The MANE Journal for Student Research, Innovation, and Design

2019
Volume 4

Featuring:

Inventor's Studio Innovations
Partially Funded by VentureWell

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August 2019

Dear RPI Community,

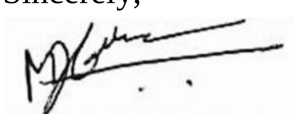
The fourth volume of MANE Student Research, Innovation, and Design Journal is being published today. Picking up from our previous iterations, we continue to showcase brilliant research and innovations performed by the undergraduate community of the MANE department.

The journal is completely student run and largely supported by the Student Advisory Council (SAC) of the MANE department. The Journal is composed entirely of undergraduate students' contributions to research and innovative solutions to design problems developed by students. The editorial staff consists of graduate and undergraduate students in the MANE department who have experienced publishing research in peer-reviewed technical journals. We are pleased that the journal continues to be a platform to undergraduate students to demonstrate their achievements early in their academic careers.

I would like to thank the Department Head, Dr. Suvranu De, and Professor of Inventor's Studio, Dr. Asish Ghosh for their continuous support and encouragement. This issue could not have materialized without the efforts of the editorial staff who volunteered their time and efforts during the review process.

I hope you enjoy this issue of the MANE Student Research, Innovation, and Design Journal. It is the culmination of many hours of hard work performed by talented students. We are very proud of the students who contribute to research at RPI, many of whom are on their way to becoming innovators, entrepreneurs, and prolific authors of impactful research publications.

Sincerely,



Mithil Kamble
Editor-in-Chief

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Section I:
Research

Xylem Filter Backpack

Kaitlin Chitaman, Adrian Collado*, Michael Decker
MANE 4220 Inventor's Studio 2
Rensselaer Polytechnic Institute
chitak3@rpi.edu, collaa@rpi.edu, deckem3@rpi.edu
**Winner of The Inventor's Studio Startup Founder Award*

In various places in the world, there are communities of people that are being displaced because of racial tension. The ethnic group that we focused on were the Rohingya people of Myanmar. Our design is aimed to help ease the struggle of the difficult terrain in their trek to safety from persecution. The design process for the physical components of a water filtration system is presented.

I. INTRODUCTION

Everyone needs water to survive. Although over 70% of the Earth is covered in water, only a small portion of it is safe to drink. For many people, having access to clean water is a luxury, not a guarantee. This is generally due to the inability to filter the water they have.

There are many solutions to water filtration currently in use around the world. Ranging from massive desalination plants to disposable pocket filters, people have a lot of options to choose from. People who lack money or resources to get ahold of these devices suffer. At the camps, there are acts being done to provide water that includes drilling boreholes, setting up water distribution systems, desludging old latrines, bucket chlorination and distributing domestic water filters. There are other technologies where backpacks are used to filter water, but these all use plastic filters that need to be disposed of and are not easily replaced which is not feasible for the Rohingya refugees.

The solution is a portable and sustainable water filtration system. In the case of the design outlined here, the system is a water-carrying backpack with an integrated xylem water filter. The backpack allows mobility for the user, **while** the xylem water filter **is fully** replaceable without needing more than a few tree branches.

By designing a system that can be sustained solely by the user, it will hopefully be more accessible to those in need, while still providing the level of water quality necessary for safe consumption.

II. XYLEM WATER FILTER

Filtering water using plant xylem tissue allows for filtering of water using a sustainable process. By reusing the mechanism that plants perform to filter water from their roots to their leaves, a near-indefinite filtration process can occur. Also, minimal work and training are needed to construct a filter in a remote area. The goal of the filter outlined in this section is to be efficient at removing bacteria from water sources, as well as being easily constructed without many external resources.

II.A. Principle of Operation

Xylem is a group of tissues within the tree that are responsible for transporting water and nutrients (in the form of sap) from the roots to the leaves of the plants.

Xylem contains multiple subtypes of tissue which are responsible for filtering and moving nutrients and water. Vessel elements form large chains of cells and are responsible for the axial transport of water and nutrients. Vessel elements give most of the strength to the tree and are only found in flowering trees and hardwoods (known as angiosperms). Tracheid are elongated cells that transport water and nutrients axially in a process like vessel elements, as well as laterally through a pit structure. Tracheid are found in all types of trees (such as conifers, known as gymnosperms).

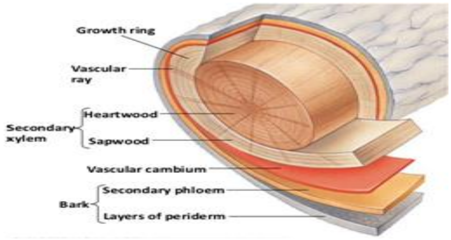

Figure 1: Tree structure.

There are two main types of xylem, known as primary and secondary xylem. Primary xylem is found at the tips of roots, stems, and buds. Primary xylem has larger tracheid and vessel elements compared to secondary elements, which limits their functionality for filtering. Their main purpose is to accumulate and distribute larger amounts of water, rather than focus on distance transportation of water. Secondary xylem is found in the trunk of the tree, as well as in branches. Secondary xylem has far smaller tracheid and vessel elements, which fare far better for water filtration.

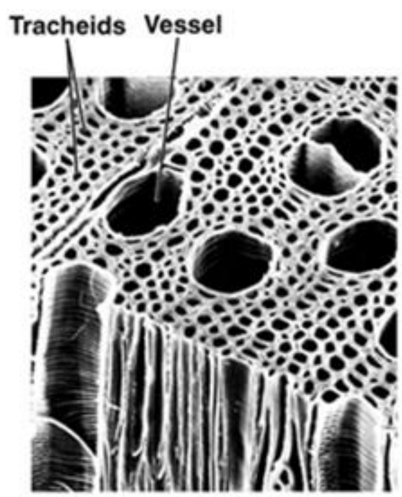

Figure 2: End view of tracheid and vessel elements.

It was found that different tree species have different tracheid and vessel element sizes, which change the rate of water transport and the amount of filtering. Conifers, such as pines, have a smaller tracheid size, which allows for better filtration. The maximal tracheid size in many conifers is a diameter of 80μm and a length of 10mm [1]. Many tracheid are smaller, and the pit size within the tracheid are on the scale of 10s to 100s of nanometers. Some deciduous trees have a pit size below 20nm, which can filter out viruses from water, however, the flow rate is lower as a result.

Water transport in live plants occurs in several ways, all of which involve inducing a higher pressure towards the bottom of the tree and a lower pressure towards the top of the tree. This can be done in a few ways ranging from increasing the pressure in the root system, to creating a negative pressure at the leaves from transpiration.

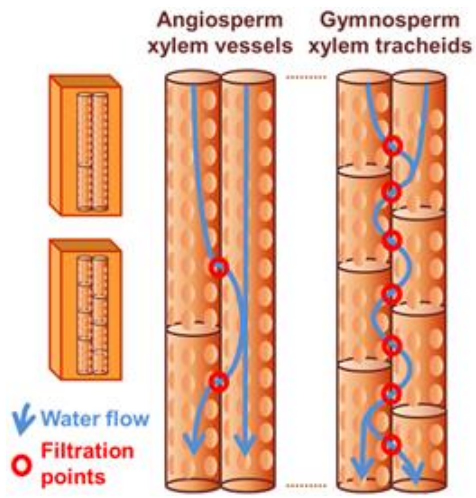

Figure 3: Water flow through xylem filter.

For the filter specified in this design, the tree species used is *pinus stronus*, which is a species of pine native to the eastern United States. Other species of pine are found around the world, with the chosen species native to parts of Myanmar, Bangladesh, and India being *pinus kesiya*. *P. kesiya* has a very similar cellular structure to *P. stronus*, and as a result, the calculations and analysis used for *P. stronus* will be used for the design of the filter using *P. kesiya*.

II.B. Filter Specifications

In the designed water filter, the only pressure mechanism needed is pressure from the force of gravity exerted on a body of water. By utilizing a 1-centimeter diameter section of a branch (now referred to as the filter) excluding the bark and outermost wood layer (removed before use) at an approximate length of 1 inch, a filtering mechanism can be constructed. The filter is inserted into a container of water with an approximate length of 2 feet. This provides a pressure of approximately 0.866 psi. The minimum pressure for xylem filtering is between 0.6 and 0.7 psi [1], which is equivalent to 1.38 feet. As a result, the filtering mechanism should hang down at least 1.38 feet from the bottom of the water container. The length of 2 feet was chosen to ensure that the filter functions properly, and at a decent volumetric flow rate.

Figure 4: Construction of a xylem water filter. a) Cut a section of branch. b) Peel the bark from the branch, exposing the xylem tissue. c) Fasten the segment of branch into a tube. d) A finished xylem filter.

With the design specifications, a volumetric flow rate of approximately 0.05mL per second was measured by researchers at MIT [2]. This corresponds to a daily flow rate of 4320mL, which exceeds the recommended daily intake of water for an adult (3.7 liters per day for an adult male, 2.7 liters per day for an adult female).

In addition to the water flow specifications, the researchers at MIT measured a bacterial rejection of at least 99.9% [2].

II.C. Filter Discussion

Although the filter specified in this design works reasonably well and is simple enough for nearly anyone to build, there are improvements that can be made that have not yet been researched.

One such improvement is the selection of the xylem material. As stated earlier, some deciduous species have incredibly small pit sizes (below 20nm), though the size of their tracheids does not shrink at the same rate. It is possible that they can trap more bacteria and potential viruses. Researchers were able to trap 20nm gold colloids within some deciduous species [3]. The smallest viruses, *parvoviruses*, are larger than this and thus can also be filtered out.

A second improvement is being able to process and preserve filters. When the xylem dries out, it ceases to function properly. This is due to the pits clogging during the drying process. As a result, the flow rate significantly drops. A secondary result of the drying process is the collapse of some tissues. This will cause water to simply pass through without being filtered, as rather than passing the water through the pit membranes it is passing directly through the ends of the cells.

