Problem Statement

Problem:
How might we reduce the amount of indoor air pollution in rural Haitian homes to prevent respiratory diseases and illness from developing?

Significance:

Indoor air pollution from burned biomass and coal stoves leads to 4.3 million deaths per year (WHO). Indoor air pollution is known as the most lethal killer after malnutrition, unsafe sex, and lack of safe water and sanitation (Perez-Padilla). The deaths are caused by large amounts of particulate matter and carbon monoxide released from rudimentary cookstoves. It is estimated 34% die due to stroke, 26% to ischaemic heart disease, 22% to chronic obstructive pulmonary disease, 12% to childhood pneumonia and 6% to lung cancer (WHO). Indoor air pollution can also cause cataracts, tuberculosis, adverse pregnancy outcomes, cardiovascular disease, and nasopharyngeal cancers (Perez-Padilla). Women and children are particularly susceptible to the effects of air pollution due to their time spent cooking indoors (WHO).

Haitians' primarily use charcoal for cooking which accounts for 39% of Haiti's overall energy usage (World Watch). They also use wood fuels which can cost up to 20% of the poorest people's disposable income (Barnes). The daily income of some Haitians can vary from $3.12 - $5 with the price of fuel costing up to $1.56 (Stoves). This becomes a huge burden on the Haitians as the cost of the fuel takes away from their ability to purchase other necessities such as food and clothes. A lot of the fuel is wasted because the fuel is only partially combusted which is where the fuel is not completely mixed with the oxygen. Because of this, Haitians must pay more than they have to for fuel.

The over use of charcoal and firewood has lead to heavy deforestation within Haiti with only 1/3 of the original forest remaining (environ). Haitian will often collect their own firewood because it is essentially free to them. However, over-collecting leads to a lack of trees in the area, and the market price of trees will increase. A lack of forest also leads to a raise in the average surface temperature which decreases the soil moisture making it harder to farm the area (Dickinson & Henderson-Sellers). This would cause food prices to increase and burden the Haitians even more. The over reliance on biomass as a fuel leads to severe environmental consequences and can affect the environment for years to come.

The over reliance on biomass leads to several burdens upon the Haitian society. The primary burden is a significant segment of the population contracting respiratory infections from the exposure to the burning biomass. This segment will be unable to perform certain jobs and and the overall economy of Haiti will suffer. The deforestation in the area leads to a higher number of flash floods and landslides which will cost time and money to repair as well as displace several people from their homes.

A cause for the problems is the Haitian reliance on the combustion of biomass for their primary source of energy. They do not have the infrastructure to get electricity from to their house and alternative forms of energy are generally unfeasible given their particular situation. So, combustion of biomass is the immediate feasible to their energy need. Other causes of the problem is a lack air recycling. The average Haitian home does not have air conditioning, therefore the air stays stagnant, and the CO and $PM_{2.5}$ stay in the air instead of being replaced by cleaner air. Generally, the source of the problem stems from their lack of energy.

If Haiti were to fix its indoor air pollution problem, then the country would improve in a variety of ways. Primarily, the overall Haitian population would be healthier and could contribute to the economy. The environment would be better protected because their would be less landslides and flash floods. Finally, depending on the solution, Haitians could end up saving money in the long run if they could more efficiently combust their material.

Stakeholders:

Four large stakeholders of this problem are the women who cook in Haiti, the families that the women feed, aid workers in the area, and the government of Haiti.

In Haiti, women often do most of the cooking, and so have experience the greatest the detriments of open fire cooking. This creates accelerated health risks for them, and on average, the women in Haiti only live approximately 62.8 years (Gender in Haiti, 2012). Because a lot of the damage associated with open fire cooking depends on exposure length and intensity, the health of these women are more affected than any of the other stakeholders.

