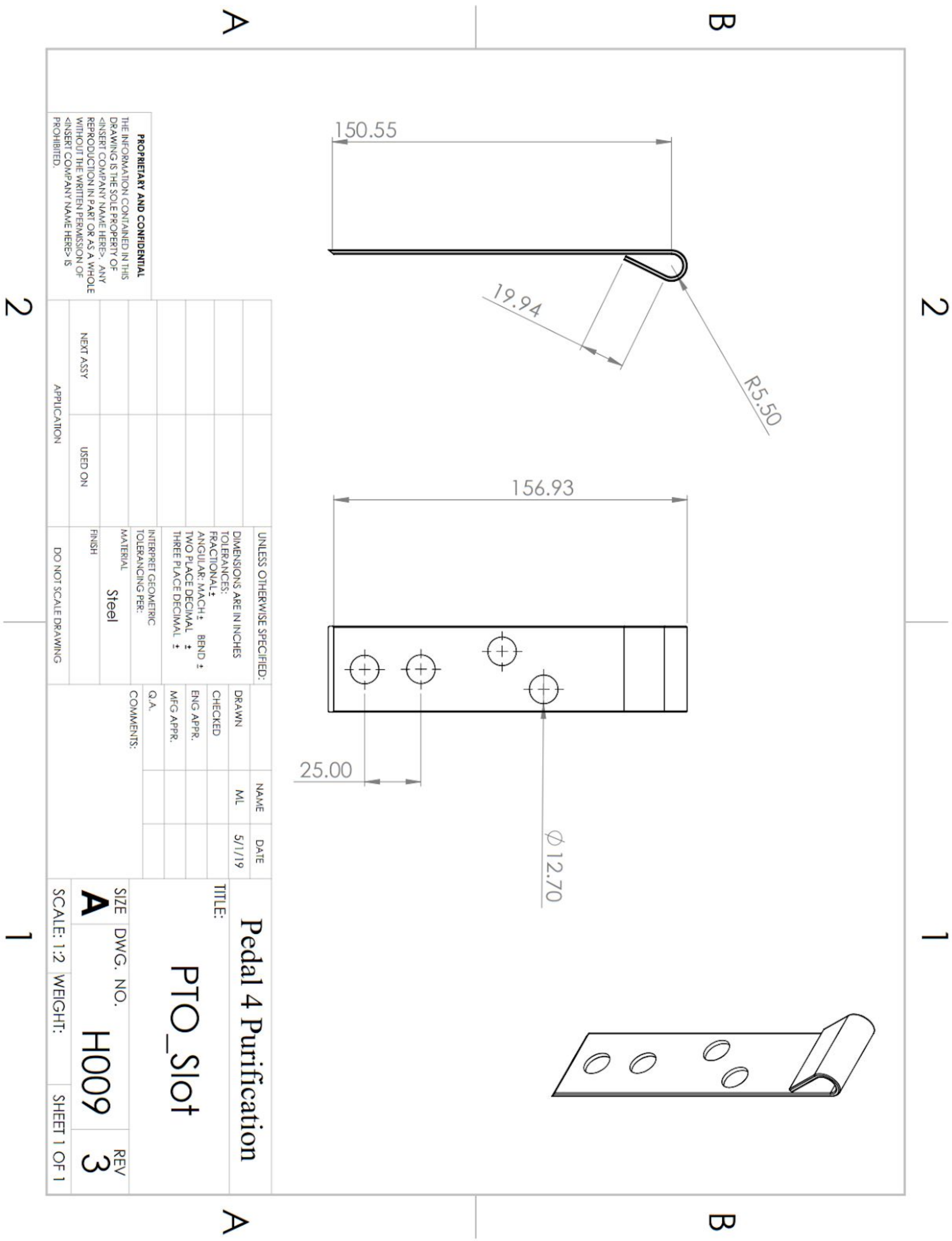
Ø12.70
R18.85
1.00
10.60
29.90
R6.15
R6.35
A
B
1
2