III.THE BACKPACK

It is common practice within refugee camps to send the women and children to walk to the hand pumps and carry the water back to the camps. Often this is a 30 - 45-minute trip. Big plastic jugs of water are carried awkwardly on their shoulders. Bamboo is used to thread through the holes of the containers in order to allow for two people to carry several buckets of water at a time. A backpack with a removable water bladder inside will distribute the weight of the water more evenly, thereby reducing fatigue and injury. To provide a drink spout and the required height for gravity-based filtration, a thin drink tube will hang from the bottom of the water bladder. At the bottom of the tube will be the xylem filter. This end piece can then be pulled up to the user's mouth to provide an easy method for drinking water.

III.A. Backpack Specifications

The backpack will be lightweight, durable, and provides pockets for additional storage and is made from a rip-resistant nylon fabric.

Table 1: Backpack specifications

Dimensions (inch)	22 x 14 x 9
Weight (ounce)	13.9
Volume (liters)	45.2

III.B. Water Bladder Specifications

A removable water bladder, with a liquid capacity of 4 liters (128 fl. oz.), can be carried inside the backpack. More than one bladder can be carried within the backpack at a time. The bladder has a wide mouth which makes for fast, easy filling and a carrying handle. The bladder can flatten and roll up when empty. It has a 42mm screw-on cap with flexible bail handle, this makes it easy to fill from an outside water source.

Table 2: Water Bladder Specifications

Liquid Capacity (L)	4
Collapsible	Yes
Screw-on cap (inches)	1.65
Material	Thermoplastic polyurethane
Dimensions (inches)	12.1 x 8.6
Weight (ounces)	4.4

IV.CALCULATIONS

$$Volume = Length\ x\ Width\ x\ Height$$

= 22" x 14" x 9" = 45.2 liter backpack

V.CONCLUSIONS

Raising awareness about the plant Xylem water filter device in refugee camps can significantly lower the spread of waterborne diseases. Xylem has been tested to remove 99.9% of all bacteria. This is a design that promotes self-reliance and is a natural approach to problem-solving. Research at MIT is being conducted on the preservation the wood’s internal structure by soaking it in ethanol and allowing it to dry for later use. Filters must be used quickly or the tissues will lose their filtering capabilities. With the ability to preserve the filters, the filter effectiveness will increase.

ACKNOWLEDGMENTS

Much of the content and design of this filter is a result of research done at MIT in 2014 [2]. It is not clear whether this process was used informally prior to their research, but the empirical data discussed would not be possible without their work.

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Application of a Biodegradable Particulate Filter for Diesel Engines and Growing Technique to Generate Dissimilar Porous Regions

Gino R. Gasbarro*†
Rensselaer Polytechnic Institute
Department of Mechanical, Aerospace, and Nuclear Engineering
gasbag@rpi.edu
**Winner of The Inventor's Studio Startup Founder Award*
†Winner of Inventor's Studio Inventor Award

Diesel engines produce soot, or particulate matter, from the combustion of diesel fuel. Diesel Particulate Filters are used to capture particulate matter as it flows through the exhaust system. This research looks at the feasibility of implementing a biodegradable particulate filter in current diesel particulate filter systems. Three separate samples were developed with varying permeability. The back pressure generated from the filters was initially tested using a differential pressure test. CFD analysis studies indicated that of the three samples tested, one sample proved to generate back pressure below the maximum threshold. This research provides initial validation that a biodegradable particulate matter filter could potentially substitute current filters used.

I. INTRODUCTION

The diesel engine, a type of internal combustion engine, was invented in the 1890's by Rudolf Diesel. Diesel was interested in trying to improve the efficiency of internal combustion engines through his love of thermodynamics [1]. Since its emergence in the 1890's diesel engines have been further developed and improved, serving as a reliable engine used in many applications. Diesel engines work using a fuel other than gasoline (petrol) found in standard internal combustion engines. Diesel engines run off of diesel fuel, which is a less-refined product of petroleum made from heavier hydrocarbons [1]. One byproduct of this fuel, due to its less refined state, is soot. Soot is a black powdery substance that consists of amorphous carbon, produced by the incomplete burning of organic matter [2]. This soot, also known as particulate matter (PM), is one of the specific pollutants regulated by the United States Environmental Protection Agency (US EPA) [3]. The US EPA has regulatory standards established to control the emissions of pollutants which include, but are not limited to, non-methane organic gases (NMOG), carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter (PM), and formaldehyde (HCHO) found in the exhaust fumes of diesel engines [4]. Out of all the regulations put into place, NO_x and PM in diesel exhaust fumes are considered to be the most critical pollutants concerning health.

This research is focused specifically on the capturing of particulate matter, which has numerous standards set throughout all different types of vehicles powered by diesel engines. The regulations set by the US EPA differ depending upon the state a vehicle is located in and the size/type of vehicle. Regardless of the preceding considerations, the standards currently state that particulate matter ranging between the diameter sizes of 2.5µm ($PM_{2.5}$) and 10µm (PM_{10}) must be captured to a certain degree [5]. To control the amount of PM that escapes from exhausts, Diesel Particulate Filter (DPF) systems have been developed to capture particulate matter. A DPF system typically consists of a ceramic core filter, most commonly made of silicon carbide. Silicon carbide filters currently have proven to be one of the most efficient materials to capture particulate matter [6].

This paper proposes the implementation of a biodegradable particulate filter to replace current ceramic core filters within a DPF system. The primary composition of the proposed filter consists of organic agriculture byproducts and the vegetative part of a fungus known as mycelium. A growing process was developed, which is discussed, to allow for different sections of the filter to have varying degrees of porosity and material compositions. The feasibility of this type of filter is initially tested by determining the amount of back pressure created in an exhaust system using this biodegradable filter. The test parameters and results are discussed. Based upon the results of the test, further conclusions are made and a

CFD analysis was conducted to determine if this filter can potentially be used in this application.

II. EXISTING INNOVATIONS

Various companies currently develop and manufacture DPF systems including Cummins Inc., Katcon Global, Rypos Inc., and Tenneco Inc. These filters all primarily work in the same way. There are many systems in existence that use various types of filter materials, but the primary filter material used is silicon carbide. Silicon carbide is the material of choice because of its efficiency and material properties.

II.A. Silicon Carbide Diesel Particulate Filters

Current silicon carbide DPF systems work by capturing soot as it flows through the device. Figure 1 depicts a typical DPF system and the soot capturing process in augmented images.

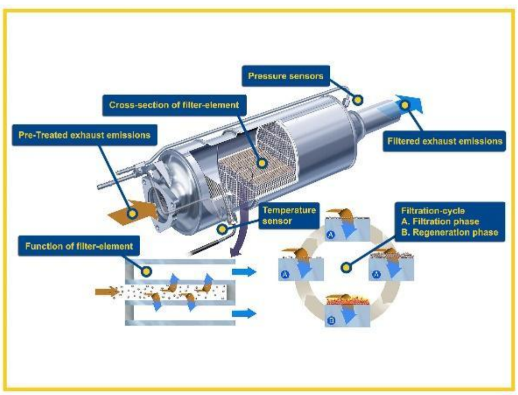

Figure 1: A typical DPF system schematic [7].

A more detailed image of the operating principles of a DPF can be seen in Figure 2. As the soot travels through a DPF, the particles are captured as the exhaust gases flow through the tiny pores of the filter walls. The microstructure of the silicon carbide allows for the tiny particles to be captured. Once the particles are captured, the purified exhaust gases flow through the open channels of the DPF and exit through an outlet exhaust.

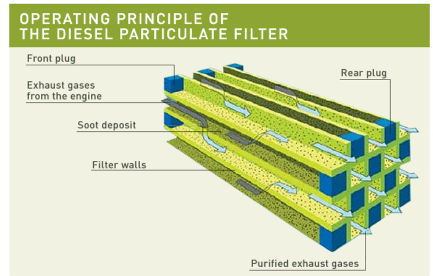

Figure 2: Particulate matter capture operating principle [7].

Manufacturers often claim that these filters have high collection efficiencies of up to 99% [8].

II.B. Issues of Current Innovations

The technologies utilized in particulate matter capture have been proven to work but do have some significant disadvantages. The first major issue with current filters is that the claimed filter efficiency and lifecycle is not always accurate. In addition, they can cost anywhere from thousands to tens of thousands of dollars for a single DPF System [9]. This does not include installation or retrofitting costs if modifications are needed to be made. Another problem is that the cleaning process of these filters can be extremely temperamental. DPF filters are typical cleaned through a self-regenerative process, which can sometimes cause sudden blockage and can lead to serious damage and warranty issues or high costs for DPF replacement [8]. Additionally, manufacturing of DPF filters are not an environmentally friendly process. These filters are developed with materials and typical manufacturing processes that require the use of fossil fuels.

III. PROPOSED SOLUTION

The proposed solution, using a biodegradable particulate matter filter in a DPF system, is an environmentally friendly filter from both a material and manufacturing prospective. The device aims to provide a new eco-friendly solution for vehicles that require the usage of DPF systems. This proposed device additionally has the capability of being manufactured at a fraction of the cost compared to current systems.

III.A. Design

The biodegradable filter design is constructed using a simple mold that allows for mycelium to grow within the voids of organic agriculture byproducts. A mold design was developed to efficiently pack the material into the mold. The main components consists of an exterior housing, base plate, internal void dowels, mold packing plate, and stabilizing plate. Additionally, a hollow dowel was created to allow for growth of alternate material to be added at a later time in the growing process as seen in Figure 3. This allows for the filter to have different porosities dependent upon the materials chosen for a specific design. This design is not limited to the pattern shown in Figure 3. Alternate dowel shapes and patterns can be used dependent upon the desired result.