The family that a woman feeds is another stakeholder of the problem, both because of the direct and indirect health effects of burning biomass on the family. While the men in Haiti are often out in the fields, many of the children are put to work helping their mothers cook (Hubbell et al., 2010). The negative particulates created by the burning of biomass can also remain in the stagnant air, and later affect individuals of the family. A woman may also develop serious health problems and as a result be unable to perform all of her daily functions as she regularly would, causing her family to indirectly be affected by the negative effects of biomass burning.

A third stakeholder of the problem are the aid workers in Haiti. There have been many aid workers working on different issues in Haiti, especially since the earthquake in 2010. Many of these aid workers and organizations are working on providing clean cookstoves to the population of Haiti, including organizations like USAID and Global Alliance for Clean Cookstoves. These organizations are definitely stakeholders in this problem because they are prompted by the negative health effects to create action, and also would be affected by any possible solutions to this problem (Lackey, 2014). As the main source of clean stoves for a lot of Haitians, these organizations are definitely impacted by the problem.

Finally, the government of Haiti is definitely a stakeholder in the problem, as the health and mortality rates in the country are its responsibility. On a side note, we thought about the fact that the people who are directly affected by the problem may not actually think that the problem is important (the people of Haiti) because they may be more focused on other issues such as actually getting food to eat. We took this into consideration while creating our solution.

Context and Existing Solutions:

In Haiti, a large segment of the population must rely on charcoal and firewood in order to cook. This leads to a heavy dependency upon the use of these biomasses. This is because they generally do not have the infrastructure to use other forms of energy and biomass is generally the cheapest form of energy (although it will cost a significant amount in the long term). They also have rudimentary ways of combusting the biomass which leads to an impartial combustion. Impartial, or incomplete, combustion leads to several harmful bioproducts such as fine particulate matter (particularly $PM_{2.5}$) and carbon monoxide. Normally, small doses of $PM_{2.5}$ and CO are not detrimental to one's health, but there are two factors which compound the effects of the CO and $PM_{2.5}$ (Valavanidis). One of the factors is that Haitians generally cook indoors. This means the CO and $PM_{2.5}$ will diffuse over a smaller volume meaning there will be a higher concentration of CO and $PM_{2.5}$ which will lead to people in the generally facility breathing in a larger amount of CO and $PM_{2.5}$. This is especially true because unlike homes in the USA, Haitian homes generally lack air conditioning which recycles the air. The other important factor is exposure. Haitian women and children who cook 2-3 times a day 7 days a week will have an extremely high level of long term exposure to these harmful byproducts. This long term of exposure will cause several long term respiratory health issues.

In an attempt to solve the issue of indoor air pollution, several people have created different iterations of efficient cookstoves. Back in 2014, Global Hearthworks launched a project known as the Lusaka Project in Lusaka, Zambia. In this project, they distributed the 2000 EzyStove which was a low cost, efficient “rocket stove” which relied on wood fuel as opposed to charcoal fuel (Global Hearthworks). They sold the stove at a low cost along with bundles of wood fuel. One reason this project failed was because of the lack of demand for the cookstoves and wood fuel. In order to keep the cost of the stove low, the project depend upon the sale of the wood fuels to subsidized the cost, but the wood fuel sales were stagnant and could not sustain the cost of the cookstove. The lack of wood sales revealed another reason the project failed. In Lusaka, wood was not seen as a commodity as charcoal was. Wood was seen as free because the poorest of the poor could simply collect the wood from around there area for free. Because of this, wood is seen as a resources for the neediest people (i.e orphans, widows, or displaced families). So the more urban residents would see wood as a free resource than something worth paying. That perception of wood greatly impacted the overall feasibility of the project. Therefore, the main reason the project failed was the economic impact of the perception of biomass fuel.

In 2013, the USAID and Haitian government partnered to try to reduce the reliance on biomass (Sal). They created clean burning cookstoves which would be subsidized by revenue from carbon financing. Carbon financing is essentially where a developing country sells their greenhouse gas emission reductions to an industrialized country. However, the staff could not meet their goal because not enough Haitians were purchasing the cookstoves because of a lack of interest and lack of purchasing power. Also, the usage of the cookstoves did not reduce the environmental impacts because of the Haitians misusing the product. Overall, the program was deemed to need an overhaul in order to have a noticeable effect.

