Cook Engineering Design Center

Final Design Review

Submitted in partial fulfillment of the requirements for

ENGS 90: Engineering Design Methodology and Project Initiation

Street and Sidewalk Sanitation

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Sponsored by

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Executive Summary

The problem identified by our sponsor, Paul Ronzano, is the growing amount of human feces on the streets of San Francisco, caused by the drastic wealth gap and resulting homelessness in the city. Not only is this problem unpleasant for San Francisco residents, but it can also be life-threatening. When waste is allowed to dry, it releases particulates into the air, including viruses such as rotavirus and Hepatitis A, both of which have made a resurgence as a result of this issue. While the most logical approach to this problem is to add more public toilets, that solution would not be feasible due to the limited space available in the city, the expensive and time-consuming process of installing bathrooms, and the limitations on open hours since the bathrooms must be attended to during times of operation. As a result we are focusing on creating a method for removing excrement more effectively than the current approach.

Research has shown a lack of individual products fitting this specific need. The current state-of-the-art involves a mix of multiple machines: pressure washers, steam cleaners, vacuums and other basic cleaning products. We initially tested the viability of multiple options for dislodging the sample including brushing, freezing, burning and pressure washing, the latter being the most effective. For removal, we chose to pursue the vacuum method, as recommended by our sponsor. Our chosen design consists of a vacuum connected to a dome-shaped nozzle placed over the feces for containment. The dome has eight small holes intended to release pressure and allow suction. An additional four holes send jets of water to the contained feces. Both mechanisms work simultaneously to uplift and remove the feces. Tests have been performed to analyze the air flow rate and volumetric rate of water. While we currently have a functional prototype, we are working to streamline the design into an easy-to-use device.

The main aspects to address in ENGS 90 include: the final dimensions of our containment dome, the dimensions of the multiple hoses, the release of aerosols, and the power source. We have devised a course of action that we will follow to succeed in building a functional prototype by February 1st, 2019. Once we have the functional prototype, we will perform final tests before manufacturing and have a functional model by the beginning of March 2019.

The market for our product is small but necessary. Even though we will be focusing our efforts on San Francisco, other cities with significant homeless populations could benefit from our product.

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1. Introduction

1.1 Background

San Francisco's affordable housing crisis has pushed thousands to the streets. With a lack of public toilets and businesses restricting their bathrooms to customers only, the homeless are left with nowhere to relieve themselves [1]. This waste is both unsightly and potentially dangerous. When excrement is allowed to dry, it releases particulates into the air that can carry viruses such as rotavirus and hepatitis A. In San Diego, for example, the city began sanitizing its streets and sidewalks to combat a hepatitis A outbreak that spread among the city's homeless population through contact with human feces [2].

1.2 Problem Statement

The San Francisco (SF) government and Department of Public Works are currently working to rid the city streets of human excrement. The city launched "Poop Patrol," a team of five individuals from San Francisco's Department of Public Works, who use power washers and steam cleaners to rid the streets of feces. The current method of feces removal is inefficient, time-consuming, and does not provide containment of fecal matter.

1.3 Project Need

San Francisco's current sanitation method includes using a power washer to lift feces off the sidewalks and using a steam cleaner on the streets. This method, however, allows the fecal matter to spread and contaminate the surrounding environment. The steam cleaner helps to sanitize the area afterward, but it cannot reach all the places the power washer spreads the fecal matter. This method also requires workers to use multiple pieces of equipment to clean one spot, making it a time consuming process. SF needs an efficient and more effective feces removal and sanitation system to ensure a safe environment for its community.

1.4 Project Goal

The main goal for our project is to create a sanitation system that effectively removes, contains, and disposes of human excrement from streets and sidewalks with a single device that prevents contamination to both the user and the public.

1.5 Objectives and Requirements

The key objectives and requirements along with their corresponding metrics, tests and importance are detailed in Table 1. To avoid bias in our rankings, each group member ranked the requirements individually before averaging the results on a scale of 1 to 5, a 5 indicating highest importance. Our highest priority functional objectives were to remove the excrement and contain the waste during the process. For our implementation requirements, the manufacturability of the design has the highest rank. Safety and reliability of our design are the two crucial constraints.

Table 1: Objectives and Requirements

Categories	Objectives	Requirements	Metric	Test	Importance
Functions	Remove excrement	Leave minimal trace	Remove 95% or more	Complete trade studies	**5.0**
	Complete task faster than SOA	For all consistencies on surfaces	complete <5 minutes	Time each trade study	**3.8**
	Contain excrement until it can be disposed of	Keep waste in controlled area	No spreading past enclosure	Use fluorescent dye to test containment system	**4.6**
		Hold waste for 10 uses	Volume <10 Gallons	Remove 5 samples without disposing	
		Ensure potential aerosols created are contained	Yes/No	Test with fluorescent dye	
	Dispose of collected waste	Easy transfer from device to final destination	1 person can dispose of < 5 minutes	Time how long it takes for one person to complete task	**3.2**
Means/ Implementations	Manufacturability	Reproducible	Yes/No	Make functional prototype	**4.2**
	Power	Capable of supplying 120V, AC power for minimum time	1 hour	Fulfill functional requirements for an hour	**3.2**
	Ease of cleaning	Minimize steps required to clean	1/day; minimal devices/self cleaning	User testing with fake fecal matter	**3.4**
Constraints	Safety	Safe for user and passersby	Yes/No	OSHA regulations	**5.0**
	User-Friendly	Easy for workers to operate	Hours of training to operate <2hrs	Perform testing with prototype	**3.4**
	Portability	One person can transport	<100lb total	1 person moves prototype	**3.8**
	Durability	Meets minimum stress test	>1lb/in impact strength (dome)	Material properties	**2.8**
	Reliability	Successfully removes feces in each instance	<1% failure to remove feces	Test prototype through multiple scenarios	**5.0**

1.6 Deliverables

The primary deliverable for this project is to create an effective street and sidewalk sanitation system that removes, contains, and disposes of human excrement through a singular device. There are three major components for this deliverable: a CAD model, a manufacturing plan to replicate the product, and an operational prototype. Our sponsor plans to demonstrate the prototype to potential manufacturers at the end of ENGS 90.

2. Methodology of Approach

2.1 Research

Through our sponsor's connections to Santa Cruz, we spoke with members of The Santa Cruz Public Works Department, specifically from Environmental Health and Operations. While our project focuses on SF specifically, they gave insights into their current process for feces removal. When compared to SF, Santa Cruz Public Works is less involved in the excrement removal process; the problem in San Francisco is both larger and more publicized than in Santa Cruz. However, Santa Cruz Public Works does perform large-scale cleanups using Vac-Con trucks that have an attached water jet and vacuum hose. In the clean-up process, the operators block off the storm drains, pressure wash the affected area, vacuum the contaminated water back into the truck, then empty the waste into a manhole cover close to the affected area or back at their facilities. At the end of use, the water from the back of the truck is decanted and the remaining solid waste is brought to a landfill. No chemicals are used to disinfect the inside of the tank--they rely on a sprayer to remove the remaining solid waste. We took inspiration from this process in our design. While this method is effective for cleaning up large-scale messes, the members of the public works department acknowledge its limited maneuverability due to the truck's large size and long set up time.

According to the Santa Cruz Environmental Health department, the most effective solution for preventing the spread of disease is to pick up the fecal matter as soon as possible. This decreases the chance of the feces drying and releasing airborne pathogens and also getting stepped in and transferred to other areas. Furthermore, it is futile to sanitize the ground since streets and sidewalks are inherently dirty, and chemicals such as bleach, have negative environmental impacts and kill enzymes necessary for wastewater treatment.

A member of the Operations department gave us some insight into the safety requirements for cleaning up fecal matter. Neither the Environmental Health nor the Operations departments can dictate the process for the removal of these excrements due to liability issues. Thus, the types of personal protective equipment (PPE) used are often determined on a case by case basis. Workers typically wear gloves, eye protection, steel-toed boots or rain boots if working in a trench, and sometimes Tyvek suits. Although OSHA does not regulate how they perform these cleanings, OSHA intervenes if it recognizes that sanitation methods are unsafe to workers or bystanders. With the upsurge in publicity for the issue, containing the feces in the cleaning process is necessary to prevent citations from OSHA. The need for a contained removal method indicates scooping is not the best option.

2.2 Trade Studies and Development of Mechanisms

In order to have consistency between our testing and a more accurate representation of streets and sidewalks in San Francisco, we built a 1.5ft by 1.5ft concrete test setup. To account for a worst case scenario, we created a rougher-than-average concrete slab. (see Appendix A, Figure A.1). We created our own samples that simulated feces using refried beans, peanut butter, and cornstarch. Using a bean-like substance as the base for our samples was recommended to us by Bill Gauley from Maximum Performance, a company that produces fake fecal matter.

Based on our rankings for our objectives and requirements, we conducted trade studies and testing for dislodging, removing, and containing the feces. Before looking at the system holistically, we studied the feasibility of each component separately. A flow chart of our design development can be seen in Appendix A Figure A.2.

2.2.a Dislodgement Mechanism

We explored several methods for dislodging the feces, with results detailed in Table A.1 in Appendix A. We attempted to scrape the samples with brushes and found they were effective at removing dry samples but not wet samples (see Appendix A, Figure A.3). To make our samples drier, we tried using a hair dryer and a freeze spray, both of which were ineffective at changing the sample's consistency (see Appendix A, Figure A.4). We then went to the other extreme: using fire to incinerate the sample. After determining feasibility of this idea through research on incinerating toilets and heat diffusion analysis (see Appendix A, Analysis 1)[3], we attempted to incinerate our fake sample using a propane torch(see Appendix A, Figure A.5). When burned, the excrement was barely scorched, even after being held under a flame for several minutes, proving the idea unviable. Our final dislodging method trial was to use a pressure washer on a contained sample that could be simultaneously vacuumed up (see Appendix A, Figure A.6). The only limitation in this method was aiming the pressurized water: once the water hit the sample, it immediately dislodged the samples and vacuumed them up. Using pressurized water was the only effective dislodging method for all consistencies, and thus is our chosen method.

2.2.b Removal Mechanism

We tested a few vacuums to determine the vacuum flow rate necessary to effectively lift the feces (see Appendix A, Table A.2). We originally tested a 30 CFM/2 HP wet-dry vacuum, which was unable to lift any of the samples. We then tested a 150 CFM/6HP wet-dry vacuum, which picked up all of the dislodged samples. Through testing, we found the 150 CFM vacuum viable, but determined a need for airflow analysis to ensure adequate suction.

2.2.c Containment Mechanism

We determined the shape of our enclosure to contain the feces during the removal process using fluent simulations (see Appendix A, Table A.3). We ran simulations for two possible shapes for the covering: a dome and a rectangle (see Appendix A, Figures A.7 and A.8). We chose to move forward with the dome shape because it had more consistent airflow and a faster inlet velocity than the rectangular shape.

In summary, at the end of the PDR, we decided to contain the sample underneath a dome, using pressure washing as the dislodging mechanism and a vacuum as the removal mechanism. In ENGS 90 we developed our chosen design into four subsystems: power, water, vacuum, and dome.

2.3 Development of Subsystems

2.3.a Power Subsystem

The current system utilizes 120V power. Testing was performed using a wall plug; however, during actual operation, the device will run using a generator located in a support vehicle. Given the vacuum and pump specifications needed for device operation, the minimum power supplied by the generator would need to be 1.4kW. We initially ran these calculations using an assumed maximum power of 4.6kW based on a 6hp motor. However, given the power and voltage specifications on the vacuum motor, it will not use more than 1.2kW. The pump uses 0.14kW. A generator can be sized using Figure B.1 in Appendix B, which presents the weight vs. power of several generators. We recommend the Honda EU2200i as it is the lightest, cheapest generator meeting the minimum specifications.

The viability of going cordless for powering the system was considered throughout the project. For our system, which focuses on retrofitting potential (discussed more in Section 2.6.b), implementing a battery powered solution was not a primary objective. However, the system's portability could be improved by using battery power instead of a generator. An analysis was performed to determine this feasibility. Since existing battery powered wet/dry vacuum systems do not generate sufficient airflow, and commercially available systems are not powered off 12V, a power inverter is needed to increase the voltage off a standard 12V battery to 120V (as well as change the current from DC to AC). A 1500W inverter would be sufficient to meet the power demands of the system. Assuming a maximum current draw of 11.5A from the vacuum and pump combined, and the use of a 12V, deep cycle battery with 120Ah capacity, the battery could provide enough power for 133 runs given an average run time of 28 seconds (See Analysis B.1, Appendix B).

2.3.b Water Subsystem

Based on results from our testing leading to the PDR, we implemented a water system with multiple pressurized jets to dislodge the excrement. Throughout our iterative prototyping process, we modified the tubing reduction to more effectively pressurize the water and adjusted our jet placement to maximize the area hit with the jets. Our initial prototype (see Appendix C, Figure C.2) had four equally spaced jets inserted into our tupperware dome. We used a ⅜" garden hose in the fluids lab and connected it to a four-way manifold. From this manifold, we connected ¼" tubing to ⅛" reducers for the jets. The main issue with this design was that the manifold for the tubing was bulky and the majority of the area under the dome was left untouched by the jets.

We moved away from tupperware and used a 5" acrylic dome, increasing the number of jets to six for our following prototype (see Appendix C, Figure C.3). We moved away from the garden hose, and purchased a 45psi, 3.3 GPM water pump. We first connected ½" tubing to the pump, and reduced the flow to ⅜" tubing. To create the 6 streams, me first split the ⅜" tubing into two streams, then to six, ¼" streams using 3-way splitters (see Appendix C, Figure C.4). We inserted all six jets near the top of the dome and pointed them towards the center. We quickly realized from testing samples that the jets all hit the same place and were ineffective at dislodging samples that were not in the jets' paths. We effectively removed the samples completely by shifting the dome during operation, but realized this was not a reliable method. This prompted us to explore changing the placements of the jet streams to mimic the effect of moving the dome.

In addition to exploring options for varying the placement of the the streams, we decided the 5" dome was too small for larger samples. We used a 7" acrylic dome and nine jets for our following iteration, increasing the number of jets to compensate for the larger area under the dome (see Appendix C, Figure C.5). We adjusted our tubing to split into three streams of ⅜", which then split into three ¼" streams each, resulting in nine jets. We kept the ⅛" reducers the same for the jets (see Appendix C, Figure C.6 for tubing layout). We set our angles such that the majority of the center was hit with jets, with five jets inserted around the top of the dome and the remaining four closer to the base of the dome. The bottom jets were evenly spaced and aimed towards the outer rims of the contained surface, to get under the samples. Although this model worked for some samples, it was unreliable since the jets still could not access some of the outer areas of the dome.

For our fourth prototype, we kept the same jet arrangement as in prototype 3, but added a swivel plate at the bottom to maximize the area hit by the jets (see Appendix C, Figure C.7). After testing, many of the jets were still hitting the same spots within the dome because they were all placed tangent to the spherical surface. We determined a need for a better method of securing the jets and further experimentation with their placement, as hot gluing the ⅛” reducers was both time consuming and inconsistent. We used geometry and Matlab to determine the angles that would maximize the surface area covered by jets, utilizing our new swivel feature that allowed the jets to sweep out concentric circles. Our Matlab code approximated a logarithmic scale to create concentric circles within the dome (Appendix D, Calculation D.1). Figure 1 shows the path of the jets when swiveled.

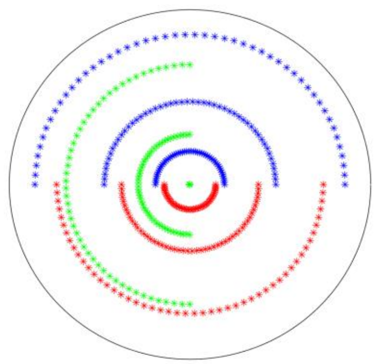

Figure 1: Colored lines show the path of each jet when the dome is swiveled 90° each direction.