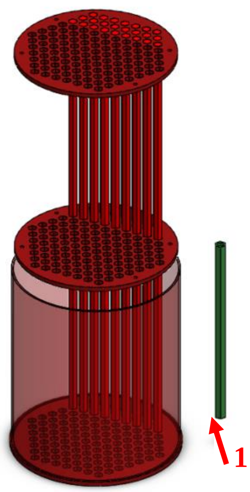

Figure 3: The mold assembly design and dowel growth inserts (1).

Using the mold shown above, the resulting filter is shown in Figure 4.

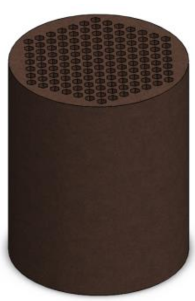

Figure 4: The resulting filter from mold design.

The microstructure of mycelium has a pore area ranging between 0.4µm^2 to 20µm^2 based upon prior research conducted [10]. The pore size of mycelium offers the capability for PM to be captured as it flows through the filters. Additionally, mycelium has a degree of heat resistance, which is beneficial for the temperatures generated in exhausts.

IV. PRELIMINARY RESULTS

The functionality of the filter design was heavily weighted on the amount of back pressure created using the filter as exhaust gas flows through it. A preliminary differential pressure test was conducted for early stage validation to determine if this filter is a feasible replacement for existing solutions. Dependent upon the engine size, the maximum amount of allowable back pressure varies [11]. For testing, a benchmark of less than 15 psi or 103.42 kPa was used. Three separate samples, with varying porosity and permeability, were made and tested using a differential pressure rig. The airflow velocity was measured at steady state using an anemometer. The outlet pressure was atmospheric (101.32 kPa) and the difference was calculated to determine the differential pressure (ΔP). Given the measured ΔP, a graph of the pressure gradient versus velocity was made to compare the samples shown in Figure 5.

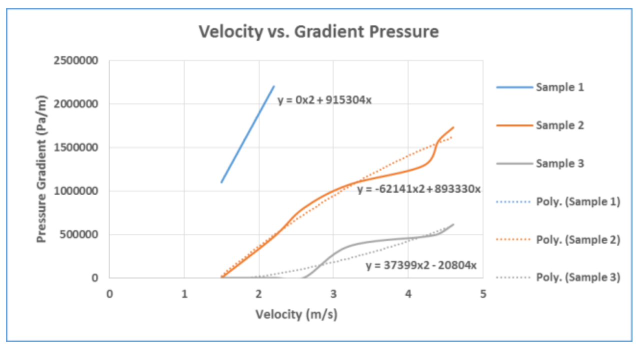

Figure 5: Gradient pressure as a function of air velocity.

Using the data collected in the differential pressure testing, polynomial trend lines were used to relate pressure gradient as a function of velocity. The assumption that pressure gradient is standard across a given thickness was made to make the simple relationship between gradient pressure and velocity. This relationship is represented by Eq. (1), where A & B are constants.

$$-\nabla P = Av^2 + Bv \qquad (1)$$

Using the relationship between pressure gradient and its dependency on velocity, Computational Fluid Dynamics (CFD) studies were conducted to look at the back pressure and airflow generated within a typical DPF system. The three equations from Figure 5 were used to characterize the permeability of the porous medium in the computer analysis.

The CFD analysis conducted for sample 1 in Figure 6, shows that the filter permeability was not great enough for the desired application. The sample generated back pressures in excess of 1,300 psi, which is almost a 9000% percent increase from the benchmark of 15 psi.

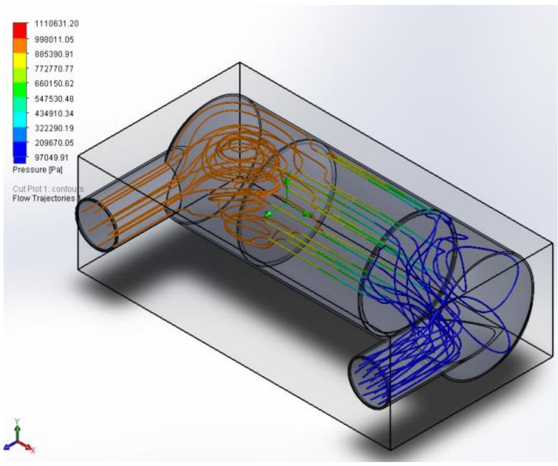

Figure 6: CFD analysis of the back pressure generated with sample 1 in DPF system.

The CFD analysis conducted for sample 2 in Figure 7, shows that the filter permeability was still not great enough for the desired application. The sample generated back pressures in excess of about 30 psi, which doubled the benchmark.

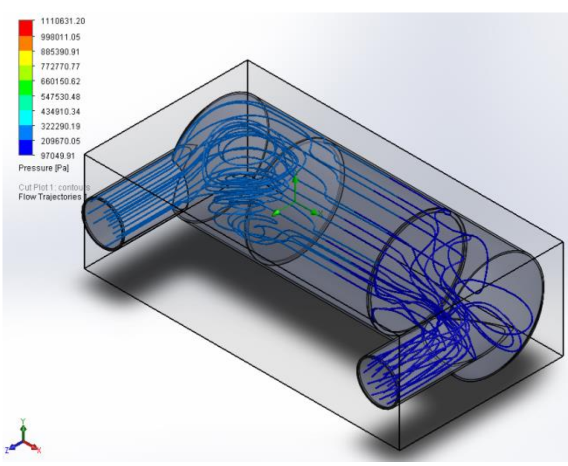

Figure 7: CFD analysis of the back pressure generated with sample 2 in DPF system.

Lastly, the CFD analysis conducted for sample 3 in Figure 8, shows that the filter permeability was great enough for the desired application. The sample generated back pressures just below the benchmark of 15 psi at about 14.8 psi.

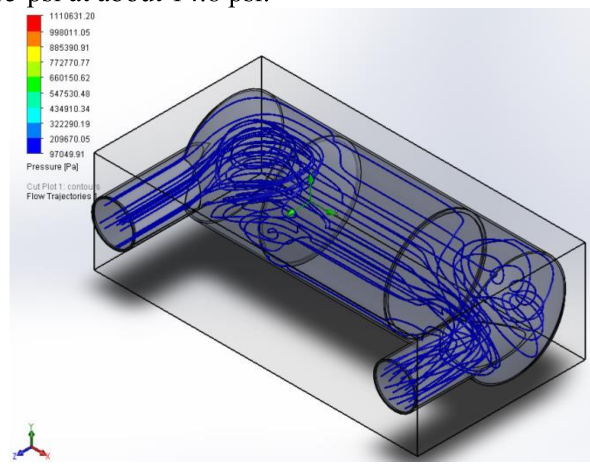

Figure 8: CFD analysis of the back pressure generated with sample 3 in DPF system.

The CFD studies conducted for all the samples further validated the potential use of a biodegradable PM filter in current DPF systems. Samples 1 and 2 are not feasible for the application, but sample 3 did prove to be feasible.

V. CONCLUSIONS

The use of a biodegradable particulate matter filter shows promise to be a feasible substitution in current DPF systems through preliminary testing. Out of the three samples tested with varying permeability, only one sample proved to have enough permeability to generate back pressures below the maximum threshold of 15 psi through a CFD analysis. This research shows the potential for using an eco-friendly product to combat the production of soot in diesel engines. Further testing should be conducted to prove the repeatability of the testing. Additional tests should be done to determine the specific PM sizes that can be captured, as well as the expected life cycle and filter efficiency.

ACKNOWLEDGMENTS

The author would like to thank Professor Asish Ghosh and Gavin Macintyre, co-founder of Innovative Design, for providing valuable input toward the development of the device. Additionally, the author thanks the NSF I-Corps program for providing funding to gain valuable information towards determining a potential target market for this device.

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Engineering a Universal High Temperature Reactor Fuel

Paul Blejwas
Rensselaer Polytechnic Institute
Department of Mechanical, Aerospace, and Nuclear Engineering
blejwp@rpi.edu

A universal fuel element composed of TRISO (Tri-structural Isotropic) fuel particles with Uranium dioxide fuel embedded in a monolithic Silicon Carbide (mSiC) matrix with an additional unfueled mSiC exterior layer which serves as cladding is proposed for use in a variety of reactor types. Due to the favorable thermal conductivity and ultimate tensile strength of the mSiC, the proposed element has several advantages over currently used fuel, including a lower operating temperature, similar or increased time until element failure after a severe accident, and decreased the rate of fuel and fission product release as compared to existing reactors in every studied instance. The analysis presented in this report can easily be applied to other fuel types and matrix materials if further exploration is desired.

I. Introduction

There are many ongoing efforts by various researchers to develop accident tolerant fuels for nuclear power reactors, including modifying the cladding of existing fuel rods and encapsulated and embedded fuel suspended in a rod-shaped matrix [1] [2] [3] [4]. The primary goal of such efforts is to develop fuels that effectively retain fission products during normal operating conditions and anticipated and beyond design basis accidents. Among the many accidents that are considered during the design of Commercial Nuclear Power Generation Facilities, the Power-Coolant Mismatch Accident (PCMA) is of particular concern. A PCMA occurs when the capacity of the primary cooling system of the reactor fuel decreases such that it is unable to adequately remove the heat generated by the fuel, leading to a temperature increase in the fuel and possible fuel melting and release of fission products. The design of a single fuel element for use in currently operating light water cooled thermal (LWR, i.e. AP-1000), high temperature gas thermal (HTGR, i.e. GTHTR300), and sodium cooled fast reactors (BN-800) has the potential to significantly reduce the dependence on active safety systems in existing and future reactors as well as allow for universal development and operating experience with little to no disruption of overall existing reactor characteristics. The elements designed for use in each reactor type differ only in their geometry and fuel masses; the same features and materials are used in different proportions in each reactor.