150.55
19.94
R5.50
156.93
25.00
Ø12.70
PROPRIETARY AND CONFIDENTIAL
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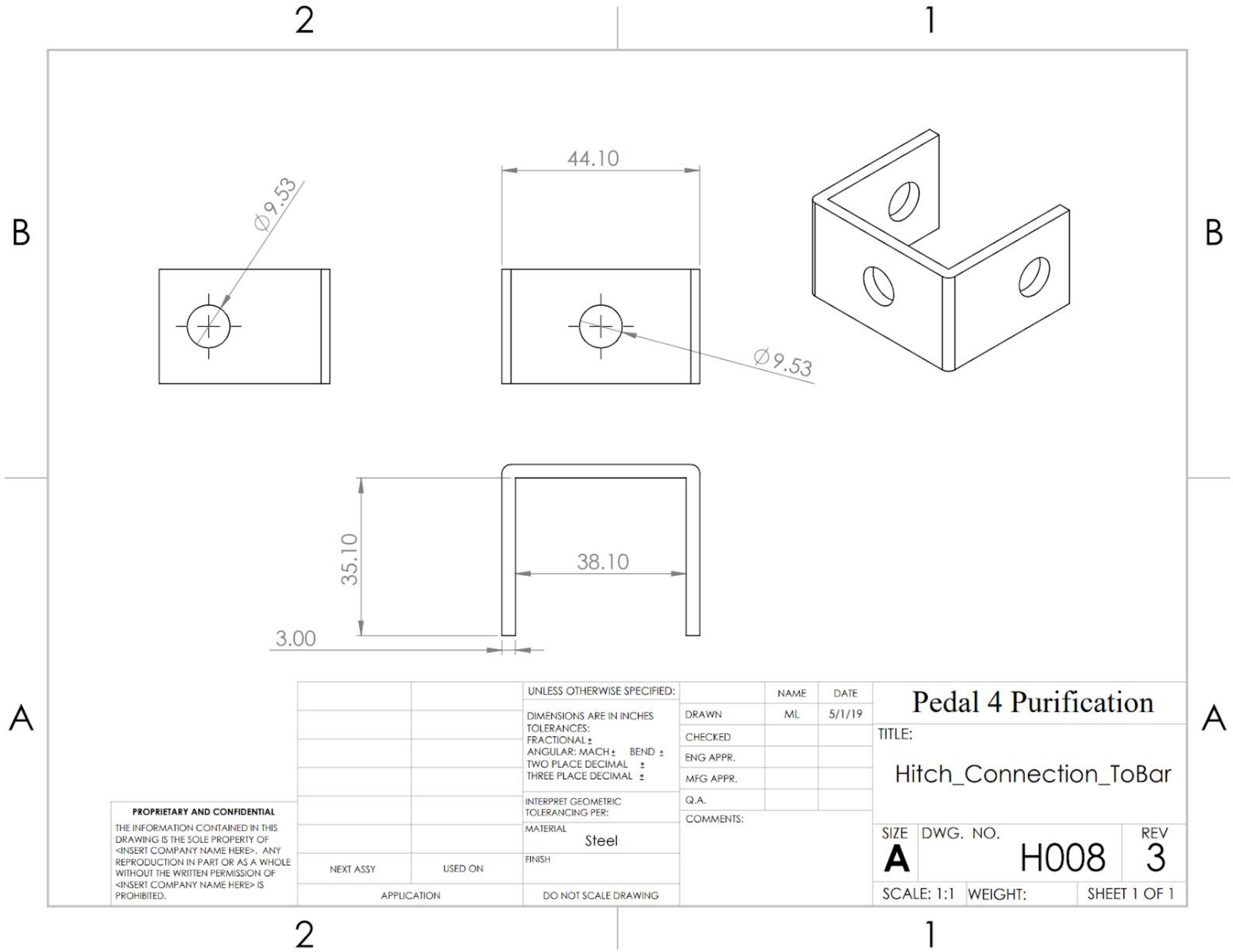
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Steel
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
ML
5/1/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pedal 4 Purification
TITLE:
PTO_Slot
SIZE
A
DWG. NO.
H009
REV
3
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1