Our fifth prototype was modeled using Solidworks with our designed angled faces and then manufactured using a thermoform (see Appendix C, Figure C.8). To improve our previous method of gluing the reducers to the dome, we incorporated through-wall 5/32” fittings that tightened with nuts (see Appendix C, Figure C.9). We tapped the through-wall reducers with ⅛” NPT and screwed on ¼” elbows NPT fittings to connect to the tubing. After testing, we learned the angles were highly efficient in covering the maximum surface area, but highly inefficient in fully dislodging the samples because of insufficient velocity of the water jets. We considered installing a stronger water pump, but determined that further reduction could achieve the necessary pressurization.

For our final prototype, we adjusted the tubing and the size of the exit jets (see Appendix C, Figures C.10.a and C.10.b). We kept the through-wall jets for installation, removed the ¼” elbows and instead flipped the orientation of the 5/32” fittings. We reduced the ¼” tubing with reducer fittings that connected to 5/32” tubing, and used 1/16” NPT fittings that screwed into the tapped through-wall fittings. Figure 2 below demonstrates the tubing configuration. The changes in cross sectional areas allowed us to optimize the water jet velocity to 3.4 m/s and proved sufficient throughout final testing. See Appendix C Table C.1 for a summary of the prototype descriptions.

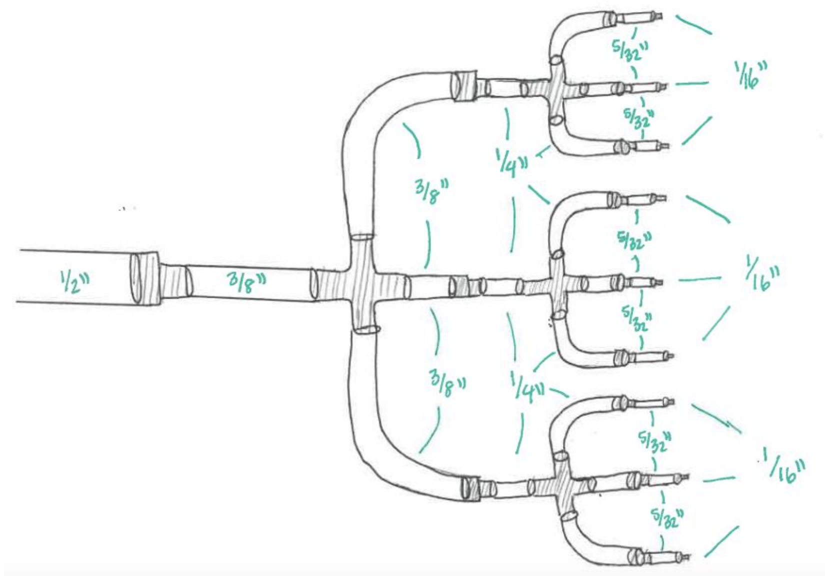

Figure 2: Tubing configuration for final prototype. ½" initial tubing is reduced symmetrically into nine 1/16" jets generating exit flow speed of 3.54m/s.

2.3.c Vacuum Subsystem

In our initial rounds of testing before the PDR, we determined that our system requires a 150 CFM vacuum to remove nearly all samples. All commercially available 150 CFM vacuums must be plugged into a wall outlet or a generator on a truck, thus limiting the portability of the device. At 80 CFM, the strongest cordless wet-dry vacuum we could find was the Ryobi 18-Volt Cordless Wet/Dry Vacuum. Keeping all other variables constant, we found that the cordless vacuum was not strong enough to completely remove most samples. We concluded that a chosen vacuum must deliver a minimum 150 CFM air flow to provide effective results.

Another consideration when testing the vacuum was the release of aerosols. When we initially ran the wet-dry vacuum with water and samples, water sprayed out the vacuum outlet tube, carrying aerosolized peanut butter, beans, and cornstarch. To combat this, we incorporated a wet application foam filter into the vacuum. To test the effectiveness of the filter, we put blue food coloring into the water tank, ran blue water through the device, and held a white coffee filter over the vacuum outlet. After running the system, the coffee filter showed no signs of blue dye or particulate matter (see Appendix E Figure E.1). We also tested this with fluorescent dye by incorporating the dye into the samples, running the system, and observing the vacuum outlet under a UV light (see Appendix E Figure E.2). No fluorescent dye was observed in the outlet or on the water tank, suggesting that no aerosols escape from the vacuum outlet when the foam filter is used. Currently, there are no available HEPA filters for wet pickups. Without a HEPA filter, there is a risk of aerosol release invisible to the naked eye. Viruses typically travel on small droplets or dust particles [4], meaning they potentially fit through the foam filter. If there is a concern for these potential aerosols released in the vacuuming process, N100 and P100 respirators, recommended by the CDC, can be worn. These masks block against 99.97% of particulates in air, and according to the CDC provide "superior protection" against contagious diseases [5].

2.3.d Dome Subsystem

As touched on in Section 2.3.b, we made multiple iterations of domes with each design improving upon either the jets, air flow, or both. For the PDR, we developed a works-like system using a tupperware dome and hose-attached pressure washer (see Appendix C Figure C.1). The dome iterations in ENGS 90 were informed largely by Fluent simulations which predicted the flow properties within the dome, as determined by air hole size, number and placement. Water jet placement further drove changes to dome geometry.

The second prototype used a 5" diameter acrylic dome (see Appendix C.3), which was too small for the average sample size, but gave us a better understanding of the suction requirements for sample removal. Once we demonstrated functionality at a 5" diameter, we increased the enclosed area to increase its capability for larger samples. However, as the enclosed area increased, it became more difficult to generate the suction needed to remove the samples. We attempted to optimize the dome's functionality at a 7" diameter because simulations showed that a larger dome would lack the sufficient airflow and suction to remove the sample (See Figure A.8, Appendix A). This constraint led to the use of 7" domes for the remainder of prototypes.

With its size chosen, our focus shifted to the flow properties within the dome. We analyzed the flow through Fluent simulations and tested experimentally, iterating between the two to determine optimum air hole placement for maximum suction. Prototypes 2-4 used ½" air holes on the side opposing the suction, with ¼" holes closer to the point of suction. These holes were spaced about 2" apart and located as the base of the dome. The flow simulation found in Appendix A Figure A.8 shows that this air hole placement develops high air speed and suction into the vacuum. The success and strong suction of prototypes 2, 3 and 4 confirmed the simulation results for the rounded domes (Appendix F Figures F.1, F.2, F.3).

In Prototype 4, the dome was mounted to the outside ring of a bearing, which swiveled around an inner bearing with weather seal applied to the bottom, forming an airtight seal along the ground, as seen in Appendix C Figure C.7. While this prototype was successful, it created a lip on the inside of the dome where sample would occasionally catch during testing. We concluded we needed to attach the dome to the inner bearing and mount the weather seal to the bottom of the outer bearing. This eliminated the lip found on prototype 4.

Up to and through the development of prototype 4, we used pre-made acrylic domes, which we modified by drilling and dremeling jet and air holes. While this approach worked well, we were unable to obtain precise jet angles. Once the angles were calculated, as discussed in section 2.3.b., we created a Solidworks model (Appendix F Figure F.4) for a dome mold that could be milled out of wood using the Shopbot (Appendix F Figure F.5). We used the mold to thermoform our dome out of ⅛" PETG plastic, which is much stronger than acrylic and has 70% of the impact strength of polycarbonate [6]. This dome design created two main problems that impacted the dome's suction ability (see flow model in Appendix F Figure F.6). First, due to minor ridges found in the thermoformed plastic, we were unable to obtain a complete seal between the metal bearing and plastic dome. Initial testing revealed a drastic reduction in suction compared to previous prototypes. To overcome this issue, we added a gasket between the dome and the bearing, preventing the air loss which was causing the lack of suction. After making this change, the prototype still had inadequate suction. The vacuum was run without jets, and pea-size pieces of sample were placed without mushing underneath the vacuum nozzle. The vacuum did not suck up the samples underneath the dome, and instead were pushed to the edges.

To improve suction, we considered the placement and size of the air holes, and the effect of the angled jet mounts. We performed experimental and modeling software testing to determine improved functionality. Experimentally, additional holes were drilled, with previous ones covered up with tape to determine if the hole placement could be altered to improve suction. We simultaneously ran Fluent simulations to test the hole size and placement changes and compared them to the baseline model that worked in the past. One of the main issues identified through simulation was the creation of dead zones, areas with zero or minimal airflow, in the modified dome design. This was partly a result of using larger, more spaced out holes, and was exacerbated by the bearing that raised the dome by 0.4", lifting the air holes farther from the ground. To solve this problem, we implemented smaller, more tightly spaced holes that were tangent to the bottom face of the dome. In both experimental testing and simulations, this improved the results, but did not entirely solve the suction problem.

We then studied the effect of the jet and vacuum wand mounting faces on the dome's suction. To compare the effect of the faces on the dome, we used modeling clay to cover the faces and bring the inside back to a more spherical shape (Appendix F Figure F.7). The suction was most dramatically improved when the clay was added to the indented surface behind the vacuum wand mount. Comparing simulations run between a completely spherical dome and our specially designed dome, both with the larger, more spread out holes from the previous prototypes, revealed what experimental testing had shown--the vacuum tube mounting face had a large impact on suction. Simulations were analyzed quantitatively to maximize flow speed and qualitatively to eliminate dead zones and turbulence.

To eliminate the problems found on the initial molded dome, we machined the vacuum wand mounting face to be approximately ½" closer to the spherical dome than in the original mold. We drilled four ½" air holes at the far side of the dome (away from the suction), each with 1.5" spacing. We spaced fifteen ¼" air holes every inch around the rest of the dome. All the holes were drilled tangent to the bottom of the dome. This fully constructed dome became our sixth and final prototype. After re-running tests, as seen in Figure F.2 in Appendix F the dome now had the desired suction and airflow properties, while keeping the faces to mount the jets.

2.4 Streamlining Design

After finalizing and integrating our four separate subsystems, we streamlined the design to make it more user friendly and aesthetically appealing. Initially, the tubes coming out of the dome were bulky and could easily snag due to the elbow nozzles which extruded an inch out of the dome. Consequently, we reduced the size of the bundle of tubes by switching from the elbow nozzles and ⅜" tubing to straight nozzles and 5/32" tubing. The nozzles no longer stuck out of the dome as far and the smaller, more flexible tubing could be bent along the shape of the dome and vacuum nozzle (see Appendix C Figure C.8).

After reducing the overall size of the tube bundle, we created a cover for the tubes to keep them in place and further prevent them from snagging. We considered both a soft cover and a hard cover. The soft cover featured black cloth that wrapped around the tubing and vacuum nozzle and could be secured by a zipper. The hard cover featured a thermoformed piece of plastic resembling a visor that clipped onto the vacuum nozzle and shielded the tubing. Due to time and resource constraints, we chose the soft cover as it was simpler to use and to manufacture. While we used cotton fabric, this would ideally be made of a waterproof fabric, such as polyurethane-laminated rip stop nylon, in the future.

2.5 Final Prototype Testing

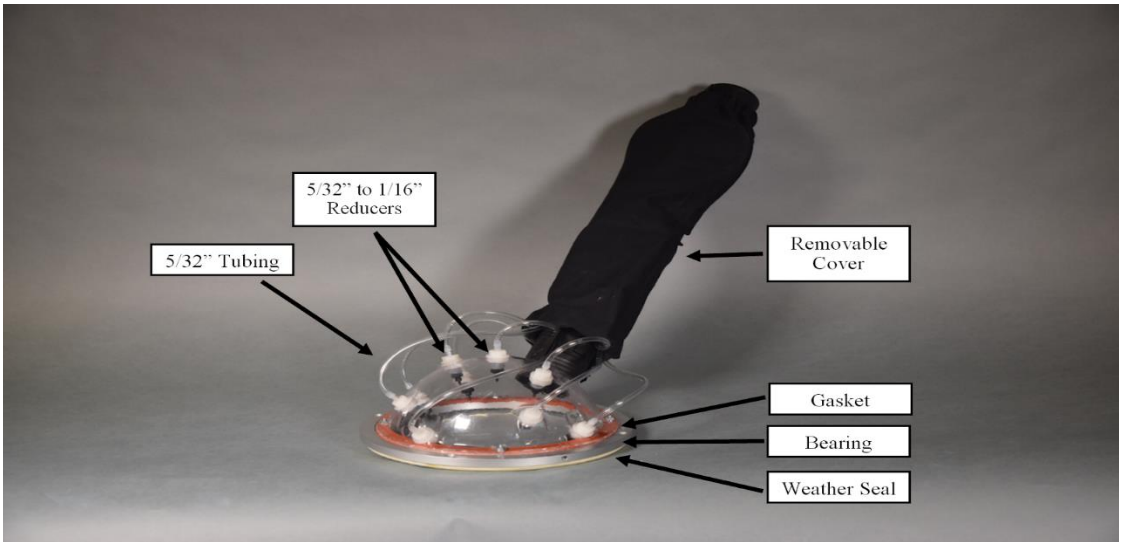

Figure 3: Final prototype (prototype 6), labeled

Our final design features a 7.5" thermoformed PETG (polyethylene terephthalate glycol-modified) dome with nine 1/16" nozzles, four ½" air holes, fifteen ¼" air holes, and one 2" inner diameter vacuum nozzle inlet. Each nozzle connects to 5/32", ¼", ⅜", then ½" PVC tubing fed by the pump. The water at the nozzles jet out at 3.54 m/s. The entire dome is mounted on the inner ring of a 10-inch (outer diameter) aluminum bearing. A gasket between the dome and the bearing creates a tight seal. The base of the outer ring is also lined with rubber foam weather stripping to create an airtight seal against the pavement as seen in Figure 3 above.

We conducted three separate tests on our final dome: an artificial feces test, a fluorescent dye test, and a dog poop test. For the artificial feces test, we made 19, 0.1-kg samples of the peanut butter-refried beans-cornstarch mixture to simulate human feces. We then placed four samples outside Thayer on the loading dock and left them to dry overnight. The other 15 samples were tested on our concrete slab. 10 samples were "stepped on", while the remaining 5 were smeared (see Appendix G Figure G.1 and Table G.1). The testing revealed that our solution was effective for removing feces in multiple scenarios, with an average run time of 28 seconds and a water usage 0.64 gallons for "stepped in" samples, 49.4 seconds and 1.2 gallons for smoothed samples, and 79.3 seconds and 1.4 gallons for dried samples.

Next we added fluorescent dye to our samples to see more clearly how much (if any) residual sample remained after running the device. As seen in the before and after pictures found in Appendix G Figure G.2, testing with a black light revealed no sample was left on the testing block after the system had been run. Additionally, no particulate was found on the inside of the dome or suction hose.

For our final test, we used dog feces instead of artificial feces. We obtained feces from a large black lab to simulate a worst case scenario. We placed the feces on the concrete slab, covered it with a plastic sheet and stepped on the sheet, poured liquid dish soap on it, then placed our device over it, and ran the device. The concrete slab was completely clean in 48 seconds. To clean the dome, we poured soap on the concrete and ran the dome for 20 seconds, after which it was fully clean (see Appendix G, Figure G.3).

2.6 Implementation

Considering our main objective for the project was to contain and remove feces from the streets and sidewalks of San Francisco, our efforts were focused on the design and testing of the dome and jets. Because our purchasers will most likely be companies that already have cleaning equipment, we designed the prototype to be retrofittable. We plan to provide the dome, nozzle, jet tubing and cover while the consumer can reference the required specifications and determine if any new equipment is necessary (See Appendix H, Table H.1).