I.A. Universal Fuel Element Composition

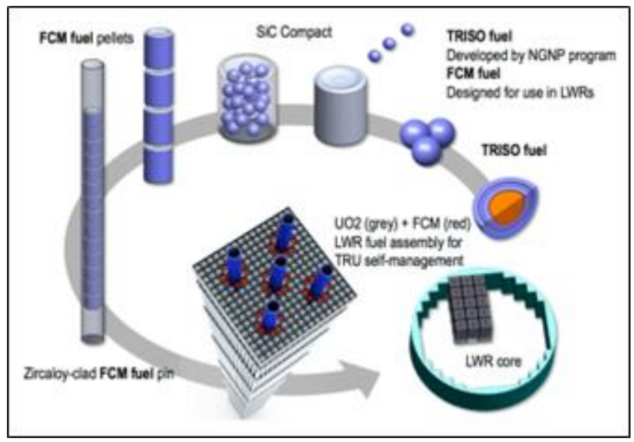

Figure 1: An existing fuel concept. Note that fuel pellets made of matrix material are used in place of a monolithic matrix. [1]

A universal fuel element is composed of three parts- small fuel particles, a matrix material to contain these particles, and an exterior unfueled zone of the matrix. For the purposes of this analysis, the fuel particles will be modeled as TRISO (Tri-structural Isotropic) particles [5]. In the universal fuel element, the particle packing fractions and fuel enrichment are chosen to match the fuel content of reference designs of the LWR, HTGR, and SCF. Figure 1 shows an existing concept for a "Fully Ceramic Microencapsulated" (FCM) fuel element of similar form to the universal fuel element developed in this report [1]; a noticeable difference is the use of fuel pellets composed of a matrix material with a physically separated cladding in the FCM concept as opposed to a monolithic fuel matrix and layered exterior fuel zone that functions as a cladding in the universal fuel concept. In either case, multiple barriers (TRISO particle coatings, matrix, and cladding) exist to prevent fission products from entering the primary coolant, more than currently exist in any of the three reference designs.

II. Methodology and Modeling

The goal of this project was to study the behavior of a composite fuel rod under both Normal Operating Conditions (NOC) and an extreme PCMA; in order to ensure a complete image of each modeled core, the hottest location in the core as well as the core average was studied. Under NOC, the failure fractions (the expected fraction of fuel particles able to release fission products to the primary coolant) were examined through the development of a one-dimensional fuel rod model which calculated the centerline temperatures of a fuel rod as well as the associated structural and thermal cladding stresses as a function of axial position for given reactor properties. The radial temperature profile of each fuel element of interest is calculated by working inwards from the bulk coolant to the composite matrix surface using the known geometrical and power characteristics of each fuel rod. The bulk coolant, fuel element surface, cladding interior, and fuel centerline temperatures at each axial location are then used to understand the axial temperature profile of each fuel rod. A dispersion fuel model was used to find the effective thermal conductivity of the fuel matrix with embedded fuel particles [6] [7], an iterative procedure was developed in MATLAB to evaluate the irradiated thermal conductivity for both the cladding and composite matrix [8] [9] [10]. Structural and thermal stresses on the cladding were considered [11]. Under PCMA analysis, the anticipated time until failure was calculated for each examined case. Here, a worst-case PCMA event is defined as a constant decay power of seven percent of that under NOC with no heat removal from the surface of the fuel rod. For both the composite matrix and cladding, only monolithic Silicon Carbide was considered. The analysis and models used in this report should easily allow for other materials to be substituted in if desired.

Each composite fuel is designed with the intent of producing an identical amount of power as that of its replacement. The geometry of the rods is kept to the same outer dimensions as that of the existing fuel such that a full core redesign of the core thermal hydraulics is not necessary. Neutronic analysis of the core was not conducted; instead, the amount of fissile material (U235) in each fuel rod (evaluated at the core average enrichment) as well as the fuel burnup of the rod is kept the same as existing reactors and all energy from the fuel rod is assumed to come exclusively from this fissile material. Under NOC, the failure of the rod is defined as the release of fission products to the primary coolant loop. This is only possible when a fuel particle, the composite matrix, and the cladding all fail in close proximity to each other in the same fuel rod. The composite matrix will not be considered a barrier for fission products, instead only the fuel particle and cladding failure fractions will be tracked. This will produce a conservative estimate of the probability of rod failures. Lastly, in the mechanical analysis of each rod, creep is not considered. For this preliminary analysis mechanical creep does not have as drastic of an effect as the other modeled parameters.

Using a MATLAB model [12], the packing fraction of TRISO particles was studied as a function of fuel enrichment. From manufacturing experience, the upper limit for embedding TRISO particles into a matrix has been found to be approximately 0.60, but a maximum packing fraction of 0.45 is more easily and regularly obtained [2]. It was found that the existing BN-800 fuel does not have a viable packing fraction; at 100% enrichment, the packing fraction is nearly 0.70. Because this value is well above the acceptable packing fraction range, modification to each fuel pin is necessary to ensure that an acceptable packing fraction can be achieved. This can be done by increasing the active core height by removing the reactor's breeding blanket and utilizing the volume for fissile fuel pellets. This will alter the linear heat generation rate of each fuel pin in the reactor, but will not affect the total power produced per fuel pin.

An upper bound on survival time for each fuel element after the initiation of a PCMA can be approximated by the amount of energy that can be absorbed by the interior of the cladding near the hottest section of the fuel element before the cladding material reaches its failure temperature. As a conservative estimate and because the modeled SiC fuel matrix and cladding have similar physical properties, the cladding of the fuel rod will be assumed unreliable when the matrix centerline reaches failure temperature, defined here as 1600ºC, where the TRISO pressure vessel failures due to thermal decomposition is no longer considered to be negligible [8]. The below equation shows the relationship between temperature change and local absorbed energy.

$$E = (T_{fail} - T_*)C_p\rho\pi r^2 \quad (1)$$

Where: E is the local energy that can be absorbed [kW-s/m], T_{fail} and T_* are the failure and local NOC temperatures, respectively [^oC], Cp is the specific heat of the matrix material [kJ/kg-^oC], ρ is the density of the composite matrix material [kg/m^3], and r is the outer radius of the matrix [m]. In order to further simplify the analysis, the densities of the particles are assumed equal to that of SiC. This assumption is conservative in that it will underestimate the density behaviors of the fuel particles and thus produce a conservative estimate for the local energy that the fuel rod can absorb. In order to verify the thermal methods used to analyze PCMA temperature increases, a standard test case was run with the FRAPTRAN 1.4 fuel transient analysis computer code [13]. A benchmark input file was selected which models a single fuel rod in an LWR undergoing a LOCA accident; the centerline temperature results were in excellent agreement, with the MATLAB model consistently over estimating the fuel centerline temperature by ones to tens of degrees Celsius, leading to conservative results. This verification gives confidence that the temperature results and their dependents presented in this report are conservative.

Somewhat counterintuitively, the survival times under both constant and decaying power do not always increase with decreased packing fraction; this is due to the high specific heat of the Pyrolytic Carbon which composes approximately 60 percent of the volume of a TRISO particle. For both the AP-1000 and GTHTR300 reactors, optimal core average packing fraction (from an accident survival perspective) appears to be around 45%. Based on the more limited data of the modified BN-800, this reactor follows the same trend, with increased survival times around the 50% packing fraction mark. For all reactors, however, the hottest rod analysis indicates that a decrease in packing fraction leads to marginally smaller increases in survival time of the element. Overall, the GTHTR300 boasts the largest survival times of all fuel elements studied. This is due to the incredibly large cross sectional area of the fuel element. In all cases, this rod design has a large mass and is therefore able to absorb more energy before reaching failure temperature than the other fuel rod designs.

Table 1: Selected packing fractions, enrichment, and core average fuel particle power particles.

Packing Fraction [%]	AP-1000 Enrichment [%]	AP-1000 Average Fuel Particle Power [mW]	GTHTR300 Enrichment [%]	GTHTR300 Average Fuel Particle Power [mW]	Modified BN-800 Enrichment [%]	Modified BN-800 Average Fuel Particle Power [mW]
60	31.2	49.8	6.5	5.5	82.7	110.1
50	37.4	59.7	7.8	6.6	99.3	132.3
45	41.5	66.2	8.6	7.3	- - -	- - -
20	93.4	149	19.4	16.5	- - -	- - -
5	- - -	- - -	77.4	65.8	- - -	- - -

Several improvements of the universal fuel element over existing fuel were made apparent through the conducted analysis. These include: a lower fuel temperature during normal operation, a grace period between the initiation of PCMA and fuel rod failure, and low release rates of Uranium and fission products under both normal operation and PCMA conditions. These improvements were achieved with no disruption to any of the geometrical, power, or operation characteristics of the three existing cores with the sole exception of the Linear Heat Generation Rate (LHGR) of the BN-800. In order to ensure compatibility with a universal fuel element and keep all other core parameters the same, the reactor must remove its breeding blanket and reallocate the volume for use by the mSiC composite fuel.

III. Conclusions

For the studied packing fractions, all reactors had maximum fuel centerline temperatures in the range of 1000 – 1200^oC and core average fuel centerline temperatures between 600 – 1000^oC under normal operating conditions. For the AP-1000 and GTHTR300 reactors, these represent significant decreases in reported core maximum fuel centerline temperatures; the maximum temperatures decrease by nearly 500^oC and 200^oC, respectively. This is due to the significant increase in thermal conductivity from pure UO2 (for the AP-1000) and carbon compacts (GTHTR300) to the composite mSiC matrix. The elimination of the gas gap and its associated temperature drop in the AP-1000 also contributes to the lower maximum temperature.