Why is it still a problem?

Our problem has not been solved yet because of a few prominent reasons. The first is poor infrastructure. It is difficult to set up permanent structures to solve the problem because the infrastructure in Haiti is unreliable. For example, in small villages, there is no grid in order to receive power from, and so a solution that requires formal energy input will fail (Henley, 2010). The second big problem is an unskilled labor force. Many current solutions to the problem utilize new and sustainable cookstoves. These usually work well until they break, and with a relatively unskilled labor force, are not able to be put back together. A third main problem is low purchasing power. Many Haitians cannot afford new technology to help minimize the effects of burning biomass. This also connects to the issue that if relatively expensive technology is implemented in an area, the locals of that area are likely to take it apart and sell it, as money is more pressing of a need than health (Offering Energy Solutions).

Proposed Work

Goal:
One aspect of our problem statement is improving the health of the individuals exposed to biomass burning by limiting the amount of PM (Particulate Matter) that they consume through the use of redirecting and changing the airflow that is directed towards the burning biomass.

Objectives:
After careful scrutiny, we splitted our main goal into four well defined objectives that encompass all sorts of works that separate theoretical and the practical sides of our solution. They are as follow:

1) Draw conclusions on the feasibility of the Gravity Assisted Fan
2) Design a low-cost plan of implementation
3) Measure the impact of the implemented airflow system on the reduction of particulate matter given out
4) Calculate the amount of income Haitian households would save due to more efficient combustion
5) Determine how we can alter the input to create increased airflow
6) Determine if the structure of the current cookstoves will have a significant impact on our ability to implement a solution

These objectives are not necessarily dependent on one another – i.e. our group might end up working on more than one objective concurrently – and they were not equally divided based on how long we expect it will take to reach each one of them. In fact, we defined them based on the rather specific – and unrelated to one another – type of work they require.

Objective 1: Determine if Gravity Assisted Fans are a feasible way to create directional airflow.

Background
This is our core objective and, consequently, will most likely require the greatest amount of diligent effort. Our proposed solution is, currently, entirely based on observations, ideas, and speculations. In order to move on with other considerations we need to certify that there is mathematical feasibility to what we are proposing. This objective will most likely go through multiple iterations due to the large number of variables for which we need to account. A few examples of what needs to be mathematically determined are: the height variation of the pulley system, the gear ratio between the pulley gear and the fan gear, and the amount of friction or force needed to rotate the pulley gear.

Methods

1) Obtain a Pulley System and Gearbox
2) Attach Gearbox to fan.
3) Alter pulley gear sizes to see which allows the fan to spin the fastest and longest.

4) Alter number of step down gears to increase friction to a point where the weight falls slowly.

Outcomes
If the velocity of the air increases for a long period of time under the flame, then a cleaner combustion will occur, the fire will become hotter, and boiling times will decrease.

Anticipated Problems
It will take a decent amount of experimentation to determine what gear ratios are the most efficient and can push the most air into an improved cookstove.

Objective 2: Design a low-cost plan of implementation

Background
The importance of our final solution's affordability cannot be overstated. Every single report from the past 30 years lists Haitians' extremely low purchase power as one of the determinant factors for their project's failure – including the most recent one by the United States Agency for International Development (USAID).
Although this observation has already led us toward a solution that does not involve the creation of an entirely new improved cookstove, our apparatus still needs to be widely accessible. Another factor to consider is the manufacturing replicability of our solution. Haiti's poor infrastructure would result in very high distribution costs, in case our apparatus could only be manufactured at the main cities. Therefore, a thorough consideration of the materials needed as well as a study on what is relatively abundant in Haiti are required.