2
1
B
A
Ø9.53
44.10
Ø9.53
35.10
38.10
3.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Steel
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
ML
5/1/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pedal 4 Purification
TITLE:
Hitch_Connection_ToBar
SIZE
A
DWG. NO.
H008
REV
3
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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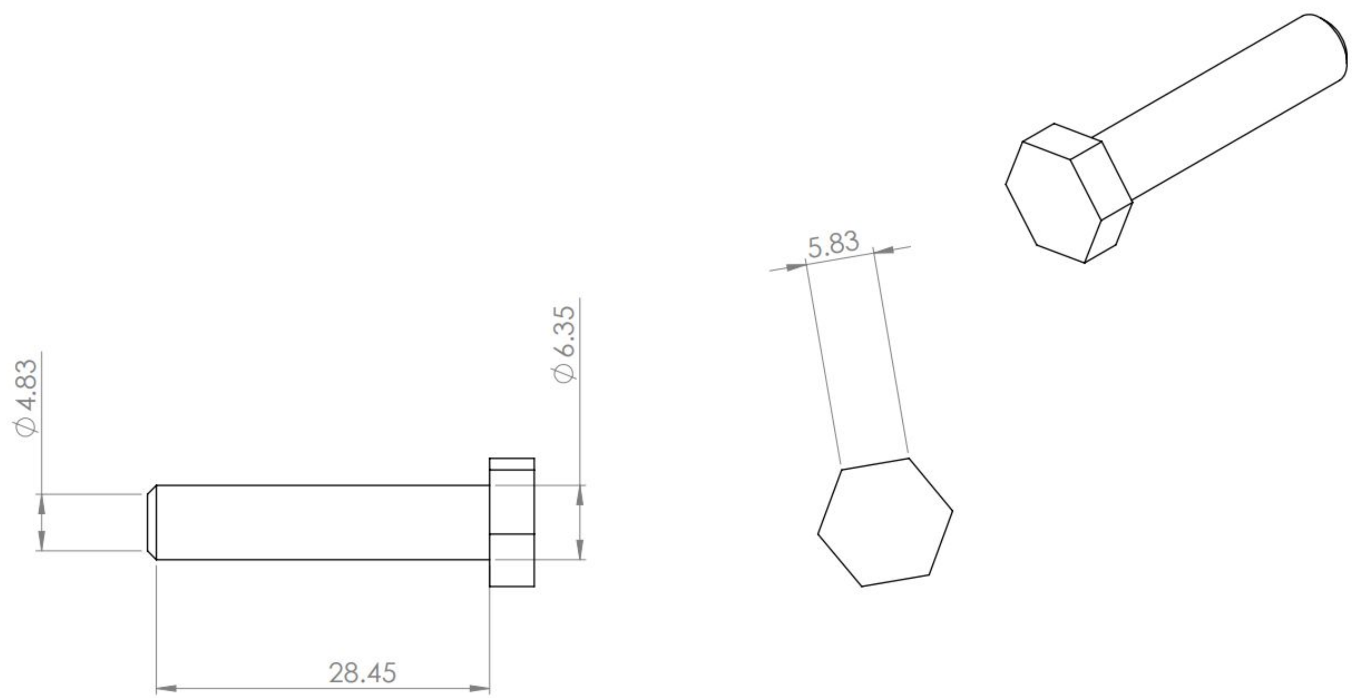

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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL Steel

FINISH

DO NOT SCALE DRAWING

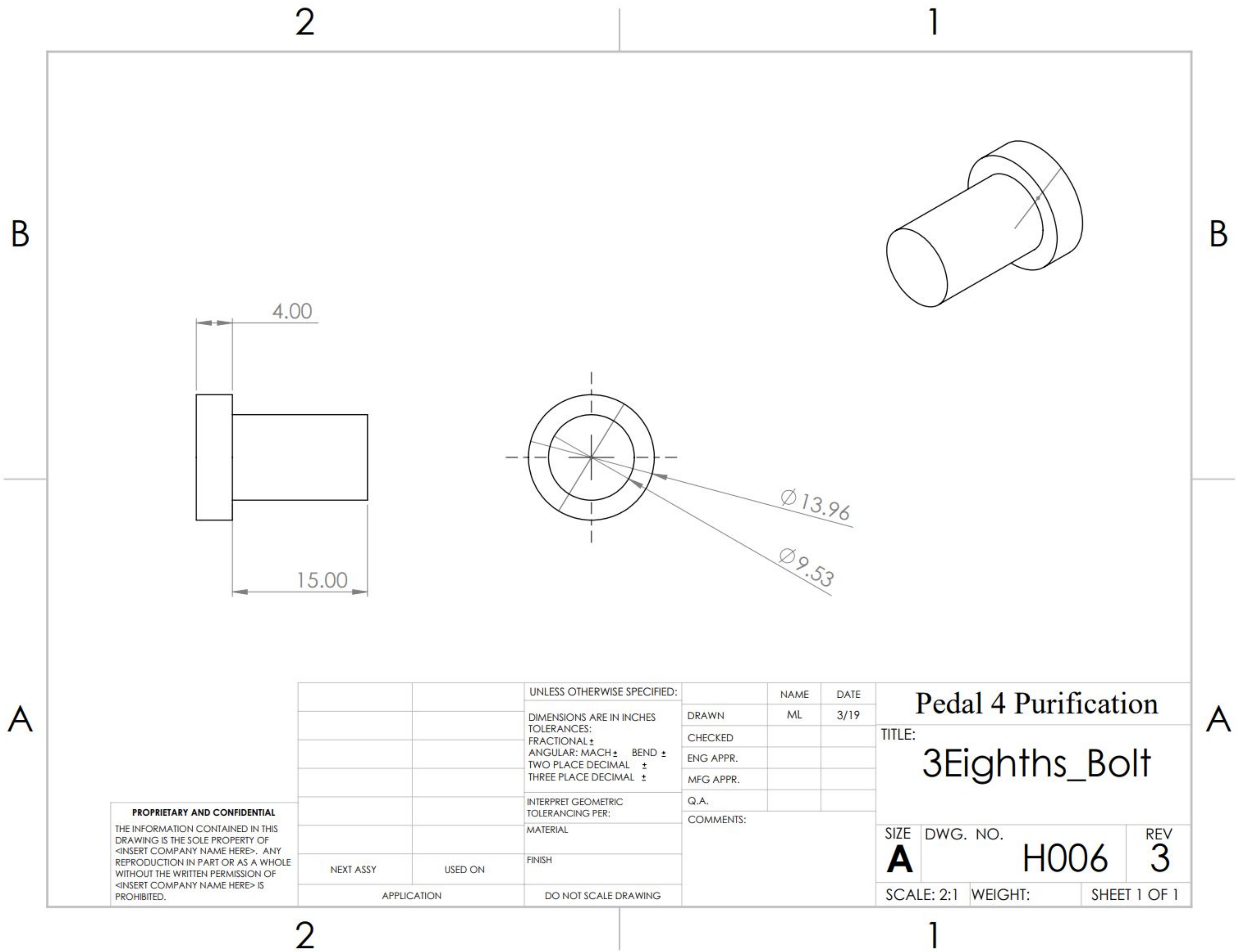
	NAME	DATE
DRAWN	ML	5/1/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