The conservative grace period found between the initiation of the PCMA event and element failure, based on a decreasing decay power, ranges from less than one hour to greater than 36 hours between the three examined reactors. Using a similar conservative analysis, this grace period is found to be on the same order of magnitude as that of the existing grace period for the AP-1000 (1 – 10 hours); in nearly all core average cases, the grace period in the GTHTR300 from the universal fuel element (> 36 hours) was found to be greater than that of the existing grace period (approximately 20 hours). This period assumes no makeup coolant inventory is available or emergency systems are operational. In reality, both the AP-1000 and GTHTR300 have passive cooling systems that at the very least greatly prolong this period; the AP-1000 is able to sustain passive cooling and stave off failure via high temperature for 72 hours [14] [15]. The GTHTR300 is currently designed such that the existing fuel element will never reach 1600ºC (conservative failure criteria in this analysis) under any conditions [16] [17]. The failure fractions under normal operating conditions for each studied instance range between 10^{-6} and 10^{-10}; this represents substantial retention of both fission products and Uranium fuel. These low failure fractions are largely attributable to the high ultimate tensile stress of the mSiC cladding and the retention of fission product gasses by the SiC TRISO pressure vessels. When failure criteria for the universal fuel elements have been met (1600ºC) under PCMA conditions, the overall failure fraction decreases significantly (between 10^{-14} and 10^{-17}); this is largely due to depressurization of the reactor, greatly decreasing the effective stress on the cladding. These failure fractions correspond to Uranium exposure rates that are between three and six orders of magnitude smaller than currently operating LWRs [18]. Future development on this universal fuel element can come in the form of consideration of alternative fuels to UO2 (such as Uranium nitride, UN) and various fuel particle designs (such as BISO- Bi-structural Isotropic- particles). These can lead to increased flexibility for packing fraction ranges, enrichment percentages, and ultimately the composite thermal conductivity of the universal fuel element and significantly alter the projected NOC operation temperature and PCMA survival time. It should be noted, however that under current regulations, any design with greater than 20% U235 enrichment is not feasible. An examination of the expected fuel particle property distributions due to their method of manufacture as well as the expected failure fractions of the particles in a fuel element due to these imperfections allows for recommendations to be made regarding the processes and particle tolerances as well as a more complete understanding of failure fractions induced by manufacturing defects. Finally, additional geometric arrangements of the fuel elements, along with the shape and size of the fuel elements themselves, could be examined to ensure smooth cross-reactor compatibility. This could possibly extend to other reactor designs not originally considered.

Table 2: Exposed kg UO2 per GWe, at PCMA failure temperature of 1600C

	PF	E [kW-s/m]	PCMA Survival Time	Exposed [kg UO2 / Gwe]
AP-1000, hottest rod	60	99.84	< 1 hr	- - -
	45	138.52	< 1 hr	- - -
	20	147.78	< 1 hr	- - -
AP-1000, core avg	60	222.20	1 - 10 hrs	1.01E-5
	45	235.84	1 - 10 hrs	7.63E-6
	20	229.95	1 - 10 hrs	3.39E-6
GTHTR300, hottest rod	60	870.04	10 - 20 hrs	- - -
	45	989.66	10 - 20 hrs	- - -
	20	984.23	10 - 20 hrs	- - -
	5	985.52	36 - 48 hrs	- - -
GTHTR300, core avg	60	1228.47	36 - 48 hrs	1.43E-3
	45	1279.73	36 - 48 hrs	1.08E-3
	20	1242.19	36 - 48 hrs	4.77E-4
	5	1222.22	36 - 48 hrs	1.20E-4
BN-800, hottest rod	60	55.05	< 1 hr	- - -
	50	72.60	< 1 hr	- - -
BN-800, core avg	60	102.80	< 1 hr	3.25E-6
	50	144.85	< 1 hr	2.71E-6

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Section II:
Innovation and Design

Nom-Nom: An All-inclusive Plastic Processor

Fariha Ahmed, Sebastian Garcia
Rensselaer Polytechnic Institute
Department of Mechanical, Aerospace and Nuclear Engineering
farihahmed25@gmail.com, sjgarciap@gmail.com

Everything from pellets to disposable plastic products eventually makes its way to landfills and oceans, ultimately causing harm to a myriad of aquatic ecosystems. The rise of 3D printing contributes to an increasing amount of plastic production, which experts believe will come to make up 20% of total oil consumed annually. Efforts to recycle have attempted to alleviate the impact of this plastic overload, but they have rarely been as successful when it comes to 3D printing technology.

This project aims to develop a comprehensive all-in-one solution to recycling plastic. It will contain a motorized grinding mechanism that will granulate recyclable plastics such as one time use bottles and reuse the resulting resin to make filament for 3D printers. Although similar solutions exist in the market, this product will aim to be user-friendly and more efficient. The team will employ an empirical approach to designing the device, bolstered by analysis based on heat flow and polymer viscometry. Solutions already on the market will be examined and reverse-engineered to see what components can be improved upon or streamlined and from the solution, benchmarking will drive the iterative design of the new solution.

I. INTRODUCTION

When plastic is not handled properly, it ends up in landfills, oceans and even in urban areas. Many fence line communities face adverse effects of large-scale plastic production, like carcinogenic chemicals that permeate through the air and contaminate their soil [2]. Even if one does not live in an area directly affected by these toxic byproducts, they may very well ingest them. One common way plastic can be potentially ingested is through seafood since fish may inadvertently consume the plastic products and byproducts that find their way into the ocean. Once in the ocean, the plastic trash can harm other aquatic animals and ecosystems as well. According to a study done by the Marine Biology and Ecology Research Centre, over 260 species that thrive from the ocean have been reported to suffer from movement impairment, reduced reproductive output, and even death as a result of plastic interactions [3]. At this rate, the lack of plastic handling and recycling is not only harming surrounding ecosystems and other species, but also the ecosystem inhabited by humans.

The idea of recycling has been a new concept to many in the last few decades. In fact, corporations and households are just now starting to adopt the idea of recycling as the idea of "going green" is becoming more and more popular. But little does every recycler know what happens to their one-time used water bottle when they toss it into the green bin. People are often content with throwing something in a recycling bin and not questioning where it goes after. People are generally alienated from the process of recycling. The problem has escalated to the point where there is currently a recycling crisis between China and the United States. China announced that they would cease to take in more recycling from America, leaving tons of recycled materials in limbo [4]. This crisis is due to the sheer volume of unclean plastic materials sent to China for them to recycle which can be very costly for them. Yet, many Americans remain blissfully unaware that their recycled goods are not actually seeing the reuse that they envisioned.

Even if everything was being properly recycled, the current methods would still not be ready to keep up with the increasing production of plastic. Landfills currently do not contain enough water or oxygen to allow for even the most degradable polyester to hydrolyze and break down [5]. If people were made aware of just how hard it is to keep up with the consumption of plastic, then they could be better persuaded to change their ways.

II. PROPOSED SOLUTION: NOM-NOM

II.A. Current Solutions on the Market

Many have tried to tackle the plastic problem within the context of 3D printing filament, but their solutions have fallen short in one or more aspects. One of the more well-known solutions, the

Protocycler, is touted as the world's only comprehensive system for turning recyclable material into printer filament [6]. This system, however, costs much more than a typical 3D printer and requires a great deal of manual input from the user, making for a somewhat inefficient process. The Filabot is another solution that requires that the user do most of the grinding of the material beforehand, and is more expensive still [7]. Additionally, the Filabot does not have a grinding mechanism and therefore no recycling component. To create new filament, virgin plastic particles are inserted into the Filabot which is not environmentally friendly as it is creating materials using 100% new plastic. The inefficiencies in these solutions can deter possible customers from the concept entirely, and instead make them resort to the typical, unsustainable filament resources. This solution space is still growing, and so there exists the opportunity for another solution to build upon those that came before to deliver a more compelling recycling experience.

Although there are similar products in the market, many are not patented. While searching for patents, a few non-US patents were discovered, but none that were eligible in the United States. Table 1, below, shows competitor products in the market alongside Nom-Nom.

II.B. Objectives

The ideal solution to this growing problem is an autonomous, multi-functional device with the consumer in mind. This device will be compact and automatic to ensure that recycling plastics is not a hassle for users. It will have a sorting component so the user can put in any type of plastic without having to read codes and determine what plastic is inserted into the machine. The device will then process the plastic and upon command start to create the desired output for the user. This could be 3D printing filament, a sheet of plastic to thermoform, or even molten plastic ready to be filled into a mold.

Table I. Compare and contrast with existing products.

Products	Nom-Nom	Filabot [6]	Proto-cycler [7]	Gigabot X [8]
Price	N/A	$3,800	$1,700	$9,500
Grinding	Yes	No	Yes	No
Melting	Yes	Yes	Yes	Yes
Printer attached	No	No	No	Yes
Automatic	Yes	N/A	No	N/A

II.C. Design Overview

This project aims to develop a new, comprehensive process that creates filament by grinding up common recyclable items such as plastic bottles. Instead of offering separate, free-standing components that each accomplish one part of the recycling process, the solution will aim to combine these functions into one user-friendly system. Unlike previous iterations, this process will also aim to be more efficient by breaking down smaller scraps like rafts and supports, in addition to the larger components. That way, more of the plastic that is put into the system is coming out as viable filament.

III. DESIGN PROCESS

The need was initially identified after personal frustration with the lack of a system to recycle old 3D printing projects as well as the increasing production of plastic products that shows no sign of slowing down. After doing some research on what products are available in the market to solve this issue, a concept was designed since none of the products meet all the desired needs. Once the first iteration was designed, a preliminary patent search was done. The search yielded no US patents with a similar mechanism, and so more validation was sought through a series of customer interviews. The need for the product was confirmed by both the customer interviews and the growing number of companies trying to tackle the same problem with similar solutions.

A couple more subsystems were added based on the feedback gained from customer interviews. One such idea was a sorting machine, which would help users sort through various types of plastics and reuse similar plastics to create another object. This component was later added as a subsystem for the entire machine after customer feedback. Table 1 below shows the customer requirements and the product/performance specifications gathered and determined after interviews and ideation phase.