Methods
1) Determine the cost of the parts needed to create the cookstove addon.
2) Determine the cost of the average Haitian buying power

Outcomes
If the cost of the parts is less than the cost of the Haitian buying power, our solution will be cost effective. Additionally, making certain that our cookstove addon doesn't significantly exceed Haitian buying power will keep the addon from entering the black market to be sold.

Anticipated Problems
Manufacturing costs, raw material cost, and transportation costs may cause the addon to be excessively expensive to Haitians. If the addon can't reasonably be bought with the money that the average Haitian can obtain then our solution will have failed. Furthermore, if we subsidize the cost and simply give away the addon, it will most likely end up being sold rather than used.

Objective 3: Measure the combustion efficiency and the reduction of particulate matter emitted

Background
Given that the first objective is successfully reached and we demonstrate that our solution is physically feasible, we would still need to find experimental evidence that it leads to more efficient combustion and, thus, lower emission of particulate matter: our central goal. The importance of this objective lies on the fact that it will allow us to compare the cost-benefit advantage our solution offers with that of improved cookstoves.

Methods
1) Obtain a Haitian cookstove
2) Place a recorded quantity of charcoal that is as uniformly sized as possible in the cookstove and light it
3) Create airflow through the charcoal fire with the predicted velocity of airflow due to the gravity assisted fan
4) Determine how long it takes to boil a known quantity of water
5) Compare that result to the time it takes to boil a quantity of water without the increased airflow rate

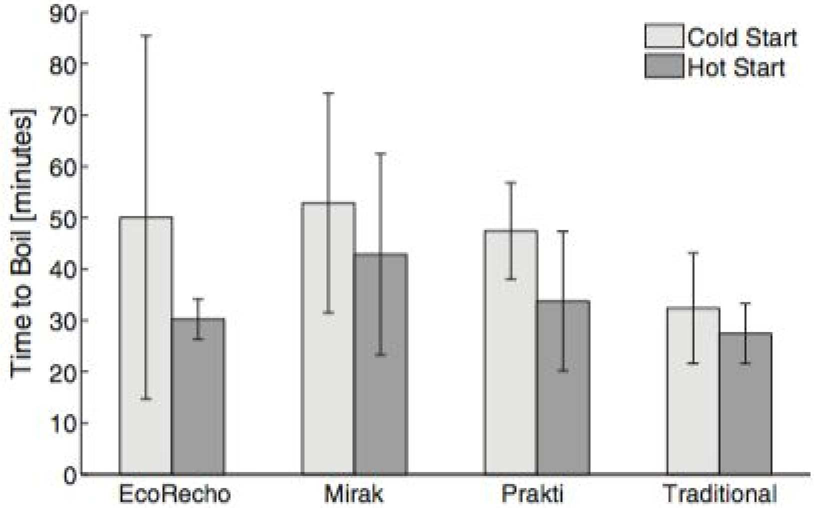
Outcomes
If the time it takes to boil water decreases, then the increased airflow increases the efficiency of burning charcoal.

Anticipated Problems
Getting a quantity of charcoal that is uniformly sized is hard to obtain, since charcoal, by its nature, comes in a variety of shapes and sizes. Some error will be introduced from varying charcoal sizes. Additionally, if the charcoal size isn't representative of the size of charcoal obtained in Haiti, the data could be skewed from actual results.

Objective 4: Calculate the amount of income Haitian households would save due to more efficient combustion

Background
One of the most challenging issues cookstove engineers face is completely unrelated to technical problems. Often times, organizations that try to implement improved cookstoves over an underdeveloped region fail because they are not able to persuade the population into spending part of their rather limited income on cookstoves. Researchers usually refer to the health problems associated with biomass burning as "silent killers" due to their highly asymptomatic nature – at least in their early stages. Therefore, our group would have to "sell" the solution not only based on the health benefits it would bring – since we are aware of their skepticism – but also make the case for its efficiency. If we accomplish the three objectives aforementioned, we would develop a low-cost, locally manufacturable apparatus that would end up increasing the combustion efficiency, thereby decreasing the time they spend cooking, and, most importantly, saving part of their disposable income previously used to buy charcoal.