Pedal 4 Purification

TITLE: OneFourthBolt

SIZE	DWG. NO.	REV
A	H007	3

SCALE: 2:1 WEIGHT: SHEET 1 OF 1


4.00
15.00
∅13.96
∅9.53
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME DATE
DRAWN ML 3/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pedal 4 Purification
TITLE:
3Eighths_Bolt
SIZE A
DWG. NO. H006
REV 3
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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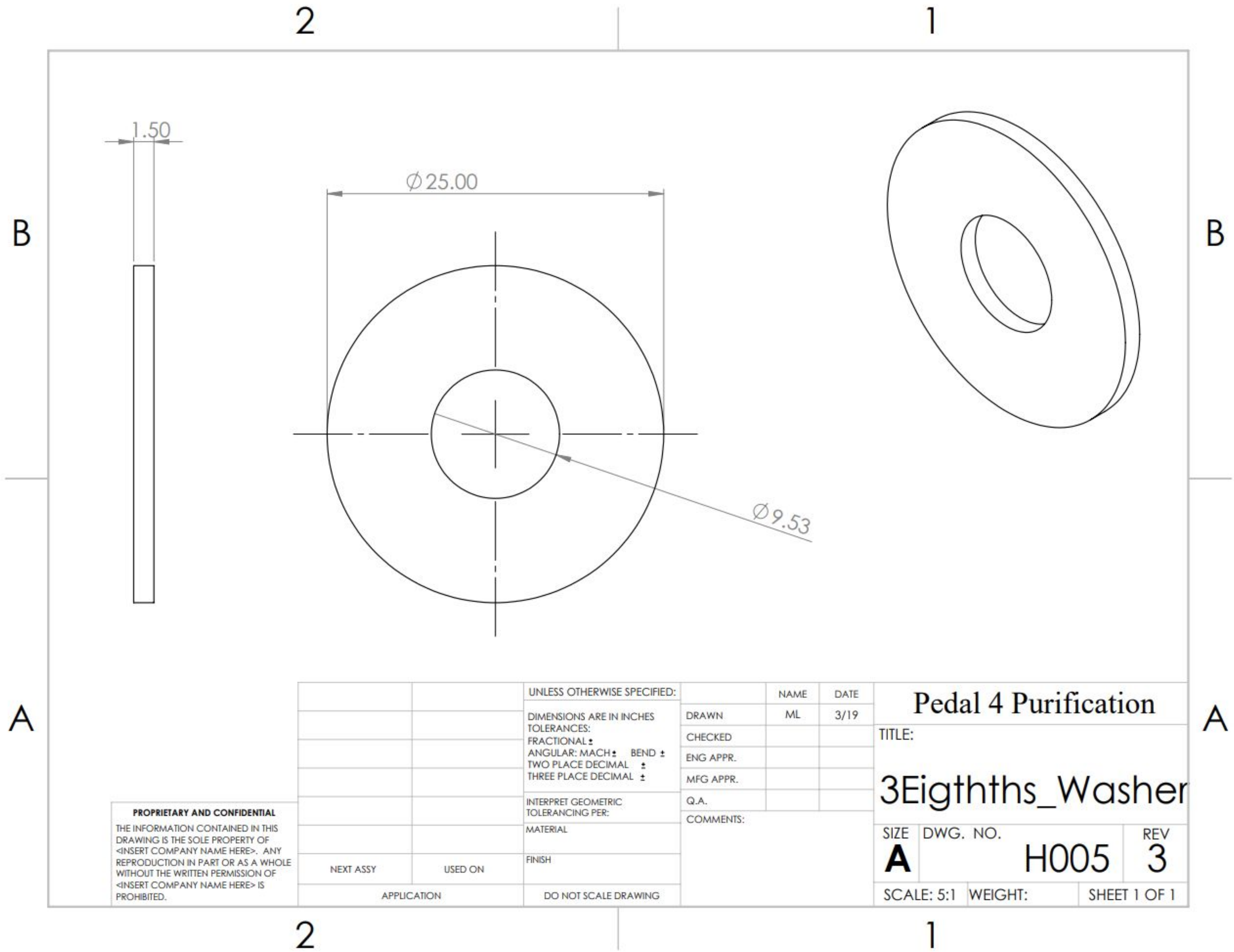
2
1
B
A
1.50
∅25.00
∅9.53
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
ML
3/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pedal 4 Purification
TITLE:
3Eigthths_Washer
SIZE
A
DWG. NO.
H005
REV
3
SCALE: 5:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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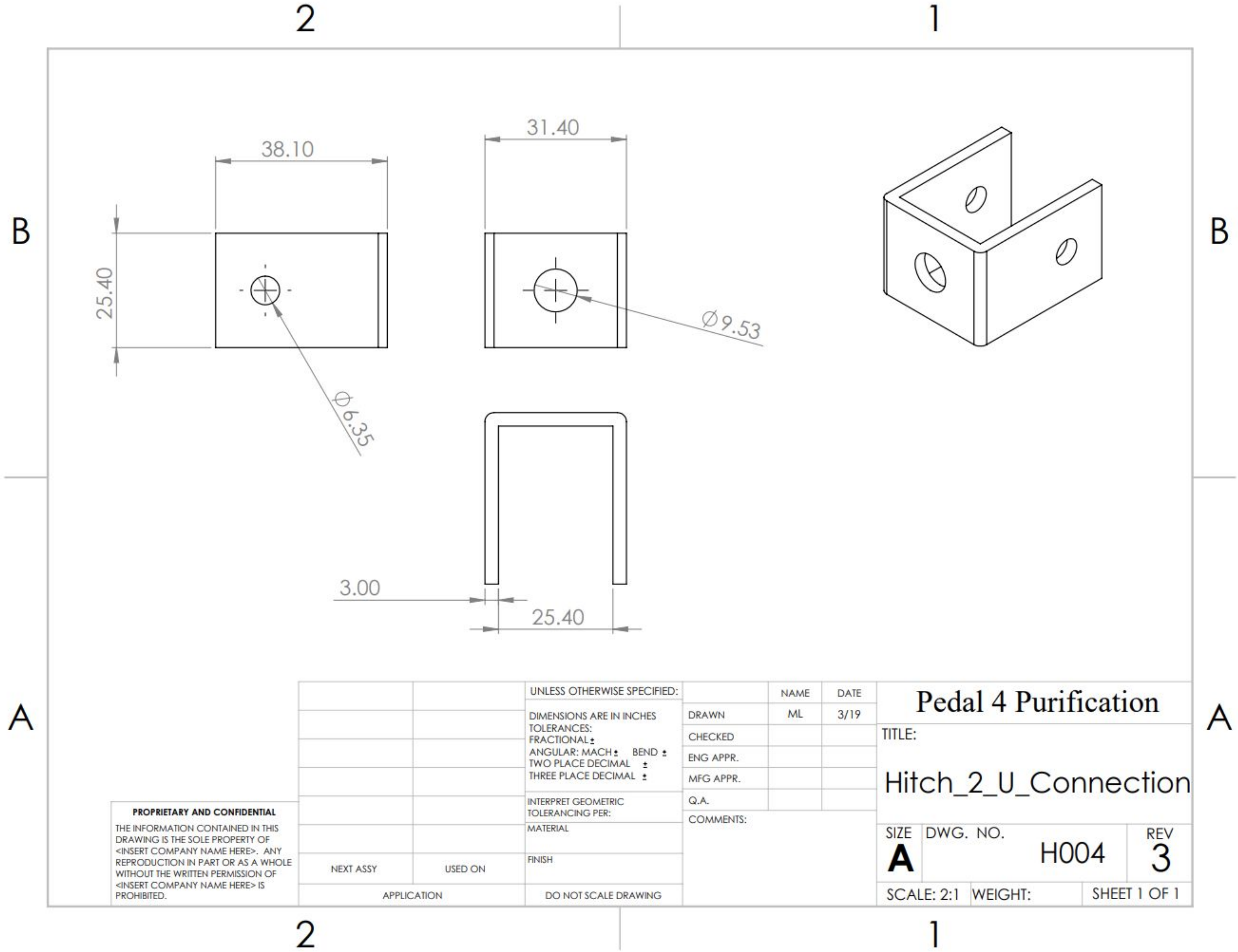