Table II. Customer Requirements & Product and Performance Specifications.

	Customer requirements	Functional requirements	Technical interpretation	Technical specs
Performance	Takes in recyclable plastic	Grinding object into pellets	Bi-directional blade	Blade stiffness
		Autonomous	Motorized	Torque requirement: 10 Nm
	Covnerts pellets into usable plastic	Melting	Single screw extrusion	Max temperature range: 180 - 260 C
	User-friendly	User experience	Graphic user interface	LCD screen dimensions: 4 x 3 in.
		Intuitive design	Minimie user inputs	No. of user inputs: <3
	Produces ready-to-use material	Outputs material in a processable form	Outputs semi-crystalline plastic strands	Strand diameter: <3mm
Product	Doesn't produce a lot of heat	Efficient heat transfer	Fan cooling	Fan sie: >50 cfm
	Not too bulky	Compact size	Minimize weight and volume	Max dimensions: 2 x 1.5 x 3 ft.
			Minimize weight	Max weight: <40 lbs
	Feels good to touch	Ergonomic	Rounded edges	No right angles
			Soft grip on handles	Neoprene handle

The approach for this project will be to first analyze and reverse engineer some of the current solutions in the market. The first component will be a grinder-like mechanism that is used to create small plastic pellets from recyclable material or even old 3D-printed prototypes. This has the potential to be automatic through the implementation of sensors that drive a motor. The next component will be a storage unit to catch and store the plastic pellets after the grinder crushes the object. Once this storage unit is filled, a screw system, similar to a miniature plastic injection molding machine, will melt down the small pellets using friction to create a molten plastic that can be extruded into the filament for the 3D printer. It will then be spun around an automatic spinning spool similar to the filament spools sold. The spool can then be detached and installed into a regular 3D printer setup where the printer will utilize the freshly recycled filament to make prints. Figure 1 illustrates a cross-section what the concept might look like. It splits the system into two subsystems - the grinding mechanism and the extruding mechanism.

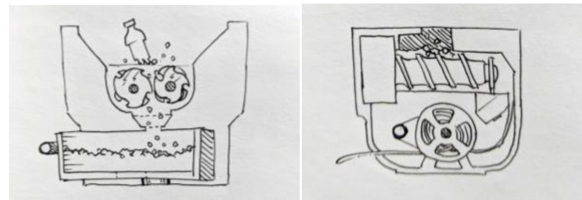

Figure 1. Initial sketch of proposed concept.

The proposed mechanism will take the best aspects of the current solutions and deliver them in a concise product. It will attempt to do so using only recycled materials, without the aid of virgin plastic or at least a much smaller quantity of virgin plastic. Current solutions make use of at least 50% new and raw plastic resin, a percentage that will decrease significantly with this product. Figure 2 breaks down system and subsystem analysis below.

III.A. Initial Prototypes

The very first physical model of the grinder is a miniature 3D printed model of a single grinding shaft with five saw blades. Figure 3 shows screenshots of the CAD model associated with the 3D printed part, Figure 4, of the first prototype.

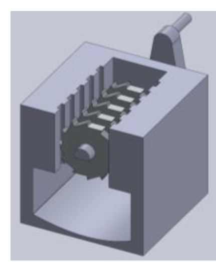

Figure 3. Isometric view of 1st prototype CAD.

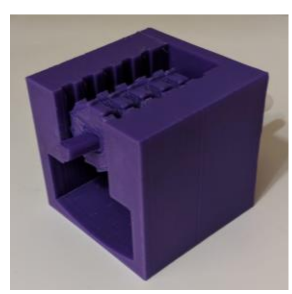

Figure 4. Isometric view of 1st prototype 3D-printed.

III.B. "Looks-like" Prototype

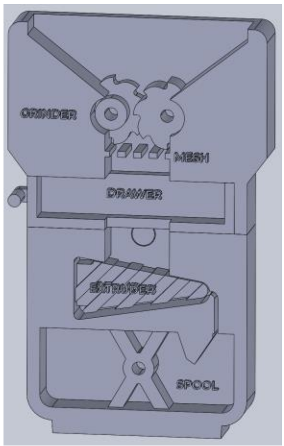

Figure 4. Looks-like prototype, illustrating the cross-sectional layout of the machine's subsystems.

III.C. Functional Prototype

The functional prototype in Figure 6 contains a double grinding shaft with inward rotation to break down plastic components. It is a repurposed credit card shredder modified to take in larger pieces of plastic parts such as old 3D prints or recyclables and grind them into smaller particles. The first functional prototype needs some improvements such as a lid for the grinder to avoid spilling plastic pieces as they are being grinded, a more powerful motor with a higher torque output to grind larger objects into finer particles, and a better mesh solution as the current one is too rigid for the plastic particles to flow through seamlessly.

Figure 6. Functional prototype for the grinding mechanism.

Figure 7. Post grinding plastic particles.

IV. FUTURE WORK & CONCLUSIONS

As this semester concludes, the final prototype created is a functional grinding mechanism which is part of subsystem 1. After testing, it was found that some modifications need to be made to the current prototype to better meet the goals of the proposed solution. The main modifications include: adding a lid to the grinder, testing various types, shapes and thicknesses of mesh, and increase the torque output of the motor for a more efficient grinder. Next steps for this project include improving the grinding mechanism while starting to prototype the other subsystems of the device. A lot of customer discovery needs to be done as well to gain a better understanding of what the final product will look like and what features it will entail.

The ultimate goal of this process is to make recycling more accessible on a consumer level, by offering tangible results that the average consumer can utilize. 3D printing is already making an impact in the mainstream discourse, and so combining that with a message of recycling can give more people another way to look at sustainability. It will also make producing filament cheaper, and thus reduce the need to generate new plastic through other means. This product will utilize plastics already available to the customer by turning their recycling into a desired product.

ACKNOWLEDGMENTS

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FDM Printing using Aluminum Waste

Marc McDonald
MANE: Innovation and Rapid Prototyping
Rensselaer Polytechnic Institute
mcdonm8@rpi.edu

Low cost self-replicating rapid prototyper (RepReps) are leading a technological revolution in distributed manufacturing. This proliferation of distributed manufacturing, however, is being hindered by the inherent flaws of fused deposition modeling (FDM) of plastics, the most common technology used in RepRaps. These flaws include a limited selection of manufacturing materials, consumption of these specialized, often virgin, materials, as well as an inability for the user to reuse the material in failed or obsolete models. Through research and development in the Inventor's studio sequence, the feasibility of a RepRap using waste aluminum as the manufacturing material was explored. Discoveries from customer interviews and operations research demonstrated a desire for the product and modifications to improve future prototypes.

I. INTRODUCTION

One of the most exciting innovations in manufacturing over the last 30 years has been additive manufacturing, often referred to as 3D printing. Hailed as the next industrial revolution [1], models can now be manufactured on demand to exact specifications without the need for single task tools and lead times. Prototypes can be printed, tested, modified, and reprinted, yet the process is susceptible to irrecoverable printing failures. If the failure is minimal, there is potential for the print to be saved in post processing, yet total losses are not uncommon and in the vast majority of cases, and any changes to the design of the model mean the original is often completely wasted. These failures are especially prevalent in FDM printing, the most common additive manufacturing technology used in consumer RepRaps [2].

II. CUSTOMERS

The primary customers will be do-it-yourselfers, Makers, and small businesses; those customers who are most interested in desktop printers. While desktop printers make up only 19.33% of the $9.9 billion-dollar total market in 2018 [3], this segment primarily uses plastic FDM RepRaps, and would be the most impacted by the improvements of aluminum FDM.

II.A. Customer Interviews

Potential customers were asked a variety of questions focused on assessing the market need for an alternative to plastic FDM, including pain-points and potential improvements. Many described general satisfaction with the capabilities of RepRaps, but also frustration with excessive waste. When asked about potential alternatives, customers insisted that print time and strength of models had to be maintained or improved.

II.B. Customer Requirements

Following customer interviews, customer requirements were determined and further specified in order to create quantifiable metrics for success of aluminum-based alternative. In Table I, the first column lists customer requirements, while the second column lists the technical specifications of the printer and models produced to meet each requirement.

For the testing of the technical strength requirement, an identically sized model to the one used in Letcher's and Waytashek's testing will be printed on the aluminum FDM RepRap. A schematic of the sample used can be seen in figure 1.

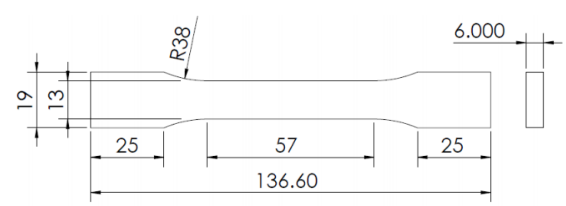

Figure 1: Tensile/fatigue specimen dimensions. [mm]

Table I: Customer requirements and technical specifications.

Customer Requirement	Technical Specification
Needs to perform as well as most consumer-oriented FDM RepRaps	Print resolution of >100 DPI on XY-plane; Total printing time of aluminum model within 10% of PLA model on 24-hour print
Recycle aluminum waste and failed models	<5% waste by model mass per print
Reliable	<10% hardware-caused manufacturing failure over 100 prints
Models are stronger than those printed in PLA	Aluminum model of Figure 1 must have ultimate tensile strength >64 MPa [4]
Desktop sized	2’ X 2’ max footprint

III. DESIGN

While both the plastic FDM and the proposed aluminum FDM will deposit material through a heated nozzle, the aluminum RepRap will require a small foundry above the build surface for the melting of the aluminum. The foundry is to be constructed with using alumina-silicate refractory bricks for insulation, Nickel Chrome kiln heating elements, and stainless steel for the crucible. While stainless steel would not be suitable for a coal-based foundry due to higher temperatures, the electric heating coils can be used to keep the foundry at 700° C, just above aluminum melting point of 660° C, but far below the melting point of type 304 stainless steel at 1400° C.