According to a recent laboratory test on improved cookstoves by Kathleen et al. , the improved cookstoves which are generally found in both urban and rural Haiti (Prakti Rouj™, Mirak™, and EcoRecho™) take significantly longer times to boil water (see chart below).



Consequently, not only are Haitians required to spend a larger share of their rather limited income in order to afford these improved cookstoves, but they also do not enjoy a short-term, “noticeable” benefit from purchasing it.

Methods

1) Using the boiling times Objective 3, find the value for (boiling time)/(amount of charcoal) for both the modified and unmodified air supply. This is the efficiency of both systems
2) Divide the modified efficiency by the unmodified efficiency to get the ratio of the efficiencies
3) Multiply the ratio by the amount of charcoal to find the amount of charcoal needed in the modified cookstove to achieve the same boiling time as the unmodified cookstove
4) Subtract the unmodified charcoal amount by the modified charcoal amount to see how much charcoal was saved by using the modified cookstove
5) Calculate the cost of that saved charcoal

Outcomes

Any money that is saved by using the modified cookstove is money that Haitians will save using the addon.

Anticipated Problems

If the change in efficiency is so small as to only save a significantly small portion of money for the Haitians, then the argument of the addon as a money/charcoal saving device is not valid.

Objective 5: Determine how we can alter the input to create increased airflow

Background

Since our solution consists of adapting pre-existing cookstoves, ultimately, the approach we take to modify the cookstoves – and create increased airflow – will determine the variables to the problem of replicability. It is pointless for us to create an efficient but rather complex solution composed of materials that are not easily found or manufactured in Haiti. Thus, the key for successfully achieving this objective will be uniting simplicity with functionality.

Methods

There are many different ways to approach this problem, but our main solutions for this section include:

- Adding a fan powered from gravity to pull more air into the flame
- Adding a pump or crank to the input to push more air into the flame
- Adding a one way valve to keep air flowing directionally.

Outcomes

If these solution are implemented, increased airflow will allow the flame to burn more cleanly than unaltered airflow. If the solutions cause directional airflow, then they will be considered successful.

Anticipated Problems

Fans: fans require power to run, which is not readily available to most Haitians. While heat may be a feasible solution, solar is a difficult power source unless a low-power fan can be found due to the high power requirements of movement of blades. This is why we focused on gravity assisted fans. Additionally, fans may not be able to produce a strong directional airflow and may only aid in pushing a small (but still significant) amount of air into the flame.

Pump/Crank: pumps and cranks can move a lot of air into the system very quickly, but may impede directional airflow unless cost of materials used to make the cookstove increases (added cost to buy specific pumps and cranks that only allow directional airflow).

One Way Valve: while a one way valve is a feasibly way to create directional airflow, a fire without an initial surge of airflow (via a pump, crank, fan, or other method) may not produce enough of a pressure differential to create a noticeable Venturi effect (and increase airflow to the fire). If the one way valve doesn't have the output pushing air out of the system, it won't be able to open since there will be no force to pull the valve into the release position. Therefore, an additional input mechanism may be needed to pair with the one way valve.

Calculations

We have determined through calculations that a 1% increase in the combustion efficiency of the improved cookstove leads to a 3% thermal efficiency increase. This means that if we can add enough air into the flame via our gravity assisted fan to produce a 1% cleaner burn, there will be a 3% increase in the thermal energy generated by the flame. This leads to shorter boiling times and a "healthier" burn. Our calculations were found by comparing combustion efficiencies in various Haitian improved cookstoves and seeing how their thermal combustion efficiencies correlated. We then found how much thermal energy was released by changing the ratio of CO_2 to CO. This ratio change could be correlated to a thermal efficiency change and converted into a thermal efficiency/combustion efficiency ratio. The final ratio ended up averaging around 3% thermal efficiency increase for every 1% combustion efficiency increase.