2.6.a Cleaning and Odors

Some important considerations when using this system are the odor of the waste tank and the method of cleaning for the device. We researched odor reducers and brainstormed three potential methods for odor control including NilOdor brand products, Potty Fresh Plus products, and soap (see Appendix H, Table H.2). The NilOdor and Potty Fresh Plus products consist of chemicals with various functional groups that react with odorous molecules, changing their shape and making them incapable of fitting into nasal receptors[7][8]. We added NilOdor to the vacuum during our testing on dog excrement and it neutralized the smell. The application of soap to the excrement before removal serves to clean the dome and fittings during the pickup. This does not neutralize the odor, however, so it is recommended that soap is used in conjunction with another deodorizing method. Considering this could be an unpleasant issue if not properly addressed, we recommend using the NilOdor.

2.6.b Retrofitting Potential

Our product can be assembled using various vacuums, pumps, water tanks, etc., that meet the specifications of the system. There are recommendations of products and assembly instructions in our User Guide (Appendix J). Those specs include a minimum of 150 CFM wet-dry vacuum and a minimum of 3.3 gallons/min, 45 psi pressure pump. The vacuum can range in size from 10 to 20 gallon tanks and depending on the amount of runs the consumer wishes to accomplish, we recommend between a 5 and 15 gallon water bucket respectively to accompany the vacuum. Our assembled prototype uses a 45 psi pressure pump, a 150 CFM, 14 gallon vacuum, and a 13 gallon water storage.

2.6.c Risk and Mitigation

Provided users know the dimensions of their vacuum and water tank, they should buy a wagon or other holding device. With San Francisco's hilly geography, the wagon's wall height must be at least halfway up the heights of the vacuum and water storage tank and must tightly fit both devices to prevent them from toppling over. Brakes should be implemented to stabilize the cart and ensure safety during use.

There are risks associated with the pump being electric. We considered incorporating a switch to control the pump, but shied away from this idea due to the risk of electrocution. Instead, we used an Air Actuated Foot Switch to operate the pump[9].

Because the tubing attached to the jets does not sit flat on the dome/vacuum tube, snagging is a risk. We considered putting a cover over the dome and vacuum want; however, we decided the dome's transparency outweighed the risk of snagging since it allows the user to determine when the waste is fully removed. Instead, we covered the dome starting at the base of the vacuum wand to reduce snagging further up from the dome.

Since human feces are a biohazard, we highly recommend the use of gloves. Optional equipment includes goggles and face mask as precautionary measures. We also propose, if possible, that the user should empty the waste at a wastewater treatment plant. If this is not possible, it can be disposed of at the nearest sewage drain.

3. Deliverables

3.1 CAD Model

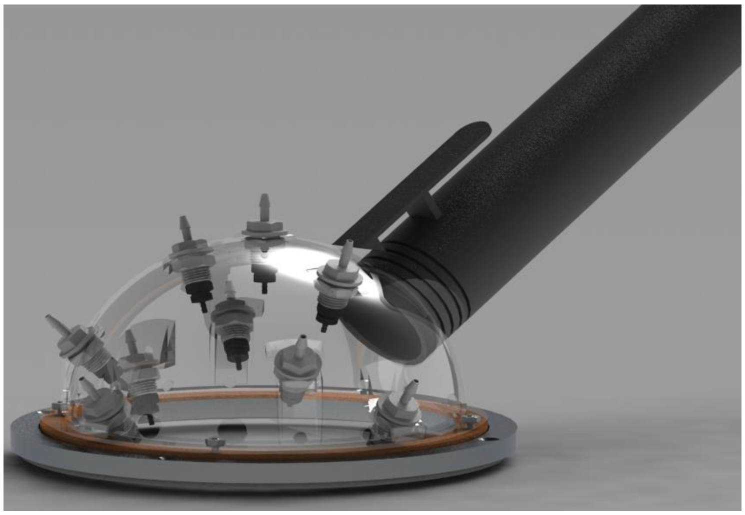

Figure 4: Rendering of final CAD model, without tubing.

3.2 Manufacturing Plan

To manufacture the dome, we first used a shopbot to make a wooden mold from our CAD model. We then thermoformed the mold using ⅛" clear PETG plastic. We cut out the mold from the excess plastic and used a drill to make the holes their appropriate sizes. We tapped 5/32" fittings with ⅛" NPT. We then tightened the fittings onto the angled faces of the dome with the nuts. We screwed on 1/16" NPT fittings onto the tapped 5/32" fittings for the jets. For the swivel plate, we used a weather seal at the bottom, added a rubber gasket to the inner plate, and secured the dome in place. Finally, we glued the vacuum wand onto the dome. A detailed description of our final bill of materials and manufacturing plan can be found in Appendix I.

3.3 Final Working Prototype

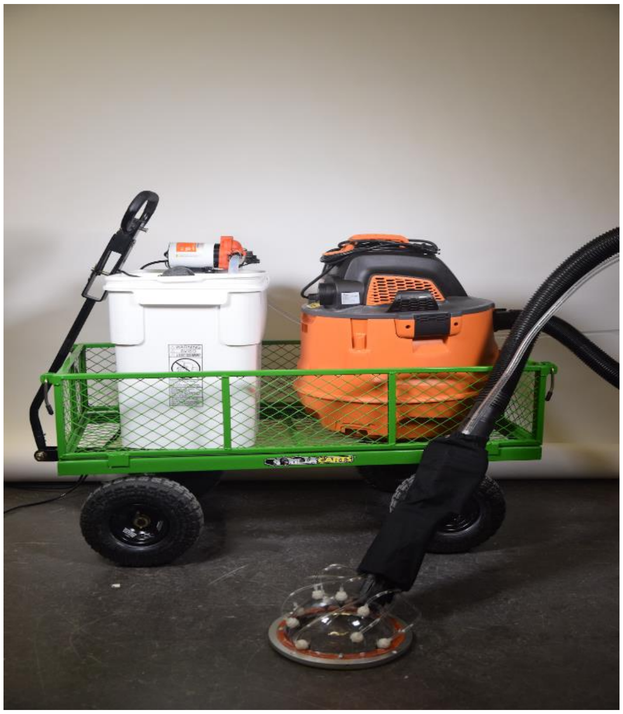

Figure 5: Fully assembled functional system (vacuum, tank, pump, cart head).
(See section 2.5 for explanation and analysis)

4. Economic Analysis

The human feces issue in SF creates a two-fold economic problem: spending on cleaning programs and initiatives increases while negative externality costs arise from the public outcry and potential health issues. In response to the public outcry about the "cesspool"[10] that is the streets of SF, new mayor London Breed has taken direct action to improve their cleanliness. As mentioned in the Introduction section, a new task-force, colloquially termed the "Poop Patrol" was created in September to proactively clean up the human feces before residents called to report them. Over $800k has been dedicated to fund the "Poop Patrol". An additional $1M was allocated to improving the Pit Stop toilet program, and $3M to fund a "hot spots" crew, focused on cleaning up areas around prominent homeless encampments [11]. While it is too soon to judge the effectiveness of these measures, their necessity is clear. SF has increased its street and sidewalk sanitation budget from $33M in 2012-13 to $65M in 2017-18 – and it plans to add $13M to its budget over the next two years [12]. However, over this same period, the number of 311 calls has continued to rise (see Appendix K, Figure K.1) [13].

Increased spending to clean the streets could represent just a small fraction of the overall cost associated with the problem. The negative externalities – loss of tourism, decline of local business, and outbreak control, all carry significant economic costs that should not be ignored. San Francisco boasts a $9B+ tourism industry, supporting over 80,000 jobs [14] and saw over 25M visitors in 2017[15]. Convention spending, accounting for $2B of this industry, has seen a decrease in revenue over the past 4 years. In a recent interview, Joe D'Alessandro, president of the San Francisco Travel Association, said that for the first time a conference directly cited the "dirty streets" as their reason for withdrawing from future events in San Francisco. The loss of this convention, which brings in 15,000 attendees, is also the loss of the $40M in business it brings in each visit [16]. In addition to the effects on the tourism industry, vacant storefronts are rising in SF, and commercial real estate brokers say that many large business clients are citing the condition of streets as the reason for choosing other locations, saying "how can you operate like this?"[17] The loss of large businesses, though not directly measured, would hit hard on San Francisco's economy.

A final negative externality from the persistence of this problem is the cost associated with potential disease outbreaks. San Diego was the epicenter of a recent Hep A outbreak. According to the San Diego County's After Action report, the outbreak cost almost $13M [18] – it also killed 20 people and hospitalized over 400, a cost that cannot be monetized. If the unsanitary streets of San Francisco cause an infectious disease outbreak such as that which occurred in San Diego, it could very easily cost millions in the tightly packed city.

The current solution to the feces issue, steam cleaners and pressure washers, each cost between $700 and $1500. Our product, which would consist of the configured dome and tubing, costs about $318, excluding accessories and including materials and labor, to produce with our current process. This could be decreased to about $243 per unit if we invested in an injection mold to produce the dome, which has an upfront cost of about $15,000[19]. If we sold the dome at a price of $500, we would need to sell 60 domes to "break even" and start gaining a profit from the injection mold and 204 domes to make the injection mold more profitable than thermoforming (see Appendix K, Figure K.2). The buyer would connect their own vacuum and water pump to the dome, provided they meet the specifications listed in the User Guide (see Appendix J). With a cost of around $120 for a vacuum[20], $260 for a pump[21], $100 for a wagon[22], and $500 for our dome, the total cost of the system comes out to around $980(see Appendix K, Table K.1). The powering mechanism, either a generator or battery and inverter, would cost an additional $1,000 or $240, respectively [23][24][25], making the total cost $1,980 or $1,220. These are roughly comparable to the less effective pressure washing and steam cleaning systems. Beyond purchase cost, the solution will have variable costs of labor and maintenance. "Poop patrol" members are currently paid over $150k (including benefits) a year. Given our end user, public municipalities, the slight price difference between the state of the art and our proposed solution is not an issue. Rather, other specifications, notably effectiveness and time to use, are much more important drivers. Our product will be improving the quality of work for the poop patrol members.

We are focusing on the issue as it relates to San Francisco; however, this is not a problem localized to SF. Other American cities, such as Miami, have dealt with the problem at smaller magnitudes, grappling with how to remove human feces [26]. Highly populated and impoverished cities like Mumbai, India lack proper sewage systems and require private contractors hired by the government to employ workers to remove the waste [27]. For this niche application, the market size will remain in the hundreds even if more cities begin facing homelessness crises like that in SF. A given city would not need more than a few of these devices. We do expect our device to be adaptable to other industries and applications, such as cleaning up bird droppings and dog feces--allowing the product to generate a market presence between 500 and 1000 devices, in which case, the domes would be injection molded (see Appendix K, Table K.2 for assumptions) [28][29][30][31]. A portable device that effectively removes a contaminant and cleans the area would be valuable in janitorial services, currently a $60B industry [32]. Zoos, national parks, and remediation service companies present further market opportunities. We could generate a profit of around $113,000 from selling 500 domes and $242,000 from selling 1,000 domes. We could also lower the material costs associated with the dome by buying in bulk, which would increase our profit.

5. Recommendations for Future Work

The final prototype is a fully functioning model. The modifications outlined below improve appearance and user experience without altering the functionality of the device. To further streamline the tubing, we designed custom 3-way splitters. Unfortunately, these did not fully resolve the streamlining issue but are nonetheless an improvement. Using angled splitters will direct the tubes more uniformly down the vacuum hose (see Appendix H Figure H.1). Additionally, while our tubing cover does prevent snagging and improve the device's appearance, improvements can be made. In the future, we would like to include a waterproof cover with increased durability.

Another aspect that would improve our product would be to add a clip lock to secure the vacuum wand to the dome, eliminating the need for glue. Injection molding would make this possible, but as explained previously, it would only be feasible with a large market. We could make the dome further retrofittable by offering domes compatible with a range of vacuum nozzle diameters so the consumer could choose a dome based on their existing vacuum.

While our current final design is easy to use and effective, the user must lean forward and hold the vacuum tube at a low angle to operate the dome and get the dome face flat on the pavement. Adding a handle would make the product more ergonomic.

Having a smooth interior for the vacuum would help the cleaning process of the tank. Since the consumer could use their own vacuum, we propose either inserting a mesh screen or slip to keep the solid pieces above the liquid, making it easier to discard the waste and prevent it from getting caught in crevices within the tank during drainage.

Overall, the determining factor of many of these aesthetic improvements are down to market size. All of the restraints on implementing these changes to the prototype are determined by potential profit.

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Appendices

Appendix A: Trade Studies/Testing

Figure A.1: 1.5'x1.5' test setup made out of 2x4s, plywood, and extra strength concrete. Surface has varied smoothness to replicate varying conditions found on city sidewalk.

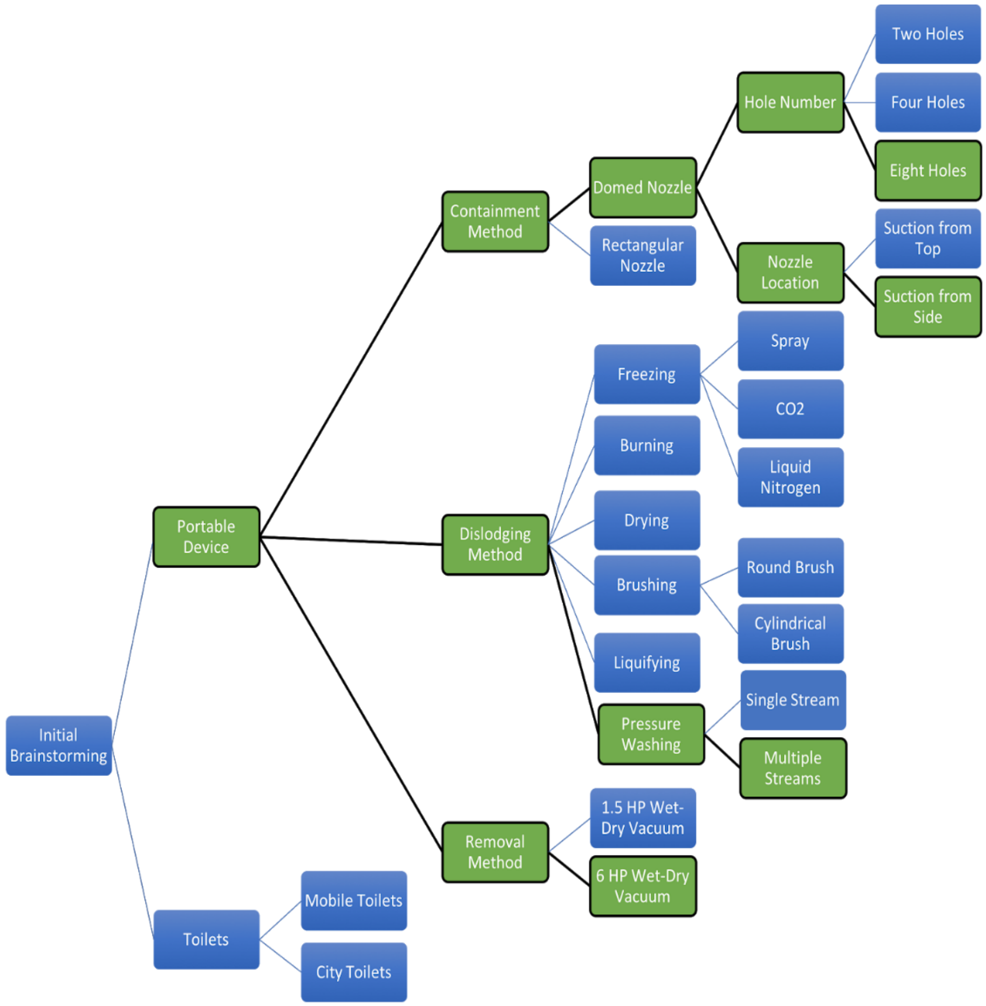


Figure A.2: Initial Design Development Tree. Green boxes detail decisions made during ENGS 89 that lead to design solution.