2
1
B
A
38.10
25.40
Ø6.35
31.40
Ø9.53
3.00
25.40
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
ML
3/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pedal 4 Purification
TITLE:
Hitch_2_U_Connection
SIZE
A
DWG. NO.
H004
REV
3
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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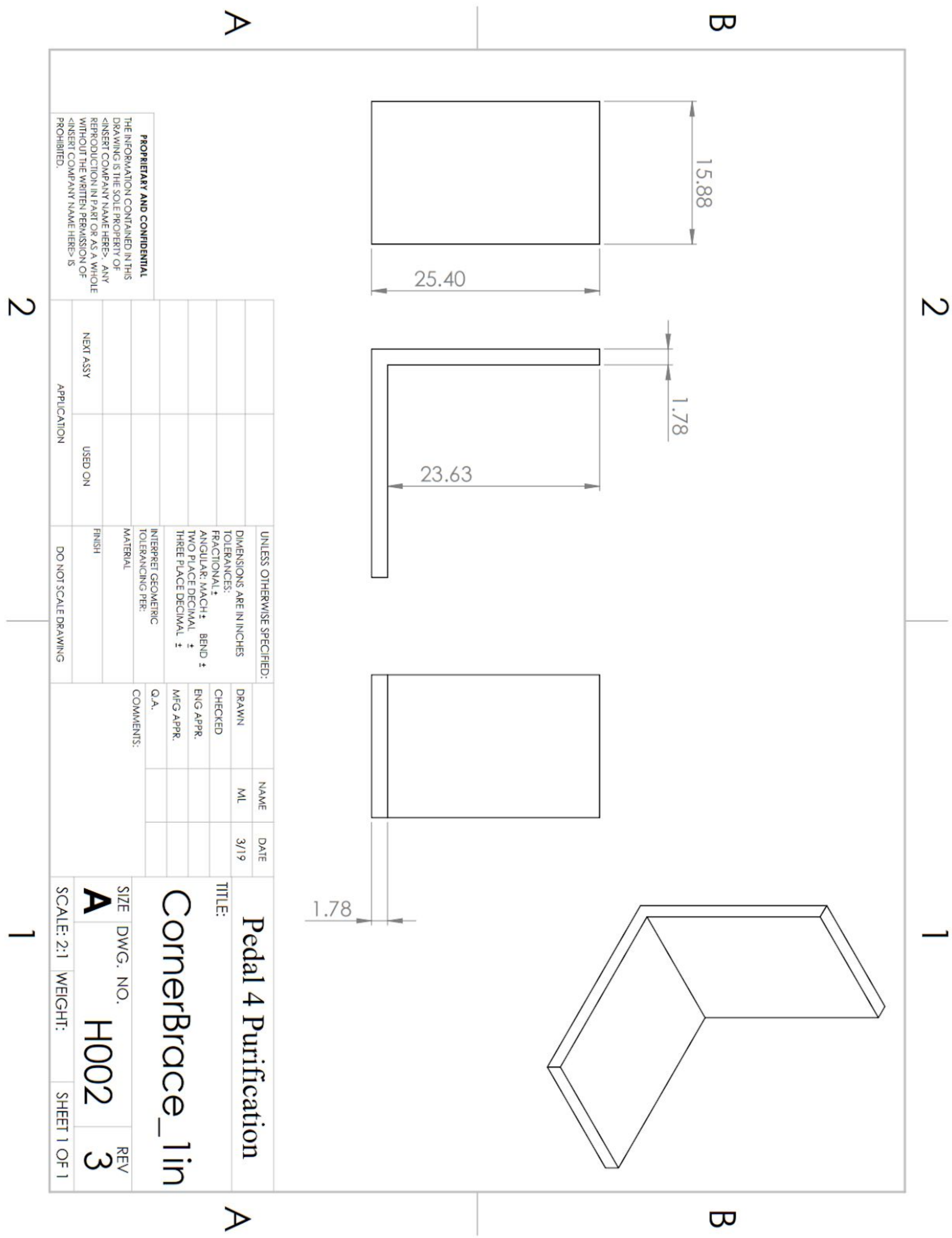