Objective 6: Determine if the structure of the current cookstoves will have a significant impact on our ability to implement a solution

Background

The preliminary information we have found throughout reports is that the cookstoves used across Haiti are somewhat similar to one another. We will have to make contact with local communities to obtain more reliable descriptions. The design of the most common types of cookstoves will be the foundation for our solution and the degree of similarity between them will most likely dictate the spread of our solution's impact.

Methods

This problem requires us to research the various types of cookstoves sold in Haiti and determine if our solution can be easily modified or have adaptive abilities to fit on multiple cookstoves. If the input/output system for most of the common cookstoves in Haiti are similar, then we can add adjustment mechanisms/additional parts to make it fit most cookstoves easily.

Outcomes

As the number of cookstoves our addon can fit/pair with increases, the success of our solution increases.

Anticipated Problems

Since the addon relies specifically on how the cookstove moves air through the system, if our addon isn't compatible with the system then the addon can't be used on that cookstove.

Project Team:

Design- We need someone that is creative and proficient with CAD and the invention studio. This person would be key in helping to design the product in a form such as CAD that would allow fabricators to replicate the product and scale production. This person would also facilitate the team's relationship with the invention studio and cut production costs by making what we can there.

Business/ Production- We need to have someone business minded that can make decisions regarding production and material costs. This person would focus on establishing a self sustaining business model that would ensure the product continues to be profitable and applicable to the community. They would also need experience in building or production that would allow them to understand how to best build the product and what tools would be needed.

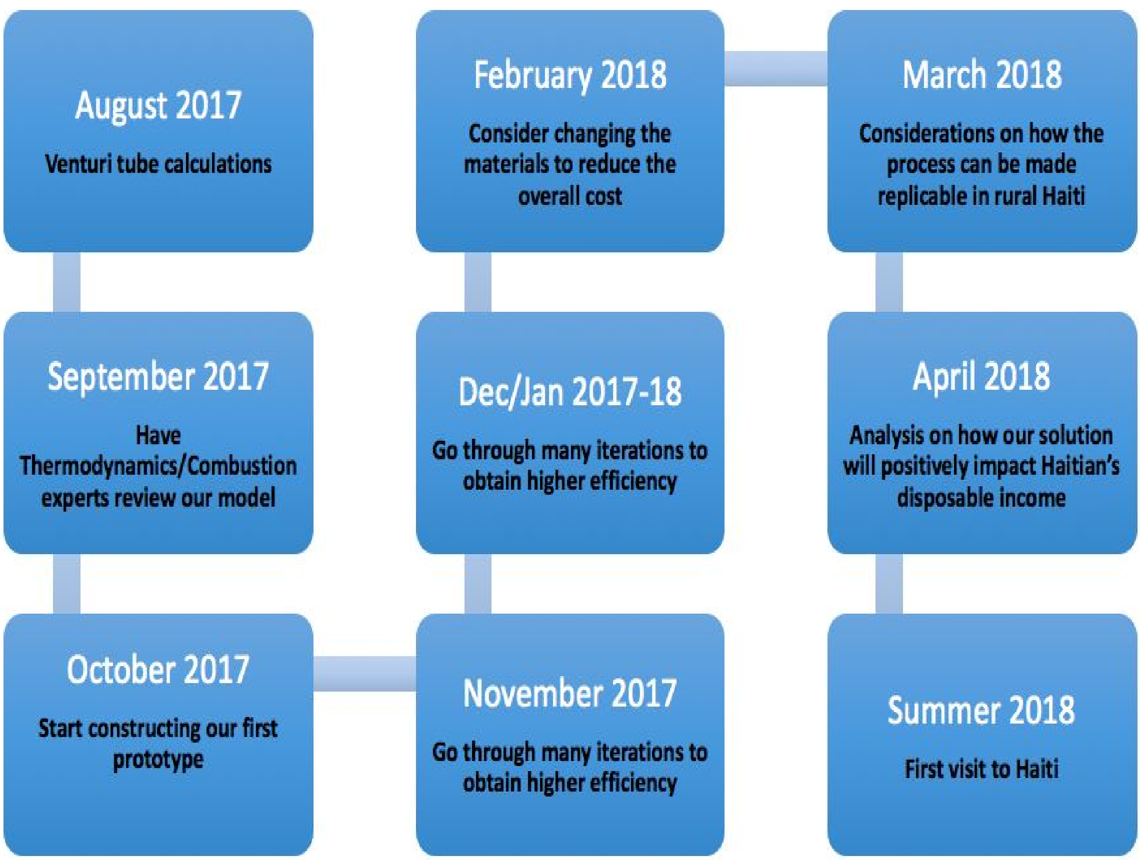
Programmer- We need a CS specialist in order to simulate any complex physics that may be unfeasible to replicate in real life especially with regard to the venturi tubes, if we decided to implement a modified input system in addition to the gravity assisted fan. This person would also be key in marketing. They would design a website and be in charge of communicating with local communities or organizations that deal with local communities.