In order to maximize print speeds and reduce the possibility of spills, the foundry and nozzle component of the RepRap will be stationary. This constraint requires the printing surface to move in the X, Y, and Z axes, which will be accomplished using stepper motors and a combination of belts and threaded rods for linear movement. For the prototype, an acrylic tank will be used for user safety, as well as allow for testing in an oxygen-free environment. While it is uncertain if the formation of aluminum oxide will significantly affect the performance of the models, in the event this is observed, the tank can be used to print in an argon environment, similar to gas metal arc welding (GMAW). Figure 2 shows a prototype design matching these specifications as well as product customer requirements.

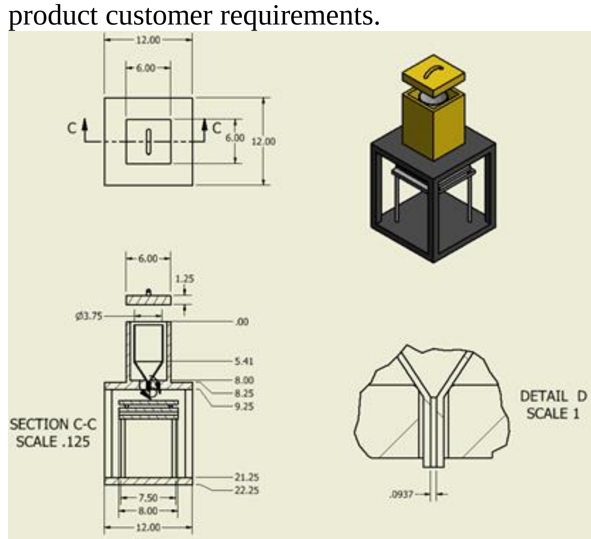

Figure 2: Computer-aided design of aluminum FDM printer prototype. [in]

IV. IMPLEMENTATION

Initial steps required to bring the aluminum FDM RepRap to market included a list of potential suppliers, input, process, output, and customers.

IV.A. Build Process

In order to construct the prototype in figure 2, a value stream mapping was constructed and shown in figure 3.

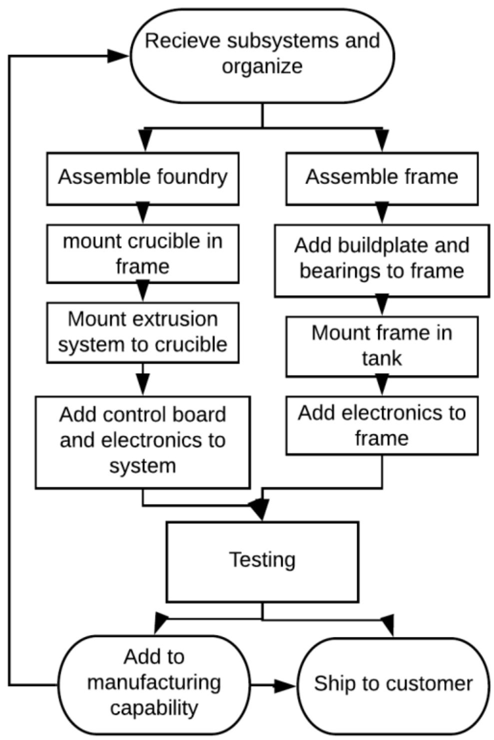

Figure 3: Value stream mapping of build process.

IV.B. Process Simulation

Using Promodel 2018, a simulation of the proposed Value Stream Mapping was designed and run. A diagram of the process map can be seen in figure 4.

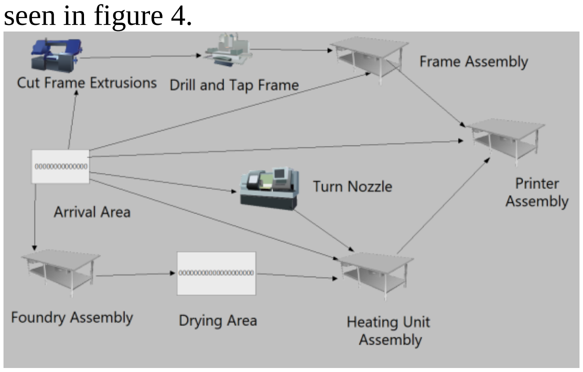

Figure 4: Schematic of process used for simulation.

Results showed 50 completed printers over 250 hours of simulated labor, with an average time in system of 913 minutes. Figure 5 shows the state at each process location as a percentage of total time. On figure 5, Green is operating, blue is idle, yellow is waiting, and pink is blocked.

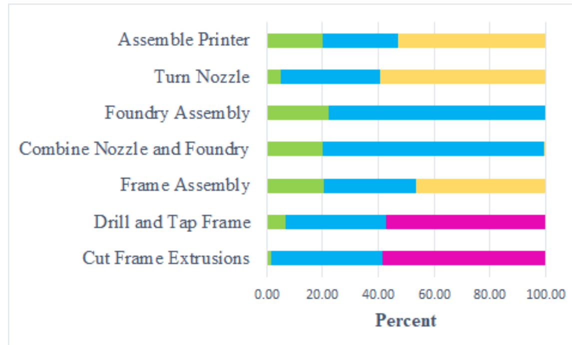

Figure 5: Location state throughout simulation.

IV.C. Customer Workflow

The process by which the customer will use the printer is described in figure 6. It is quite similar to the process already used for RepRaps, with the exception of a longer warm up time and the ability to include past prints in the collection of printing material.

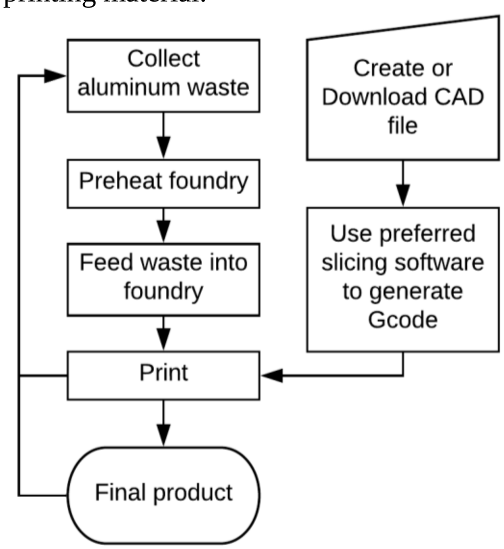

Figure 6: Value stream mapping of customer operation.

IV.D. Suppliers

Due to the small size of initial production, potential suppliers were ranked on quality, value, speed, and proximity to Rensselaer Polytechnic Institute. Proximity was especially important for the tanks, aluminum extrusions, and refractory material, as long distance shipping these components could significantly impact the cost to manufacture each RepRap. Table II lists selected potential suppliers for each component or subsystem.

Table II: List of suppliers and subsystem supplied.

Subsystem	**Supplier**
Electronics	Adafruit
Frame, Crucible, and Nozzle	80/20 INC
Tank	All Bright Aquariums
Rods and Bearings	McMaster Carr
Foundry	Lontto Refractory

VI. CONCLUSIONS

RepRaps are shaking up the entire manufacturing market, yet products in the consumer electronics segment are wasteful and limited. By using aluminum as a printing material, as opposed to plastics such as PLA, users would be able to print stronger and more durable models, while also recycling failed and obsolete models. Additionally, users would be able to freely source their materials used, creating a new vector for distributed recycling. Future work on this project will include determination of technological viability through prototype development, continued market research, and streamlining of build process to maximize value added time.

ACKNOWLEDGMENTS

Special thanks to Dr. Asish Ghosh and Tracy Schierenbeck for their experience and guidance throughout this project. Additional thanks to Brian Sposato and Peter Strbik for their partnership in Inventor’s Studio 1.

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Scalable Smart Home System for Houses, Hospitals, and Assisted Living Facilities

Christie Chen[2], Christine Ku[2], Su Ying Sun[1]
Rensselaer Polytechnic Institute
[1]*Department of Mechanical, Aerospace, and Nuclear Engineering,*
[2]*Department of Electrical, Computer, and Systems Engineering*
cheny38@rpi.edu, kuc3@rpi.edu, suns7@rpi.edu

Smart home systems currently available are not robust or adaptable enough to provide efficiency and comfort for users in multiple facets of their lives. The solution discussed combines several aspects of a person's needs into one connected system. Specifically, the lighting, health, and appliance sectors are analyzed more in depth with different products created for each sub-system, including Smart Lighting, eTextile Therapy, and the Food Tracker. This design addresses the need for better sleep, the prevailing chronic pains, and domestic food waste problem. By creating a more rigorous system, users who are infirmed, busy, or otherwise restricted will be able to be independent and have self-sustainable lifestyles.

I. Introduction

As people nowadays emphasize efficiency and pursue more convenience in life, more and more smart home devices are out in the market, such as Amazon Alexa, Google Dot and iRobot. However, these existing smart home technologies are not robust or scalable enough to adapt to the physical assistance needed by people. This project's purpose is to integrate multiple large sub-systems to benefit people who have busy schedules, people with disabilities, and the elderly in a variety of settings. Each sub-system can be used in combination or individually depending on the environment this product would be applied to.

I.A. System Design and Description

This smart home system consists of a series of Internet of Things components, such as lighting control, home security, appliance automation, sensors and robots. Each of the subsystems will communicate with each other and accomplish tasks with minimal human control. It will not only provide more comfort and pleasant to people, but also save time, money and energy.