Table A.1: Summary of Trade studies from Engs 89

Dislodging Method	Trade Study/Test	Results
Brushing	Use brush attached to drill to dislodge wet and dry samples from testing setup	Effective on dry samples but not wet samples
Freezing	Use freeze spray to solidify sample	Cooled sample, failed to freeze it
	Use CO_2 or Liquid Nitrogen to solidify sample	Safety concerns too high (pressurized gas is dangerous to transport; cold temperatures could cause frostbite) [12]
Burning	Use propane torch to incinerate wet and dry samples	Fire failed to incinerate feces
	Determine time necessary for ground to cool off with simulation	Heated area should cool within 5-10 minutes
Drying	Use hair dryer to dry wet sample	Hair dryer failed to dry the sample
Power Wash	Use power washer to dislodge wet and dry samples from test set up	Successfully lifted samples from testing slab

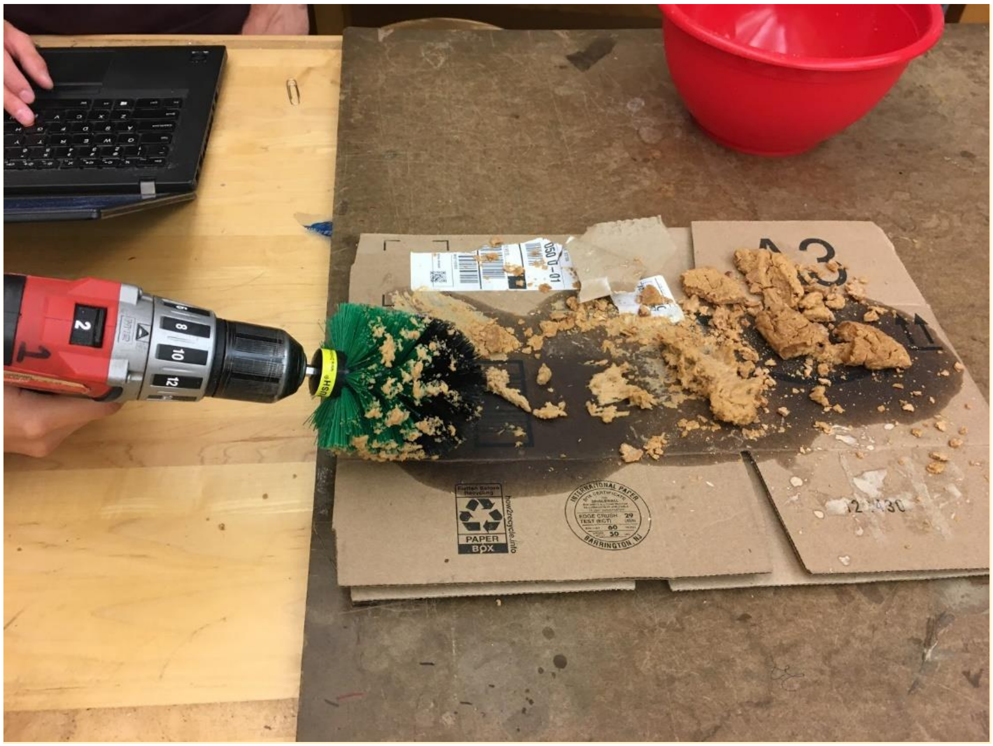


Figure A.3: Testing removal of wet sample using cylindrical brush attached to drill.

Figure A.4: Testing freeze spray to solidify sample. Sample was chilled but did not freeze and spray left a liquid residue.

Analysis A.1: Heat Diffusion Analysis

One concern of burning the feces is the amount of time would take for the concrete to return to a safe temperature. For this analysis it was assumed that the container covering the excrement has perfect insulation and the heat is only being lost to the concrete. This estimate is conservative because some of the heat will be lost through the container.

In order to estimate this time, a Gaussian solution to the heat equation was used. The following is the general form of the equation[33]:

$$T(x,y,z,t) = \frac{T"}{(4\pi t)^{3/2}\sqrt{D_x D_y D_z}} e^{-\frac{1}{4t}(\frac{x^2}{D_x}+\frac{y^2}{D_y}+\frac{z^2}{D_y})}$$

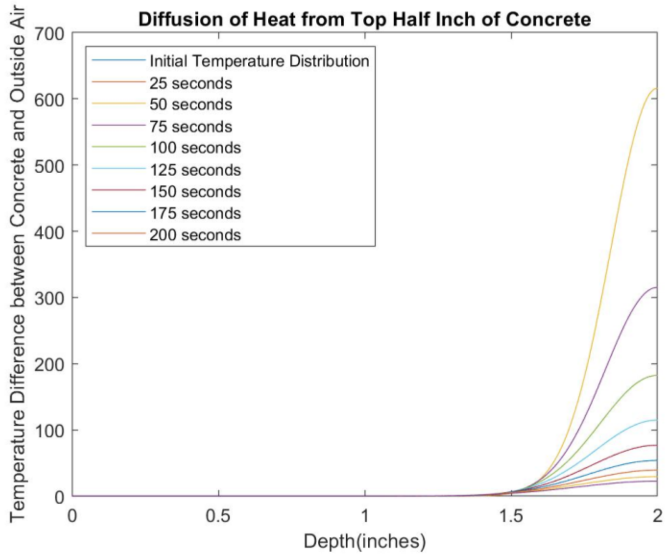
(*This equation was taken from the National Programme on Technology Enhanced Learning in India)*

In order to simplify the analysis, the rate of diffusion is assumed to be the same in the x, y, and z directions since it is surrounded by concrete on all sides. Therefore, x=y=z and $D_x = D_y = D_z$. With these assumptions, the following is the modified equation:

$$T(x,y,z,t) = \frac{T"}{(4\pi t D)^{3/2}} e^{-\frac{3x^2}{4Dt}}$$

This equation was plotted over time in Matlab. The following assumptions were made:

1. The actual time required for the heat to diffuse will be two times larger than estimated by this solution since it is only able to diffuse through the bottom half of the space.
2. The initial width that is at the hot temperature is 0.5 inches, which represents the depth of the concrete at the high temperatures. This is controlled by adjusting the initial time the simulation is started at. A width of 0.5 inches occurs with a starting time at 100 seconds.
3. The initial maximum temperature difference of around 600 degrees Celsius was obtained by adjusting until the temperature maximum was at that height.



The graph is of the diffusion in only a single direction, but it would be the same in all directions starting from the heated portion of the concrete. From here we can estimate the order for the amount of time it would take for the heat to diffuse to a safe level. The temperature difference goes down to about 20°C after 200 seconds, or 3.3 minutes. Assuming the air temperature is around 21°C, the temperature on the ground would be around 43°C, which is hot but will be quickly cooled off by the air. Doubling this time to account for the concrete being on only one half of where the heat is applied gives an estimate of 6.6 minutes. Since conservative estimated were used for the assumptions, it is safe to say it would cool in less than 10 minutes.

The following is the Matlab code used to generate the plot:

```
%Gaussian Heat Diffusion Analysis

width = 2 %inches, far enough down into concrete to assume it remains cooled

x= linspace(0,width,10000)
t= linspace(0,200,9)

%constants for concrete
density= 2400 %kg/m^3
cp= 850 %J/(kg*K), range of 0.75-0.96
k= 0.5 %W/(m^2*K)
D= k/(cp*density)
```

```
Tprime= 0.000000009 %T prime required for beginning temperature difference
between spot where heat was applied and ground

%for loop for plotting temperature distributions over x for different times
for i=1:length(t)
T= Th/((4*pi*(t(i)+100)*D)^3/2)*(exp(-3*((x-
width)*0.0254).^2/(4*(t(i)+100)*D)));
plot(x,T)
hold on
end

%Code for plot
 title('Diffusion of Heat from Top Half Inch of Concrete')
axis([0 2 0 700])
xlabel('Depth(inches)')
ylabel('Temperature Difference between Concrete and Outside Air')
legend('Initial Temperature Distribution','25 seconds','50 seconds','75
seconds','100 seconds','125 seconds','150 seconds','175 seconds','200
seconds','location', 'Northwest')
```

Figure A.5: Sample being burned with propane torch outside of Thayer. The torch scorched the top of the sample but never caught on fire.

Figure A.6: Using pressure washer attachment in conjunction with vacuum to remove samples from test setup. The combination was able to remove both wet and dry samples.

Table A.2: Trade studies and testing for removal using vacuums with different flow rates in cubic feet per minute.

Removal Method	Trade Study/Test	Results
30 cfm Wet-Dry Vacuum	Check feasibility by vacuuming samples	30 cfm vacuum is unable to remove wet and dry samples from the test setup
80 cfm Cordless Wet-Dry Vacuum	Check feasibility by vacuuming samples	80 cfm vacuum is unable to remove wet and dry samples from the test setup
150 cfm Wet-Dry Vacuum	Check feasibility by vacuuming samples	150 cfm vacuum is able to remove wet and dry samples from test setup

Table A.3: Trade studies and testing for containment

Containment Method	Trade Study/Test	Results
Dome	Analyze airflow using CFD simulation	Faster inlet velocity & more dispersed airflow
Rectangle	Analyze airflow using CFD simulation	Slower inlet velocity & gaps in airflow

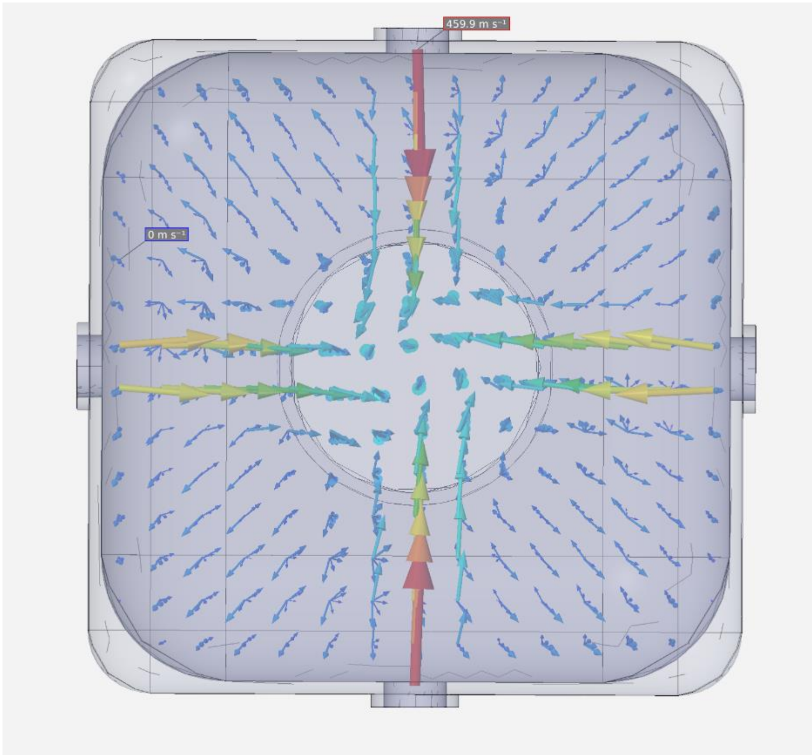


Figure A.7: Square Geometry, 4 air holes, vertical suction

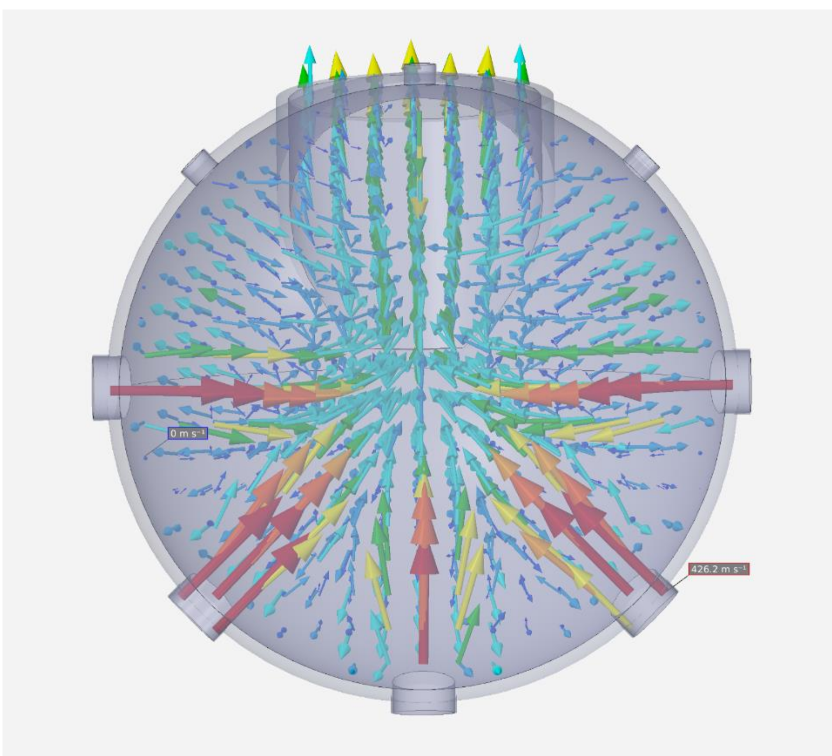


Figure A.8: Circular Geometry, 8 air holes, side suction

Appendix B: Power

Figure B.1: Graph of generator weight versus power generated. The red point indicates the optimal generator power and weight to run the device (Honda E2200i for $1,159.95).

Analysis B.1:

Known Variables:
Vacuum: 120V at 10.5A(max)
Pump: 115V at 1.0A(max)

Assume:
12V battery with 120Ah
Average run time = 28sec = 0.077hr
Max Total Current = 10.5A + 1.0A = 11.5A.

For 1 Run: 11.5A * 0.077hr = 0.9Ah
<u>120Ah/(0.9Ah/run) = 133 runs per battery</u>

Appendix C: Prototypes

Table C.1: Description of prototypes

Prototype number	Dome Description	Air Hole Description	Water Jet Description	Water Jet Placement
1	6" Tupperware	Near base, 6 total. ½"holes evenly spaced	4 Jets, ⅛" Reducer	Evenly spaced near bends of tupperware
2	5" Acrylic Dome	Near base, 6 total. 3 ½" holes opposite suction, 3 ¼" holes close to suction	6 Jets ⅛" Reducer V = 1.33m/s	Top of dome, evenly spaced, pointed towards center
3	7" Acrylic Dome	Near base, 8 total. 4 ½" holes opposite suction, 4 ¼"holes close to suction	9 Jets, ⅛" Reducer V=0.885m/s	5 around top, 4 evenly spaced near base
4	7" Acrylic, Swivel plate	Near base, 8 total. 4 ½" holes opposite suction, 4 ¼"holes close to suction	9 Jets, ⅛" Reducer V=0.885m/s	5 around top, 4 evenly spaced near base
5	7 ½ " Thermoformed plastic, Swivel plate	Near base, 8 total. 4 ½" holes opposite suction, 4 ¼"holes close to suction	9 Jets 5/32" Reducer V=0.567m/s	Angled in concentric circles
6	7 ½" Thermoformed plastic, Swivel plate	Near base, 19 total. 4 ½" holes opposite suction, 15 ¼"holes evenly spaced around remainder of dome	9 Jets 1/16" Reducer V=3.54m/s	Angled in concentric circles

Figure C.1: Prototype 0 - Proof of concept prototype developed for PDR presentation, using tupperware and hose-attached pressure washer.

Figure C.2: Prototype 1 **-** Using pressurized jets and circular dome with vertically mounted vacuum to remove samples from test setup. The combination was able to remove both wet and dry samples.