Physics/chemistry- We need someone that understands the intricacies of the physics associated with pressures, airflows, and temperatures. This person would be important for making a solution even possible. They would work directly with the designer to create a realistic model. They would also be in charge of measuring and conducting experiments on the physics of the solutions. They would detail the to the programmer what physics components they would need simulated.

Outreach and production- We would need 1-3 people to focus on the logistics of the cultural impact of the product and how to best interact with the community. This person/team would be able to describe to the programmer what would be the most effective form for marketing. They would also look into the feasibility and ramifications of domestically producing the product.

Advisors- Jonathan, Raj and Dr. Davis- They all either have contacts within Haiti or experience in the field of energy/combustion in developing regions

Timeline:



Budget:

Materials and supplies

Cookstoves, sheet metal, metal shears, charcoal, manual air pumps, heat tolerant caulking to create air tight seal, O-rings and sealing gaskets, pressure monitors, metal Hole saw(sheet metal and cast iron), heat tolerant glue and solvents to prep surface, temperature sensors, tool to measure volume of air flow to compare input and output, calipers, tape measure- all materials and tools above would be used to test and prototype the design, concept of venturi tubes and gravity assisted fans and make it applicable to Haitian cookstoves(~500)

Equipment

Plasma cutter(CNC)- (~4000) This would possibly be needed to scale up uniform production in an economically efficient way

Services

Welding- We need professional welders in order to ensure an airtight seal on our product, patent lawyers- we need to hire patent lawyers to make our product profitable without threat on our intellectual property and possibly provide licensing opportunities for our design concept to be used in different applications

Travel

Travel to haiti(plane and car rental)- We would need at least two trips to haiti. The first would be to gain more in depth insights on the culture and feasibility of our solution in the community. The second trip would be to implement our prototype. More trips may be necessary after our prototyping in order to continue the scaling of our product.

Expected Outcomes and Future Directions

By the end of this year, when this project finishes, our team should have a clear and concise plan regarding how we will actually begin the creation aspect of the the product design, and basically begin the prototyping process to final development/patenting(Hopefully). In addition, our project plan should be so defined and fine-tuned that we could be able to both describe the entire process that our group had went through, as well as explain all aspects of our design and what it entails.

By the end of year two, our prototype should most likely be created by then, and we should have traveled to Haiti by then to see our product in action, as well as chiseling some final details and/or making any necessary modifications to the product. Depending on who continues to work on the project, and who leaves, we may need to spend time with new team members and catch them up and inform them on what we are working on, and what it potentially means for the people of Haiti, but that shouldn’t be a problem as our draft should have all aspects of our project entailed.

In the off chance that our testing and evaluation concludes that our solution is not in fact a feasible solution, then we will still move forward with the same problem statement, but would go back to the brainstorming process and maybe even partially change the problem statement itself to focus more on something we know we can make an impact in.

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