15.88
25.40
1.78
23.63
1.78
PROPRIETARY AND CONFIDENTIAL
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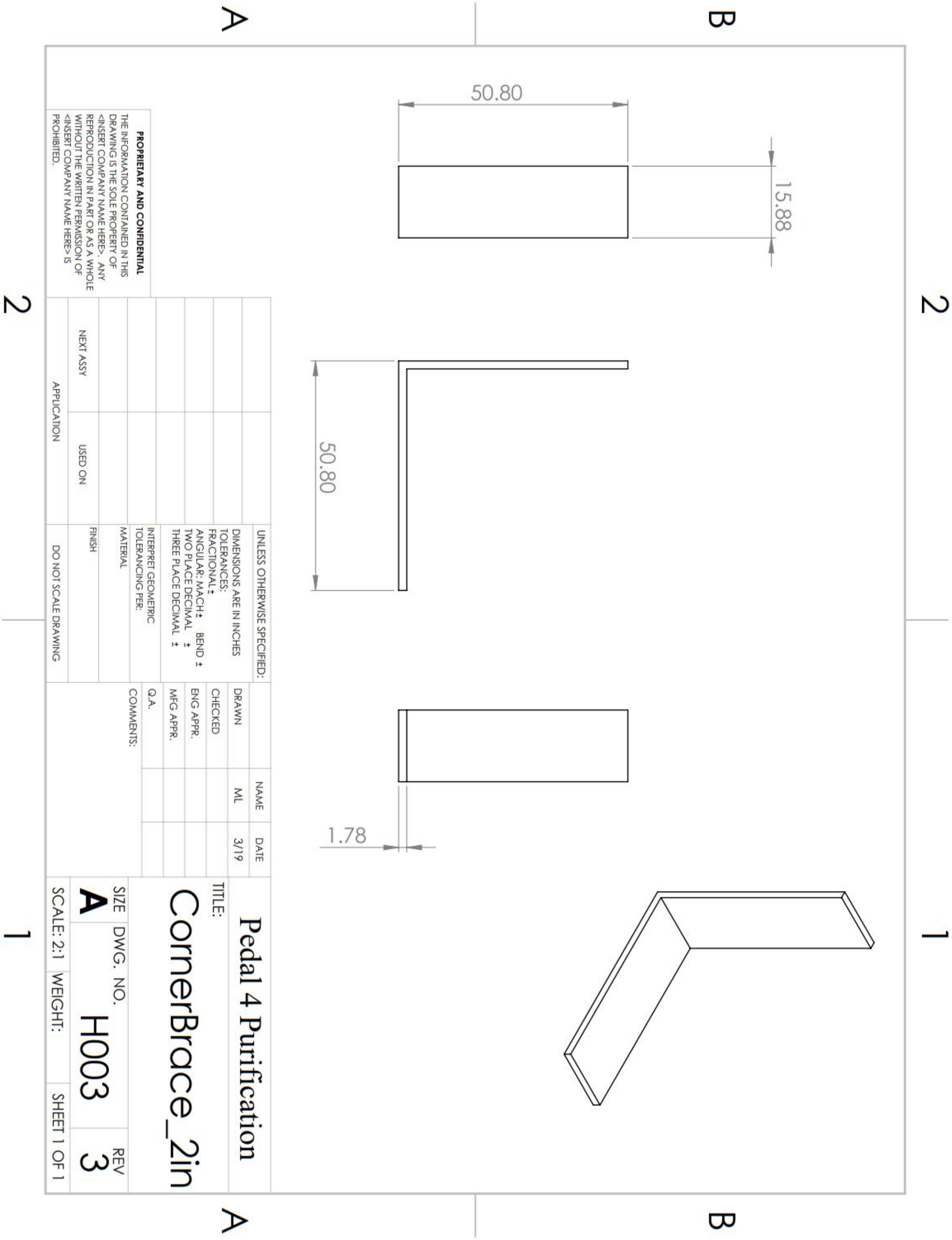
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
ML
3/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Pedal 4 Purification
CornerBrace_1in
SIZE
A
DWG. NO.
H002
REV
3
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
A
B
2
1