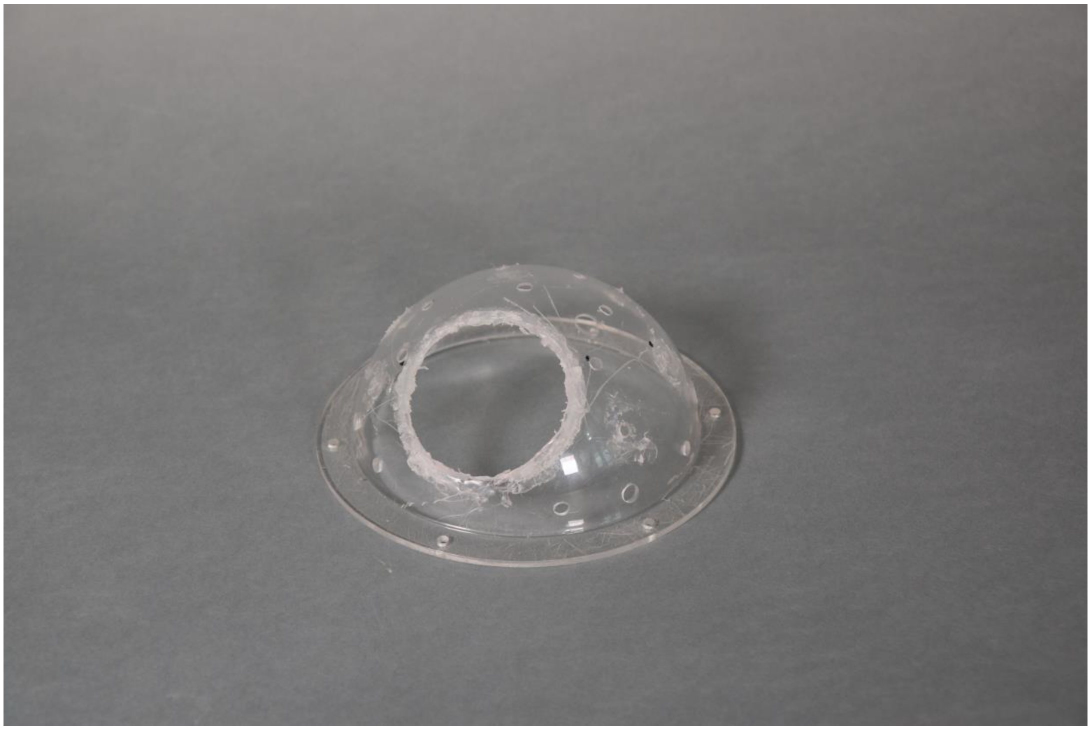


Figure C.3: Prototype 2 - 5in dome, utilizing 6 jets, angled vacuum wand mount. **No tubing shown due to testing and iteration. Multiple jet positions were examined**

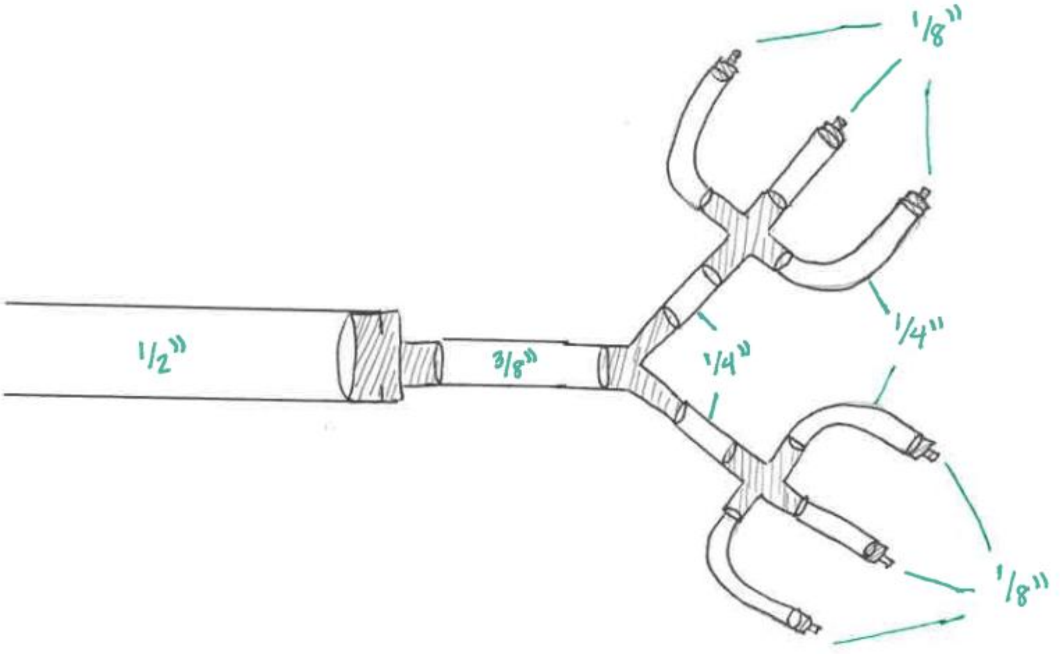


Figure C.4: Prototype 2 Tubing Arrangement

Figure C.5: Prototype 3: 7 in dome utilizing 8 tubes(not 9 as shown below due to lack of necessary splitter at time of creation) This was the prototype demonstrated at the CDR presentation. 9 jets were added after the presentation.

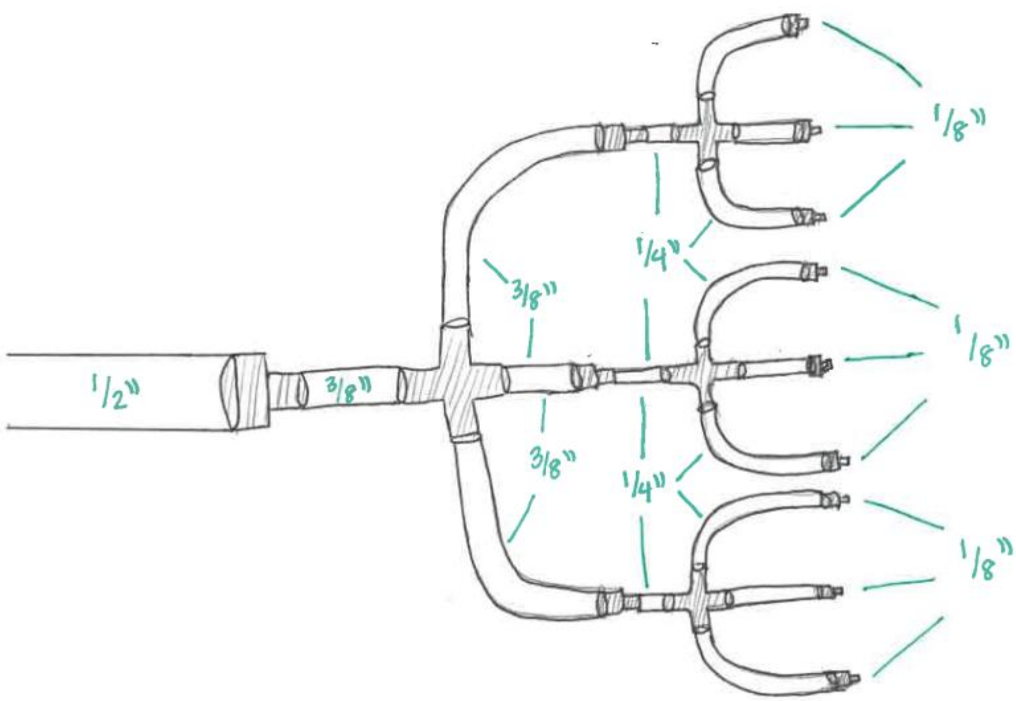


Figure C.6: Prototype 3 & 4 Tubing Arrangement

Figure C.7: Prototype 4 - 7in dome with 9 jets. Major addition from prototype 3 is the swivel bearing.

Figure C.8: Prototype 5 - 7in thermoformed dome, 9 jets utilizing 90 degree angle dome attachments. Note addition of gasket between dome and bearing to create reliable seal. This dome failed to develop desired suction due to turbulence developed by jet mounting faces.

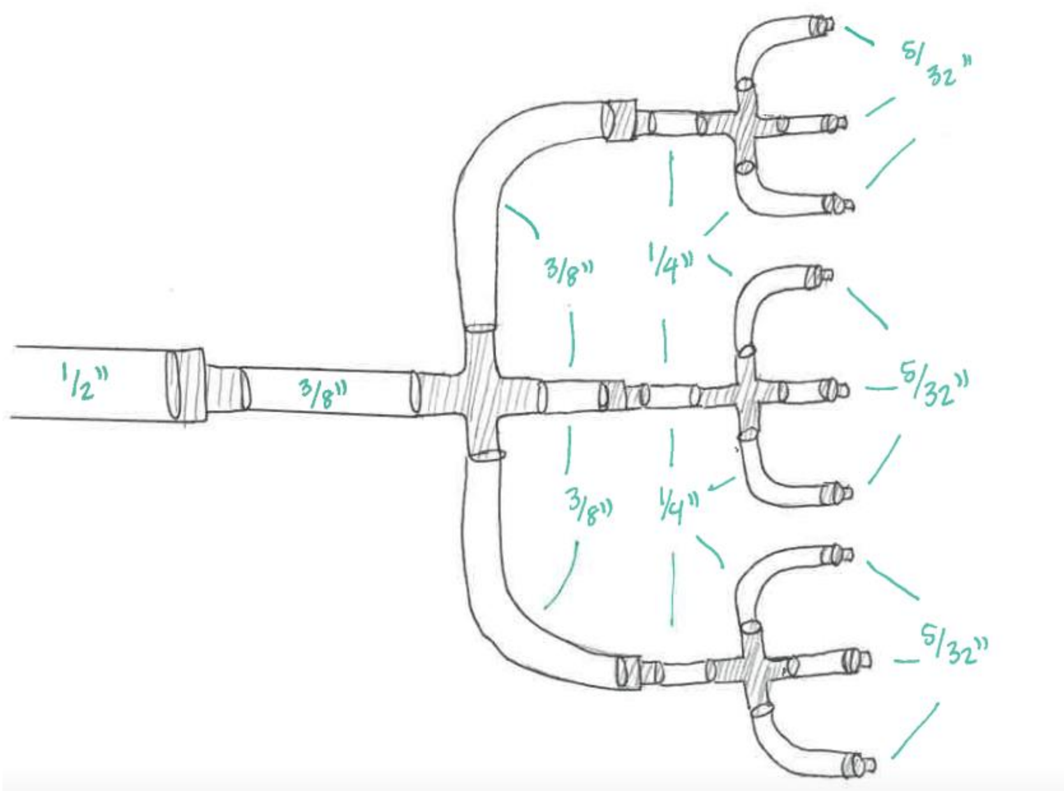


Figure C.9: Prototype 5 Tubing Arrangement: This tubing arrangement failed to generate the necessary jet velocity to effectively remove sample from the testing block.


Figure C.10.a: Final Prototype


Figure C.10.b: Final Prototype

Appendix D: Water

Calculations D.1:

<u>Jet Velocity Calculation</u>

Diameters:

1. ½" =0.0127*m*
2. ⅛" = 0.003175*m*
3. 5/32"= 0.0039687*m*
4. 1/16" = 0.001587*m*

Areas:

$A1 = ¼ *\pi*(0.0127m)^2 = 1.26677\times10^{-4}\ m^2$

$A2 = ¼ *\pi*(0.003175\ m)^2 = 7.9173\times10^{-6}\ m^2$

$A3 = ¼ *\pi*(0.0039687\ m)^2 = 1.23708\times10^{-5}\ m^2$

$A4 = ¼ *\pi*(0.001587\ m)^2 =1.97808\times10^{-6}\ m^2$

Q = volumetric flow rate = V*A

Ignoring frictional losses, due to mass conservation Q remains constant

$Q = 3.3GPM = 6.309x10^{-5}\ m^3/s$

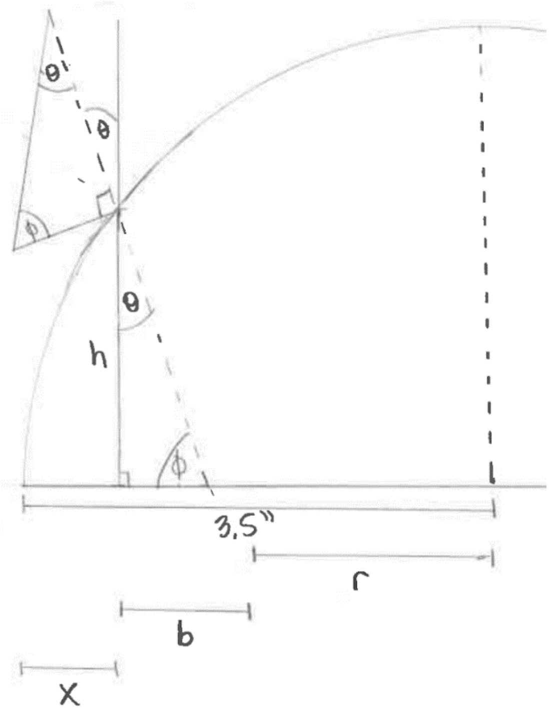
N = Number of jets

q = volumetric flow rate at each jet = Q/N

$V_{jets} = q/A$

Prototype	N	$q(m^3/s)$	$V_{jets}\ (m/s)$
2	6	$1.05*10^{-5}$	1.33
3	9	$7.01*10^{-6}$	0.885
4	9	$7.01*10^{-6}$	0.885
5	9	$7.01*10^{-6}$	0.567
6	9	$7.01*10^{-6}$	3.54

Angle Calculation



h → Desired height of angled face
X → Length determined from CAD model from corresponding height h.
r → Length where jet hits
b → Base of right triangle
ϕ → Face angle
θ → Complementary angle

θ = arctan(b/h)
ϕ = 90 – θ

Jet	r	h	ϕ
1	0"	3.75"	90
2	0.5"	3.7125"	69
3	0.67"	3.7125"	71
4	1"	2.2125"	46
5	1.33"	2.2125"	50
6	1.66"	2.2125"	56
7	2.44"	1.2125"	50
8	2.58"	1.2125"	54
9	3"	1.2125"	70

Matlab Code:

The following is the Matlab code used to generate the jet trajectories:

```
%Function showing area hit by jets

circr = @(radius,rad_ang)  [radius*cos(rad_ang);  radius*sin(rad_ang)];        % Circle Function For Angles In Radians
circd = @(radius,deg_ang)  [radius*cosd(deg_ang);  radius*sind(deg_ang)];      % Circle Function For Angles In Degrees
N = 50;% Number Of Points In Complete Circle
ang1_1 = 0;
ang1_2 = pi;
ang2_1 = pi/2;
ang2_2 = 3*pi/2;
ang3_1 = pi;
ang3_2 = 2*pi;
%%Jet radii are on a logarithmic scale from 1in to 6in in diameter
%%Define Jets starting on the left side of the dome
r_angl_1 = linspace(ang1_1, ang1_2, N);                    % Angle Defining Arc Segment (radians)
radius_1 = 3;                                  % Arc Radius
xy_r1 = circr(radius_1,r_angl_1);                        % Matrix (2xN) Of (x,y) Coordinates
%figure(1)
plot(xy_r1(1,:), xy_r1(2,:), 'b*')
hold on;

r_angl_1 = linspace(ang1_1, ang1_2, N);                    % Angle Defining Arc Segment (radians)
radius_2 = 1.66;                                 % Arc Radius
xy_r2 = circr(radius_2,r_angl_1);                        % Matrix (2xN) Of (x,y) Coordinates
%figure(1)
plot(xy_r2(1,:), xy_r2(2,:), 'b*')
hold on;

r_angl_1 = linspace(ang1_1, ang1_2, N);                    % Angle Defining Arc Segment (radians)
radius_3 = 2/3;                                 % Arc Radius
xy_r3 = circr(radius_3,r_angl_1);                        % Matrix (2xN) Of (x,y) Coordinates
%figure(1)
plot(xy_r3(1,:), xy_r3(2,:), 'b*')
hold on;

%%Define Jets starting on the center of the dome
r_angl_2 = linspace(ang2_1, ang2_2, N);                    % Angle Defining Arc Segment (radians)
radius_4 = 2.4;                                 % Arc Radius
xy_r4 = circr(radius_4,r_angl_2);                        % Matrix (2xN) Of (x,y) Coordinates
%figure(1)
plot(xy_r4(1,:), xy_r4(2,:), 'g*')
hold on;

r_angl_2 = linspace(ang2_1, ang2_2, N);                    % Angle Defining Arc Segment (radians)
radius_5 = 1;                                  % Arc Radius
xy_r5 = circr(radius_5,r_angl_2);                        % Matrix (2xN) Of (x,y) Coordinates
%figure(1)
plot(xy_r5(1,:), xy_r5(2,:), 'g*')
hold on;

r_angl_2 = linspace(ang2_1, ang2_2, N);                    % Angle Defining Arc Segment (radians)
radius_6 = .01;                                 % Arc Radius
xy_r6 = circr(radius_6,r_angl_2);                        % Matrix (2xN) Of (x,y) Coordinates
%figure(1)
plot(xy_r6(1,:), xy_r6(2,:), 'g*')
hold on;
```

```
%%Define Jets starting on the center of the dome
r_angl_3 = linspace(ang3_1, ang3_2, N);                    % Angle Defining Arc Segment (radians)
radius_7 = 2.58;                                  % Arc Radius
xy_r7 = circr(radius_7,r_angl_3);                        % Matrix (2xN) Of (x,y) Coordinates
%figure(1)
plot(xy_r7(1,:), xy_r7(2,:), 'r*')
hold on;

r_angl_3 = linspace(ang3_1, ang3_2, N);                    % Angle Defining Arc Segment (radians)
radius_8 = 1.33;                                  % Arc Radius
xy_r8 = circr(radius_8,r_angl_3);                        % Matrix (2xN) Of (x,y) Coordinates
%figure(1)
plot(xy_r8(1,:), xy_r8(2,:), 'r*')
hold on;

r_angl_3 = linspace(ang3_1, ang3_2, N);                    % Angle Defining Arc Segment (radians)
radius_9 = .5;                                  % Arc Radius
xy_r9 = circr(radius_9,r_angl_3);                        % Matrix (2xN) Of (x,y) Coordinates
%figure(1)
plot(xy_r9(1,:), xy_r9(2,:), 'r*')
hold on;

% Plots circle showing outside of 7""
xCenter = 0;
yCenter = 0;
theta = 0 : 0.01 : 2*pi;
r = 3.5;
x = r * cos(theta) + xCenter;
y = r * sin(theta) + yCenter;
plot(x, y, 'k' );

hold off;
% Draw An Arc Of Blue Stars
axis([-1.5*radius_1 1.5*radius_1    -1.5*radius_1  1.5*radius_1])          % Set Axis Limits
axis equal % No Distortion With ‘axis equal’

logspace(0, .48, 8)
```

Appendix E: Aerosol Testing

Figure E.1: coffee filter before running blue dye test (left), coffee filter after running blue dye test (right). Note: the small water spot on the filter pictured on the right was due to residual water on our hand, not water from the vacuum outlet.

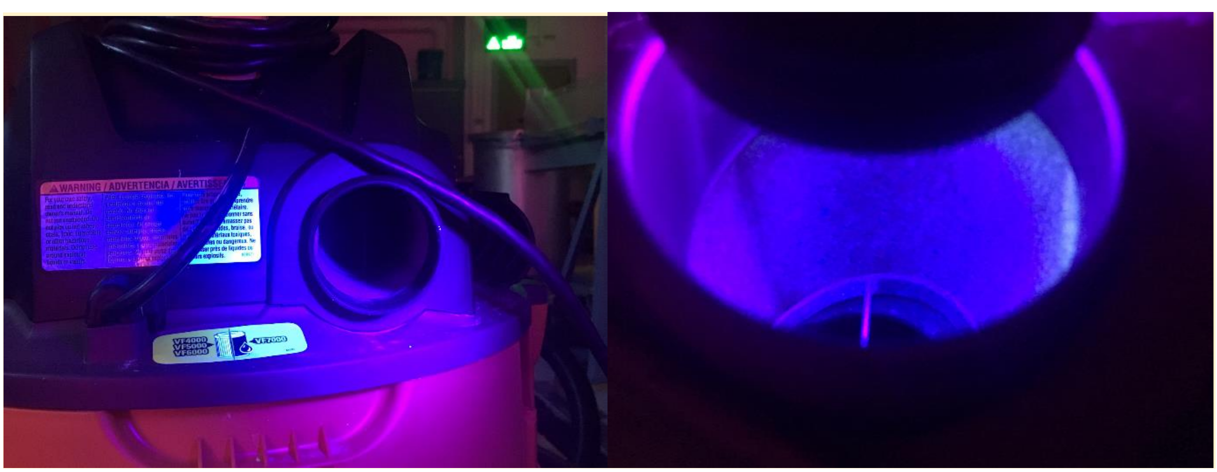


Figure E.2: Images of vacuum outlet after running fluorescent samples through the device. No fluorescent particles are visible inside or on the edge of the vacuum outlet.

Appendix F: Dome

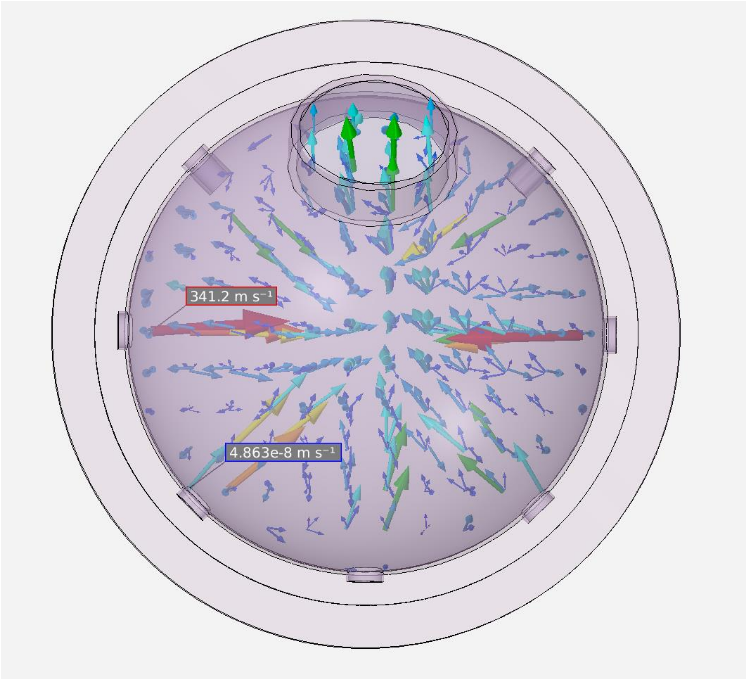


Figure F.1: Prototype 5 with Smooth inner walls -- note the presence of a defined suction path into the vacuum tube, as well as a lack of turbulence.

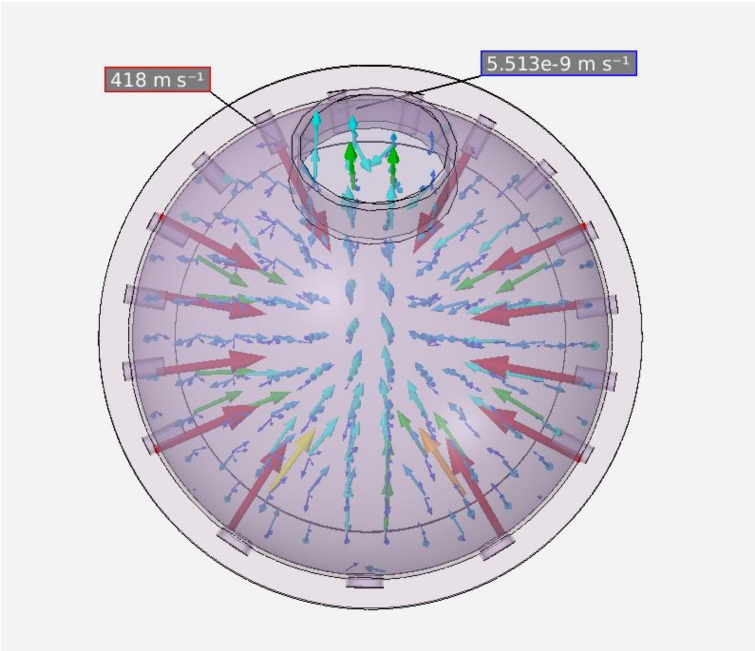


Figure F.2: Prototype 5 with increased number of air holes to eliminate dead zones. Note the number of high speed inlets, as well as a clearly defined airflow into the vacuum suction tube. This model strongly influenced the final placement of air holes in prototype 6.

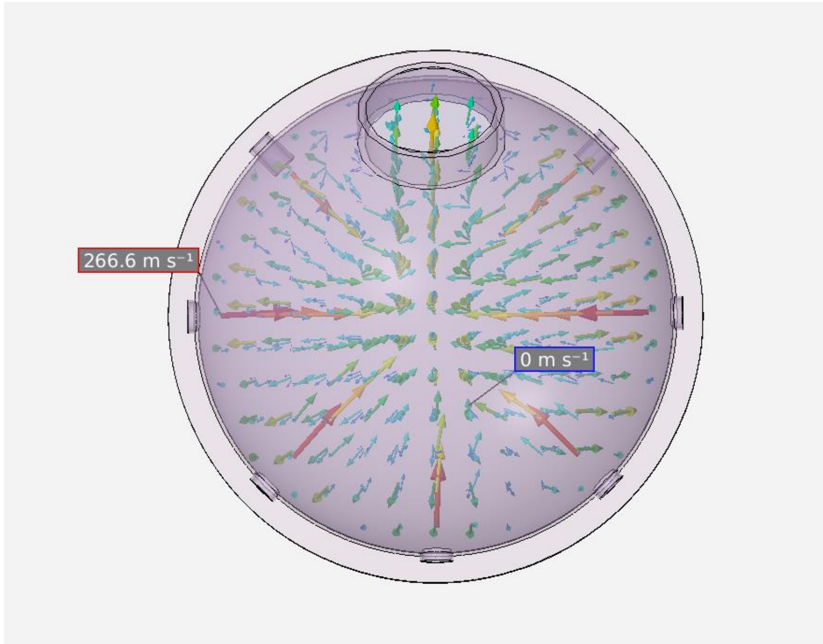


Figure F.3 : Dome sizing analysis: 8" dome showing the significantly slower airflow at inlet compared to the 7" dome. This simulation strongly influenced the decision to use 7" diameter dome.

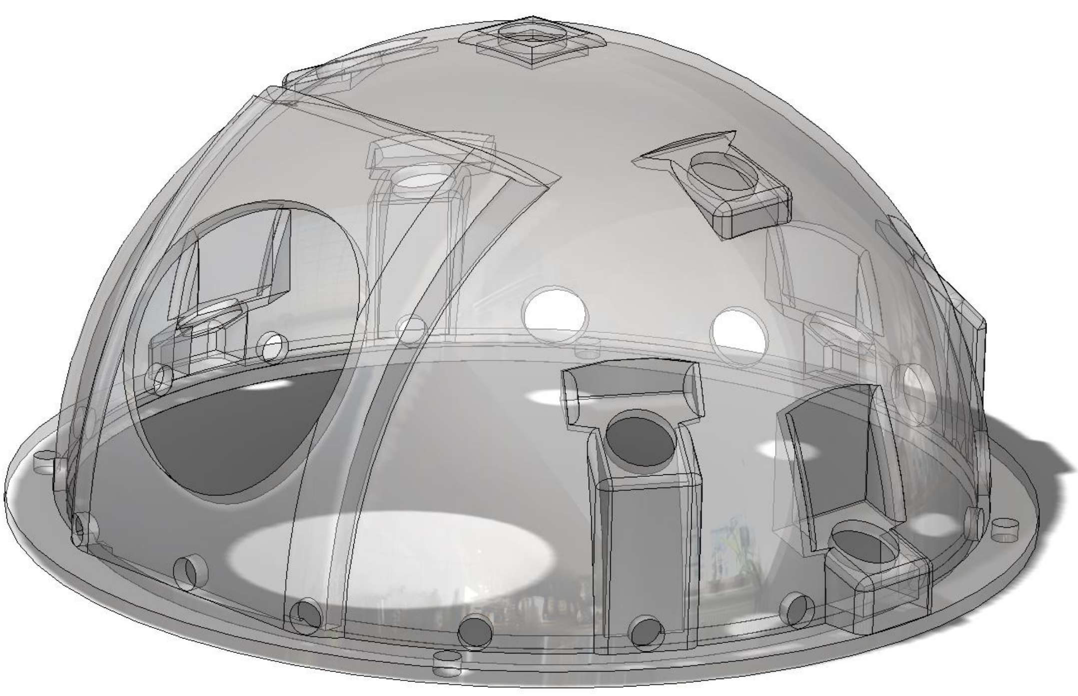


Figure F.4 : CAD model of dome, showing jet mounting faces, air holes and vacuum mounting face.

Figure F.5: Shopbotted wooden dome used as mold for domes in prototypes 5 & 6.

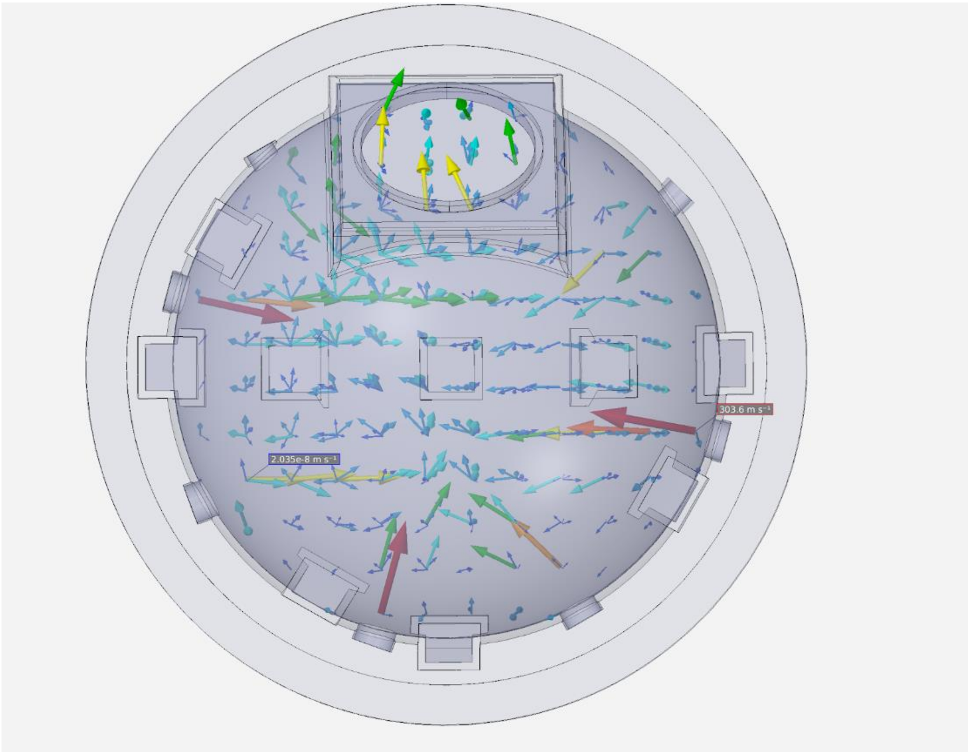


Figure F.6: Prototype 5: There is no defined flow present from the ground to the suction point. Additionally there exists turbulence throughout the dome, visualized as the multidirectional vectors originating from a single point.

Figure F.7: Prototype 5 filled with molding clay to test the effect jet and vacuum mounting faces had on airflow and suction.

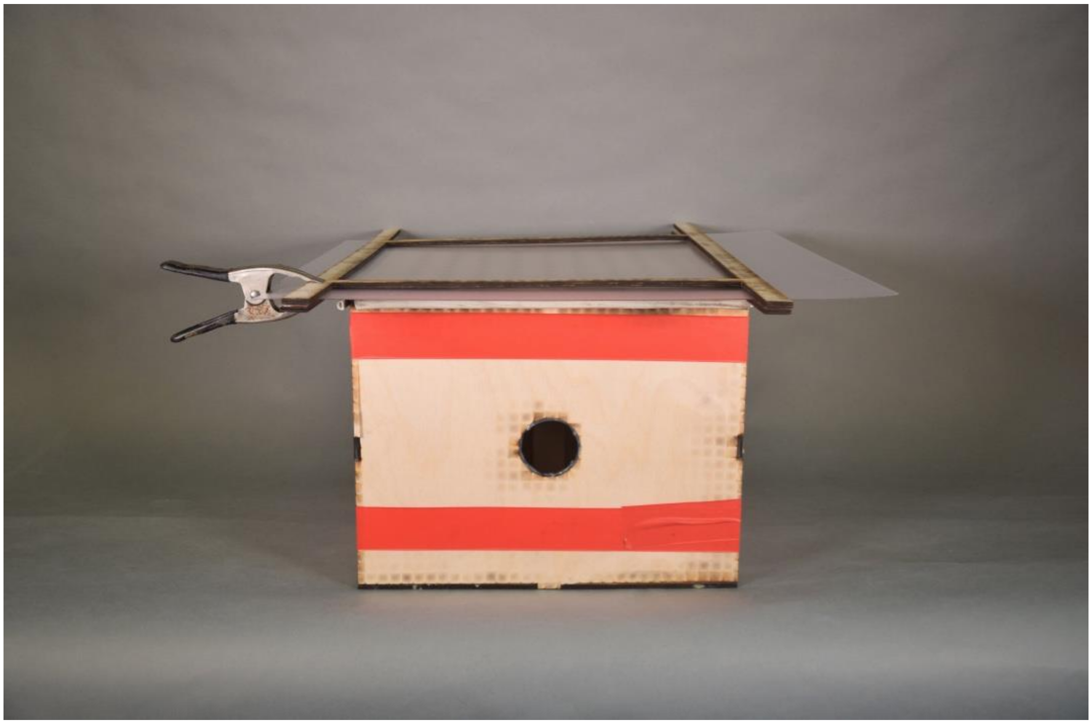


Figure F.8: Homemade thermoforming machine -- this machine was used for the creation of multiple iterations of prototype 5. It utilizes a 150CFM vacuum pulling air through a 16"x16" box. Custom clamps were made to hold and heat plastic using existing heating element.

Appendix G: Final Prototype Testing

Table G.1: Final prototype testing data. Measuring total run time and water use for system tested under variety of conditions.

Final Prototype Testing: "Stepped On" Samples		
Trial Number	**Run Time (seconds)**	**Water Used (gallons)**
1	32	0.875
2	22	0.1875
3	20	0.3125
4	36	0.8125
5	29	0.5625
6	30	0.375
7	28	1
8	34	0.875
9	27	0.625
10	25	0.75
Average	**28.3**	**0.6375**
Standard Deviation	**5.056**	**0.273**
Median	**28.5**	**0.6875**

Final Prototype Testing: Dried Samples		
Trial Number	**Run Time (seconds)**	**Water Used (gallons)**
1	87	2.5
2	51	1.25
3	100	3.25
Average	**79.33**	**1.433**

Final Prototype Testing: Smoothed Samples		
Trial Number	**Run Time (seconds)**	**Water Used (gallons)**
1	62	1.928
2	48	1.522
3	53	1.218
4	38	0.942
5	46	1.224
Average	**49.4**	**1.3668**
Standard Deviation	**8.877**	**0.375**
Median	**48**	**1.224**

Final Prototype Testing Summary		
Type of Sample	**Average Run Time (seconds)**	**Average Water Use (gallons)**
Stepped On	28.3	0.6375
Smoothed	49.4	1.224
Dried	79.3	1.433

Figure G.1: Smeared (left) vs. stepped on(right) "fake" samples

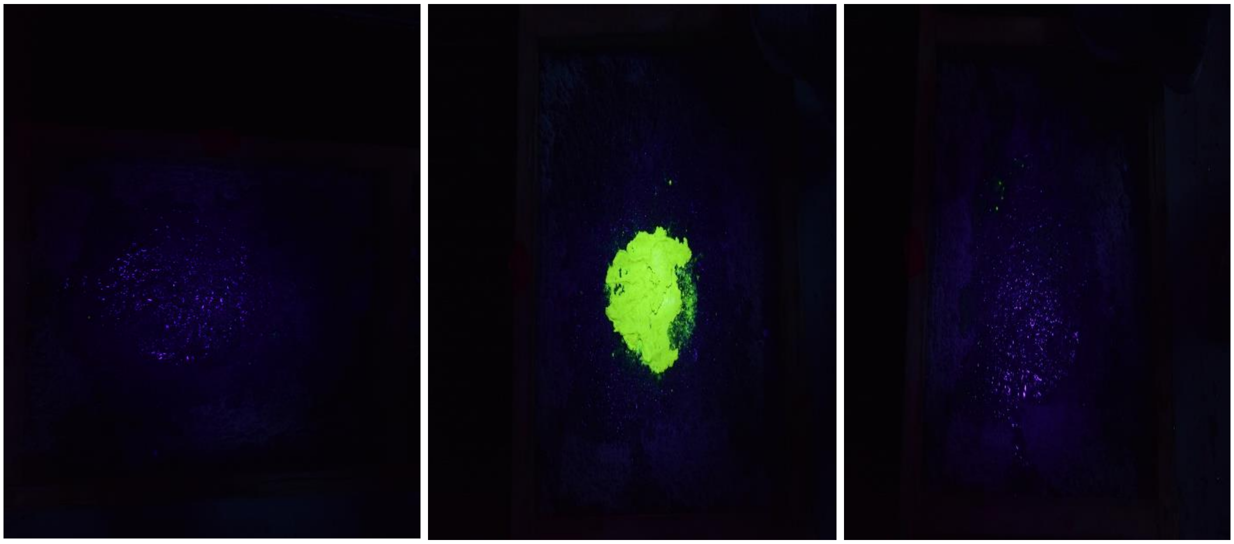


Figure G.2: Fluorescent dye test. Left: baseline slab (purple light is UV light refracted off the concrete, not the dye). Middle: peanut butter-refried beans-cornstarch sample with green fluorescent dye. Right: slab after test.

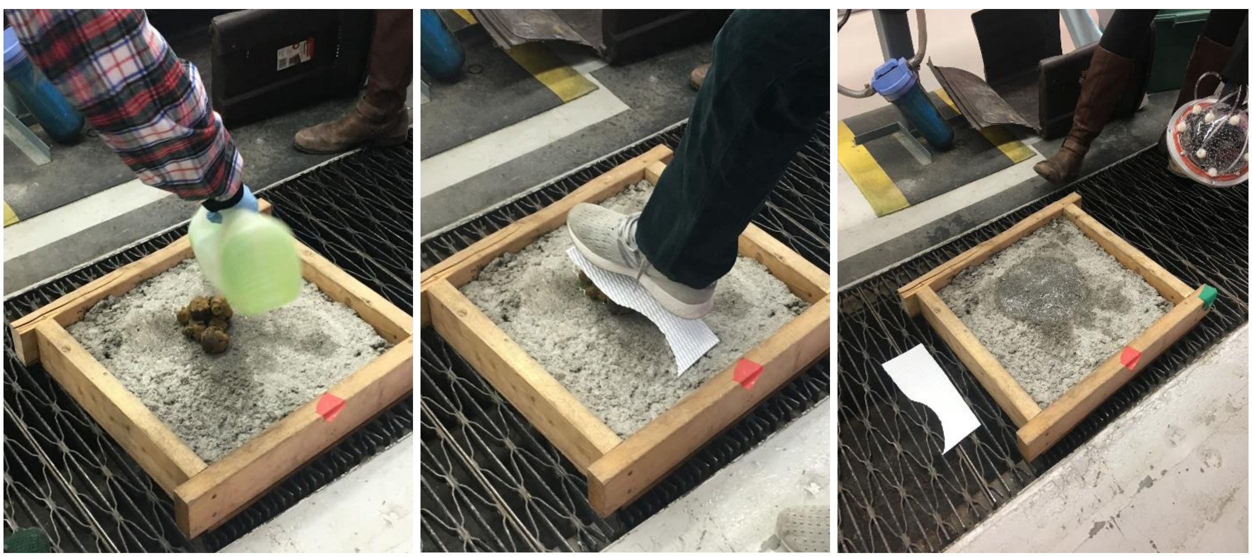


Figure G.3: Dog poop testing. Left: feces and liquid soap. Middle: stepping on the feces simulates a real-life worst-case scenario. Right: after the dome has been run.

Appendix H: Implementation

Table H.1: Requirement Specifications

Dome	80 sq. in. Surface Area
	3" Height
	Consistent airflow pattern
Water jets	Holes located on lower half of the dome
	Angled to dome
	>10 gal water supply
Pump	Volumetric flow rate (>3.3GPM)
Vacuum	Air Volume (>150CFM)
	Weight (<20lb)
Storage tank	10 Uses before dumping
	Portable without lifting
	10 gal volume
	Easily cleaned(smooth surfaces, no sharp corners)

Table H.2: Different options for masking/neutralizing odors

Deodorizer	Details	Feasibility
NilOdor[34]	The formula changes the shape of odorous molecules, making them incapable of fitting into nasal receptors. NilOdor products contain chemicals with multiple functional groups such as aldehydes, alcohols, and carboxylic acids that interact with molecules that have odor-causing functional groups.	We used the NilOdor Tap a Drop Product, which only cost $6.55 and is said to last for 400 applications, during testing. It was effective at masking odors and would likely be a good low-cost solution.
Potty Fresh Plus [35]	Sold by Surco Portable Sanitation Products. It has a biocide that breaks apart molecules causing bad odors. It is the same formula that is used in porta potties. There are both solid packets and liquids available for deodorizing.	The method seems promising, especially because it would be easy to drop a packet into the waste container to neutralize odors.
Soap	Pleasant soap smell masks the smell of excrement.	This method has the benefit of also cleaning the dome and vacuum tubing as the dome is running. Does not neutralize odors, however, so effectiveness may decrease.

Figure H.1: Custom 3D printed 3-way splitter to streamline tubing

Appendix I: Manufacturing Plan

Bill of Materials				
ITEM NO.	ITEM NAME	DESCRIPTION	QUANTITY	DESCRIPTION OF USE
1.1	Lazy Susan Bearing	10" outer diameter	1	Swivel dome
1.2	Screws	6/32"	4	Secure dome to bearing
1.3	Washers	No. 6	4	Secure dome to bearing
1.4	Nuts	6/32"	4	Secure dome to bearing
1.5	Clear PETG Sheet	24"x 24" x ⅛"	1	Construction material for dome
1.6	Water and Weather Resistant Foam Rubber Seal	32"	1	Create water and airtight seal
1.7	Rubber Gasket	26"	1	Create airtight seal
1.8	Vacuum Wand	20"	1	Connect to dome and vacuum for suction
1.9	Wood	9"x 9"x 4"	1	Create mold
2.1	Masterkleer PVC Clear Tubing	½" Tubing	2'	Connects water source to inlet and outlet of pump
2.2	High-Pressure PVC Clear Tubing	⅜" Tubing	15'	Transfers water from pump to 3-way splitter
2.3	High-Pressure PVC Clear Tubing	¼" Tubing	3'	Transfers water for smaller 3-way splitters
2.4	Masterkleer PVC Clear Tubing	5/32" Tubing	3'	Transfers water to thru-wall reducers
2.5	Plastic Barbed Tube Fitting	½" to ⅜" Reducer	1	Reduce to increase flow speed of water
2.6	Plastic Barbed Tube Fitting	⅜" 3-way splitter	1	Split stream into 3
2.7	Plastic Barbed Tube Fitting	⅜" to ¼" Reducer	1	Reduce tubing to increase flow speed of water
2.8	Plastic Barbed Tube Fitting	¼" 3-way splitter	3	Split into 9 streams

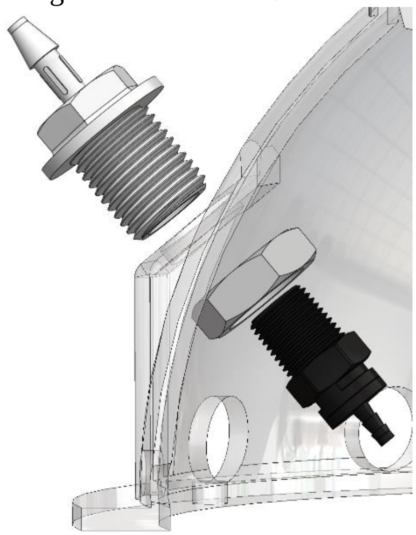
2.9	Plastic Barbed Tube Fitting	¼" to 5/32" Reducer	9	Reduce tubing to increase flow speed of water
2.10	Plastic Barbed Tube Fitting	Thru-wall, 5/32" Tube ID x ¼" NPSM Male	9	Reduce stream; secure jets to angled faces
2.11	Plastic Barbed Tube Fitting	1/16"Tube ID x ⅛" NPT Male	9	Reduce stream, screw into thru-wall adapters
2.12	Cut-to-Length Hook and Loop Cable Ties	5'	1	Secure tubing in place
2.13	Custom Sleeve	20"	1	Aesthetic function; cover tubing

Manufacturing Plan

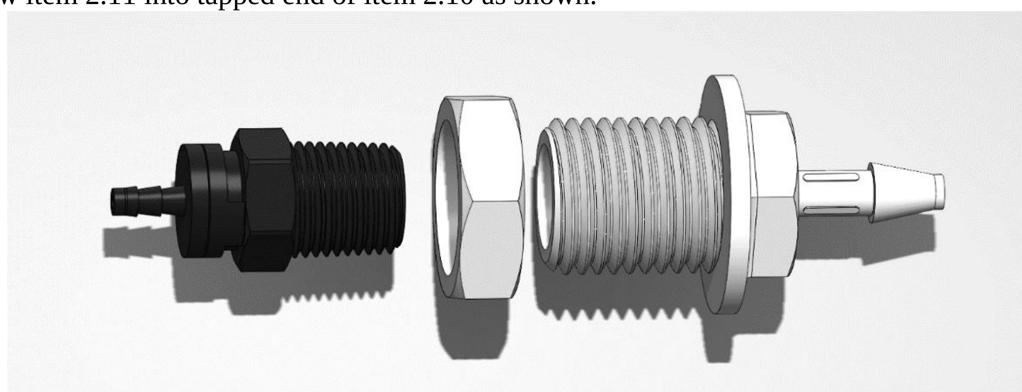
Dome:

1. Create wooden mold from CAD model using item 1.9 on a shopbot.*
2. Sand finished mold to desired smoothness.
3. Use plastic sheet, item 1.5, to thermoform mold.
4. Cut excess plastic until the dome's circular lip is 8".
5. Line up swivel bearing, item 1.1, with inner rim.
6. Center drill holes on circular lip such that they are aligned with swivel bearing's holes.
7. Drill 3/16" holes at location of center drills from step 6.
8. Center drill centered on the 9 angled faces of the dome.
9. Drill 0.5125" holes at location of center drills from step 8.
10. Opposite to suction, center drill 4 times at height of 0.27" from base, evenly spaced 1.5" apart between angled faces.
11. Drill ½" holes at location of center drills from step 10.
12. Center drill 15 times at height of 0.15" from base, evenly spaced around remainder of dome. Reference CAD file for exact location.
13. Drill ¼" holes at location of center drills from step 12.
14. Mark suction hole.
15. Cut suction hole with dremel.
16. Attach weather seal, item 1.6, to the bottom, outer rim of swivel bearing, item 1.1.
17. Align gasket, item 1.7 into inner rim of bearing, item 1.1.
18. Tighten gasket between bearing and dome's lip using items 1.2, 1.3 and 1.4 as shown.