A
B
2
1
50.80
15.88
50.80
1.78
PROPRIETARY AND CONFIDENTIAL
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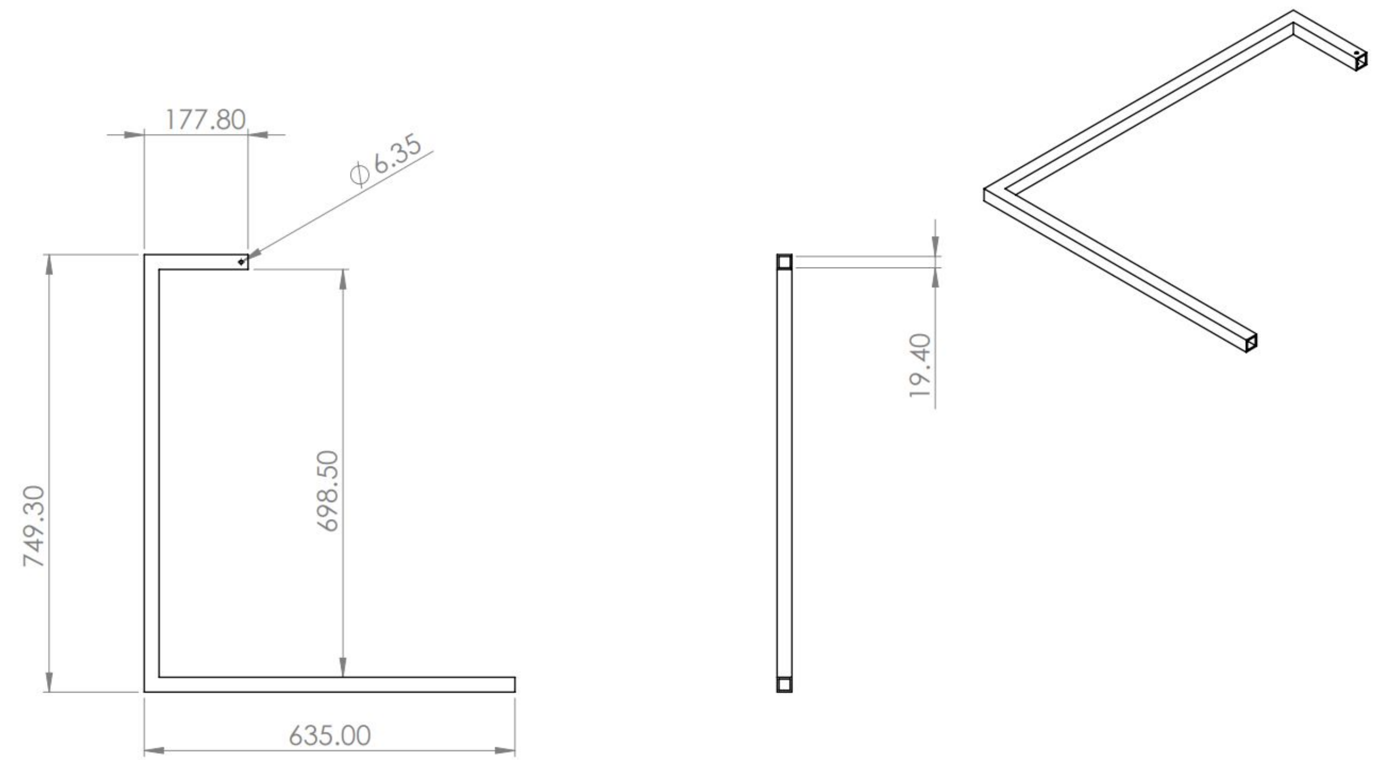
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
ML
3/19
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Pedal 4 Purification
TITLE:
CornerBrace_2in
SIZE
A
DWG. NO.
H003
REV
3
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1



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NEXT ASSY	USED ON	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±		
APPLICATION		INTERPRET GEOMETRIC TOLERANCING PER:		
		MATERIAL Aluminum		
		FINISH		
		DO NOT SCALE DRAWING		

	NAME	DATE
DRAWN	ML	5/1/19
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

Pedal 4 Purification

TITLE: Hitch_2_Bar

SIZE A | DWG. NO. H001 | REV 3

SCALE: 1:10 | WEIGHT: | SHEET 1 OF 1