19. Tap rear side of item 2.10 with ⅛” NPT.
20. Screw thru-wall fitting 2.10 through angled face as shown.



21. Screw item 2.11 into tapped end of item 2.10 as shown.



22. Mount vacuum wand, item 1.8, securing with epoxy.

*Note that Steps 1 through 15 could be replaced by injection molding.

Tubing:

1. Cut 4” of ½” tubing, item 2.1.
2. Insert ½” to ⅜” fitting, item 2.5 into tubing cut in step 1.
3. Cut 10’ of ⅜” tubing, item 2.2.
4. Insert tubing cut in step 3 into fitting, item 2.5.
5. Insert 3-way ⅜” splitter, item 2.6, into tubing cut in step 4.
6. Cut 2, 6” long sections of ⅜” tubing, item 2.2.
7. Insert tubing cut in step 6 into sides of splitter.
8. Cut 1, 4” long section of ⅜” tubing, item 2.2.
9. Insert tubing cut in step 8 into center splitter.
10. Insert 3, ⅜” to ¼” fittings, item 2.7, into 3 tubing openings.
11. Cut 3, 2” long ¼” tubing, item 2.3.
12. Insert tubing cut in step 11 into splitters.
13. Insert 3, 3-way ¼” splitters, item 2.8, into 3 tube openings.
14. Cut 6, 7” long sections of ¼” tubing, item 2.3.

15. Insert tubing cut in step 14 into sides of splitters.
16. Cut 3, 5” long sections of ¼” tubing, item 2.3
17. Insert tubing cut in step 16 into center of splitters.
18. Insert ¼” to 5/32” fittings, item 2.9, into 9 tube openings.
19. Cut 9 sections of 5/32” tubing to appropriate lengths to reach 5/32”, ensuring tubing is not bent as shown.
20. Cut 3, 18” velcro straps, item 2.12.
21. Secure tubing against vacuum wand, item 1.8, using velcro straps cut in step 20.
22. Place sleeve cover tight against tubing and vacuum wand.

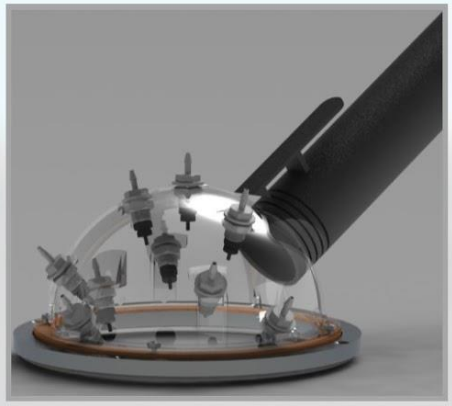
Appendix J: User Guide

Poop Buster - User Guide

About Our Product

This product is designed to clean up messes while keeping you clean. It was originally constructed to contain and remove human fecal matter from the streets and sidewalks of San Francisco; however, it can be used to clean any localized, semi-solid mess that can be contained within a 7.5 inch radius.

The clear dome protects the user and surrounding environment from contamination, while also allowing the user to see the cleaning process and ensure the mess is fully removed. The 9 high-pressure jets combined with the swiveling base enable the user to dislodge every part of the mess efficiently and effectively. The following sections provide assembly and user instructions.



Assembly Instructions

1. The dome head arrives fully assembled. Use the head with a wet-dry vacuum, water tank, water pump, generator or battery/inverter, and push-cart/dolly/wagon. See reverse side for recommendations.
2. Place wet-dry vacuum and water tank into wagon or cart.
3. Mount water pump on cover of water tank. Run inlet tube from tank to pump and from pump to head.
4. Connect vacuum hose to head attachment. Connect water tube to head attachment.
5. Plug wet-dry vacuum and pump into generator or inverter/battery. CAUTION: do not get power sources, plugs, or inlets wet.
6. Black sleeve can be removed and replaced, if desired.

User Instructions

1. Ensure that vacuum hose and water hose are properly connected to the head.
2. If desired, pour liquid soap over contaminant.
3. Place dome over waste.
4. Turn on vacuum.
5. Turn on water pump.
6. Let device run for 10-90 seconds depending on waste size and consistency. Spin dome on swivel to ensure all waste is dislodged.
7. Once no waste remains on the sidewalk, turn off pump.
8. When power washer nozzles no longer spray water and little to no liquid remains in the dome, turn off the vacuum.
9. Lift dome off the pavement.
10. To clean the system, pour liquid soap onto pavement, place dome over soap, turn on vacuum followed by pump, and let run for approximately 15 seconds. Turn off pump, turn off vacuum.

Who You Gonna Call?

| Website: www.ThePoopBusters.com | Email: Team@ThePoopBusters.com |
| Call: 978-886-4552 |

Recommendations for System Components

Vacuums:

- RIDGID 14 Gal 6-Peak HP Wet Dry Vac
- Dayton 32 gal. Contractor 6.5HP Wet/Dry Vacuum, 12A
- Shop-Vac 20 Gal 6.5 Peak HP High Performance Wet-dry Vac

Water Pumps:

- Seaflo 45 psi 3.3 gpm pump,
- Lippert 689052 Flow Max 3.3 GPM Water Pump
- Flojet Quad II Water Pump—3.3 gpm, 115V

Power Sources:

- Honda EU2200i generator
- Nautius 31 Deep Cycle Marine Battery + HAMMERDOWN 1500W 12V Power Inverter

Carts/Wagons:

- Gorilla Carts 800 lb Steel Utility Cart

Additional Accessories:

- Air-Actuated Foot Switch with Three-Prong Outlet

Appendix K: Economic Analysis

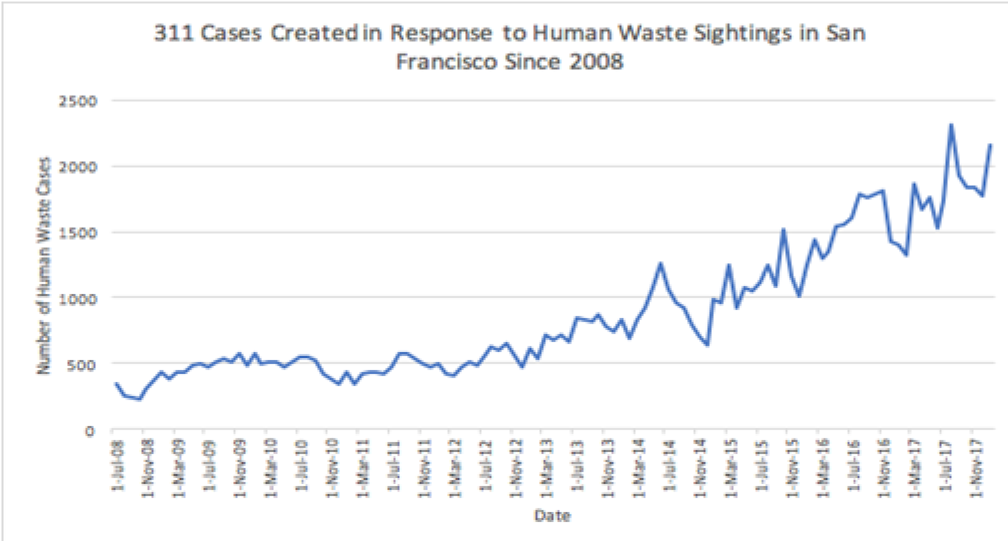


Figure K.1: 311 cases created in response to human waste sightings in San Francisco

Table K.1: Table estimating the total cost to manufacture the final prototype, with and without investing in a $15,000 injection mold.

Cost of Dome				
ITEM NAME	**DESCRIPTION**	**QUANTITY**	**UNIT PRICE**	**COST**
Masterkleer PVC Clear Tubing	½” Tubing	2’	$1.46/ft	$2.92
High-Pressure PVC Clear Tubing	⅜” Tubing	10'	$3.42/ft	$34.20
High-Pressure PVC Clear Tubing	¼” Tubing	3'	$2.40/ft	$7.20
Masterkleer PVC Clear Tubing	5/32” Tubing	3'	$0.34/ft	$1.02
Plastic Barbed Tube Fitting	½” to ⅜” Reducer	1	$0.68/unit	$0.68
Plastic Barbed Tube Fitting	⅜” 3-way splitter	1	$1.76/unit	$1.76
Plastic Barbed Tube Fitting	⅜” to ¼” Reducer	1	$0.66/unit	$0.66
Plastic Barbed Tube Fitting	¼” 3-way splitter	3	$1.46/unit	$4.38
Plastic Barbed Tube Fitting	¼” to 5/32” Reducer	9	$0.82/unit	$7.38
Plastic Barbed Tube Fitting	Thru-wall, 5/32" Tube ID x ¼” NPSM Male	9	$1.29/unit	$11.61
Plastic Barbed Tube Fitting	1/16”Tube ID x ⅛” NPT Male	9	$2.91/unit	$26.19
Lazy Susan Bearing	10” outer diameter	1	$18.99/unit	$18.99
Screws	6/32”	4	$0.05/unit	$0.20
Washers	No. 6	4	$0.033/unit	$0.13
Nuts	6/32”	4	$0.05/unit	$0.20
Clear PETG Sheet	24”x 24” x ⅛”	1	$17.28	$17.28
Water and Weather Resistant Foam Rubber Seal	24”	1	$0.67/ft	$1.34
Rubber Gasket	7' diameter ring	1	$4.97/unit	$4.97
Vacuum Wand	20”	1	$9.97/unit	$19.97
Cut-to-Length Hook and Loop Cable Ties	5'	1	$0.392/ft	$1.96
Custom Sleeve	Zippered sleeve with elastic on edges	1	$5/unit	$5.00
Total Material Cost				$168.04
Total Labor Cost without injection mold		2 hours per dome	$75/hour	$150.00
Total Cost of Individual Dome Manufacture without Injection Mold				**$318.04**
Total Labor Cost with Injection Mold		1 hour per dome	$75/hour	$75.00
Total Cost of Individual Dome Manufacture with Injection Mold				**$243.04**

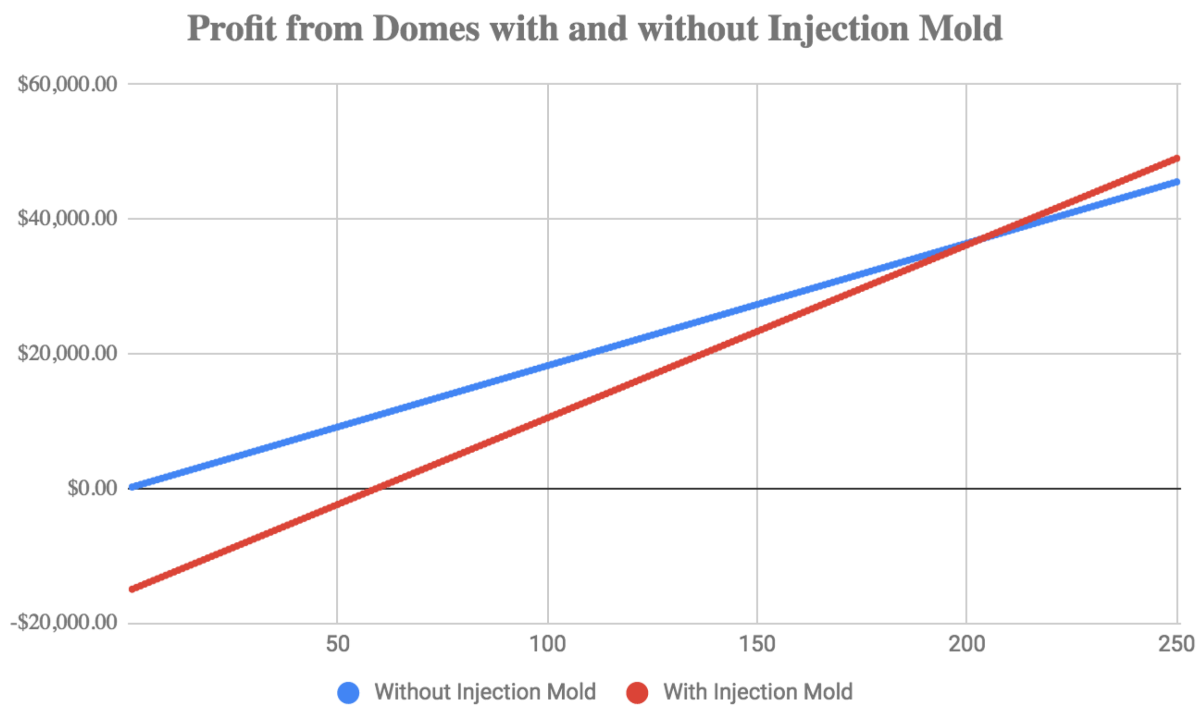


Figure K.2: Graph of profit from domes with and without an injection mold, assuming that the investment in a $15,000 injection mold cuts the labor hours for assembly from two to one. 60 domes are required to "break even" and start gaining a profit from the injection mold, and 204 domes are required to make the injection mold more profitable than thermoforming.

Table K.3: Cost of additional system components required to operate dome.

Cost of Additional System Components	
Dome	$500
Vacuum	~$120 [20]
Pump	~ $260[21]
Wagon	~$100 [22]
Total Cost of System without powering Option	**~$980**
Generator	~$1,000 [23]
Total Cost with Generator Powering Option	**~$1,980**
Deep Cycle Marine Battery	~$110 [24]
12 Volt Power Inverter	~$130[25]
Total Cost with Battery Powering Option	**~$1,220**

Table K.2: Table estimating the market size for the product. Assumptions: U.S. Municipalities include the 10 most highly populated cities in the U.S.; International Municipalities include the 5 most highly populated cities in China and in India; Each US city will need approximately 5 devices; Each city in China and India will need approximately 10 devices; 10% of all U.S. universities will have 1 device; 10% of all U.S. zoos will have 1 device; 2% of all U.S. State Parks will have 1 device.

Users	**User Count**	**Devices**
U.S. Municipalities	10	50
International Municipalities (India and China only)	10	100
U.S. Universities (national total)	2000	200
U.S. Zoos (national total)	2000	200
U.S. State Parks (national total)	8000	160
TOTAL		710

Appendix L: Deliverables Agreement

Engineering 89/90 Deliverables Agreement

The following agreement serves as a contract of intended product deliverables by a team consisting of Alyssa Baker, Cara Cavanaugh, Julia Jackson, Brandt Slayton, and Rafananda Tejada. The primary deliverable is to create an effective street and sidewalk sanitation system that removes, contains, and disposes of human excrement by the end of ENGS 90 in March 2019. There are two major design components for this deliverable. The two components are a working CAD model and drawing, and an operational prototype of the entire system.

1. **CAD Model:** The team will identify and design a suitable system to safely handle and contain human excrement removal and disposal in public spaces to prevent contamination to both the users of the system and the general public and create a CAD model of the system.

2. **Manufacturing plan**: The team will create a detailed manufacturing plan that details a reproducible system.

2. **Operational Prototype:** The team will create a manufacturable, portable, operational prototype of the system described in the CAD model that can be taken and demonstrated to manufacturers.

Team Members:

Alyssa Baker

Cara Cavanaugh

Julia Jackson

Brandt Slayton

Rafananda Tejada

Sponsor:

Digitally signed by Paul Ronzano

Paul Ronzano