Figure 1: Initial Sketch of Smart Home System

Table I: Sub-Systems of Smart Home System

Sub-Systems	**Customer Needs**	**Interpreted Specifications**
APP	An app for humans to make decisions	The APP of the smart home system allows humans to make decisions after receiving signals from sensors and watch.
Climate	Home temperature always stays at the most comfortable degree.	The smart home system shall adjust the temperature to adapt human body temperature.
Lighting	Help fall asleep faster and stay asleep longer	The smart home system shall adjust the lighting to adapt human body situation and human

		preferences.
Security	Doors and windows are open and closed automatically in a secure way	The smart home system shall open, close and lock the doors and windows automatically based on human's needs.
Appliances	House supplies and groceries are always in stock	The smart home system shall keep track of supplies and groceries and restock if necessary.
Robots	Provide physical help	The robots shall do most of the physically action for humans

II. Sub-System Design and Analysis

Three subsystems are presented in the following section: health, lighting, and appliances in the form of e-Textile therapy, smart lighting, and a food-tracking device. Each sub-system addresses a different problem space and uses a variety of innovations to satisfy the identified user requirements.

II.A. User Health: e-Textile Therapy

II.A.1. Problem Definition

According to the National Health Interview Survey conducted by the National Institute of Health in 2012, "25.3 million adults experience chronic pain and nearly 40 million adults experience severe levels of pain" (National Center for Complementary and Integrative Health, 2015). Chronic body pain is a condition that can manifest in many different forms including lower back pain and knee pain, and stem from a variety of diseases such as fibromyalgia and multiple sclerosis. It is "often defined as any pain lasting more than 12 weeks" (Chronic Pain: Symptoms, Diagnosis, & Treatment), and it is notoriously difficult to control and mitigate.

II.A.2. Customer Needs and Specifications

Table II: e-Textile Requirements and Details

Customer Requirements	Technical Interpretation	Technical Specification
Can accommodate multiple health conditions	Options for frequencies	1-20 Hz depending on disease
	Does not affect other bodily functions	Minimal side effects
Comfortable	Soft material	Cotton, 200 thread count
	Large enough to cover bed	Full size: 54"x75"
Can be used self-sufficiently	Does not require many operations	3 operation steps
	Does not need separate power or devices	Outlet: 120V
Connectivity	Ability to link with other IoT devices	Transfer health data automatically
Affordable	Comparable to normal bedding costs	<$150

II.A.3. Solution Description and Validation

The system level design of this innovation is an application of PEMF therapy technology and smart textiles. It is fabric, most likely in the form of a duvet for the first iteration, that a chronic pain sufferer could use at night in order to alleviate their pain. By embedding transducers and sensors into the fabric, different frequencies could be used to treat the user. The treatments would be based on user inputs of which health condition they have and where. The fabric would also track vitals such as heart rate, body temperature, and blood pressure to make sure that the user is safe. These biometrics would also be linked to the rest of the smart home system. The product would use conductive thread to connect all the sensors and transducers. There would be a main control panel in which the user could interface with the product to customize the treatment. The form of the fabric can also be changed into wearable clothing. They do not have to spend time strapping on a device or driving to a treatment. It would simply be performed while they are resting.

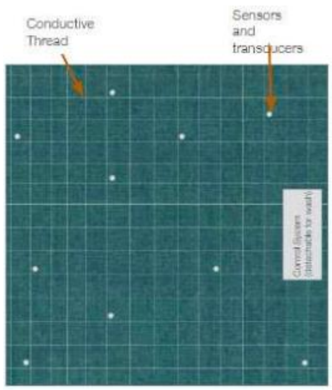

Figure 2: General Layout of e-Textile for Therapy

II.B. Smart Lighting

II.B.1. Problem Definition

According to the National Institute of Health, there are 30 percent of the population in the United States who complain about having problems falling asleep, staying asleep and being unable to sleep and wake up at the right time. Circadian rhythm plays an important role in human health. If the circadian rhythm gets disrupted, this can lead to low productivity, digestive problems, and decreased sleep effectiveness. Many night-shift workers, or people frequently travel across different time zones will most likely suffer from circadian rhythm disorders.

II.B.2. Customer Needs and Specifications

Table III: Customer Requirements for Smart Lighting Sub-System

Customer Needs	Interpreted Specifications	Technical Specifications
Help fall asleep faster	Respiratory rate and heart rate during sleep	Breathing rate: 6BPM Heart rate: 50-70 BPM
Help stay asleep longer		
Effectiveness	Advanced algorithm	Error rate < 5%
Efficiency	Energy and power usage	Electricity bill shall not exceed the current bill.

II.B.3. Solution Description and Validation

The Smart Lighting System includes three main components: a wearable device, advanced algorithms, and advanced light bulbs. The user firstly enters his/her desired sleeping schedule, then the advanced algorithm will compute the ideal breathing rate, heart rate, and brain wave pattern that matches the schedule. The wearable device will constantly detect and monitor the user's biometric data, and the data will be synced and stored in the cloud. An advanced filter designed to eliminate the noisy signals will extract the useful patterns such as the user's sleeping pattern and brain waves. The algorithm will then compare the actual data to the desired pattern, and compute the brightness and color temperature of the lighting that should be adjusted to. A command will be sent to the light bulbs and the lighting will be adjusted.

Although this design mainly tackles the sleeping disorder problem space, it can be used as a morning alarm and a motion detector. Since the user enters the desired wake up time, the lighting will be adjusted to the correct brightness based on the user's biometric data, in order to wake the user up naturally and effectively. If the user forgets to turn off the light and leaves the house, the light will be automatically turned off after a certain period of time (decided by the user).

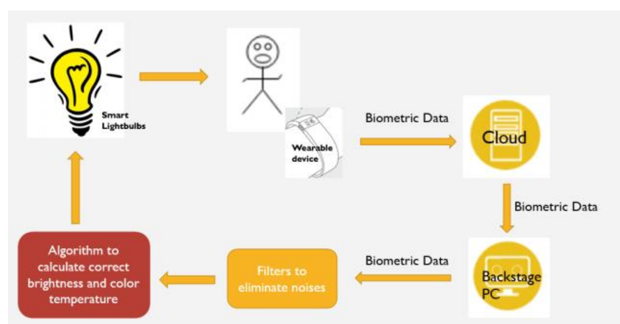

Figure 3: Flowchart of Smart Lighting

II.C. Appliances: Food Tracker

II.C.1. Problem Definition

According to the Food and Agriculture organization (FAO) of the United Nations, over a third of global food production goes to waste, and about 43% of food waste occurs in our home. Out of all these foods being wasted, one in eight Americans is food insecure. Reducing food waste from individual household level by planning and efficiently consuming the food will bring significant impact in the global level and will benefit all the earthlings.

II.C.2. Customer Needs and Specifications

Table V: Food Tracker Requirements and Details

Customer Needs	Interpreted Specifications	Technical Specifications
Convenience	Provide meal plans and prepare meals	Calculate the needed nutrition from user health info and generate meal plans based on daily 2,000 calories.
Efficiency	Fully use up the purchased food	Ensure the real-time matches food tracking data and prioritize "old" food in planning process.
Reliability	Correctly identify the food item and its freshness.	360° scanning to collect data for identification.

II.C.3. Solution Description and Validation

The Food Tracker, as shown in the schematic below, is composed of a display screen, a food container, and a gripper attached at the bottom of the container. The user can just place the purchased groceries in the container and allow it to collect the item information and organize them by the gripper and the help of a robot. The scanner is embedded on the inner walls of the container, recording the shape, the look, and the smell of the item for reliable identification and freshness tracking. The display screen allows user to access food information easily and be informed of the task status assigned to other appliances including meal preparation, laundry, house cleaning, and dish washing. The system within the device can calculate the nutrition needed by the user based on the health information provided from user's smart watch and generate a list of meal plans based on the available food while prioritizing the "old" food. As user confirmed the meal, orders will be sent to cooking appliances to prepare the meal with the help of a robot.

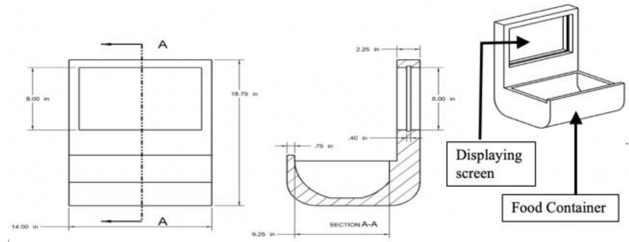

Figure 4: Food Tracker Schematic

Figure 5 shows the finite element analysis performed on the device with a maximum load of 30 lb-f. A maximum deformation of 20 in is located at the edge of the container. Since the value is so small, it is considered negligible and within the reasonable range. The maximum stress of 12.88 psi is located at the 90° corners shown in red, indicating the critical region for cracking to occur. Modification of the corners would need to be done to improve the stress durability.

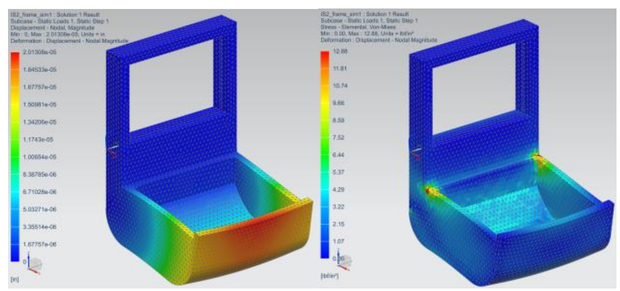

Figure 5: Finite Element Analysis for Displacement (left) and Stress (right)

II.C.4. Risk Analysis

Table VI: Risk Table

Risk Level	Possible Failure Mode	Actions Taken
H	The sensor in the wearable device fails to function.	Wearable device shall allow users to change the lighting and report to customer service.

H	The algorithm fails to recognize the pattern of the data.	Test the algorithm with various sample data sets.
H	The conductive thread breaking or tearing during washing.	Instruction manual, make the fabric a duvet/removable, waterproof components.
H	The container cracks at the sharp corners due to high loads applied.	Consider a reasonable factor of safety to modify the corner and improve the part's strength.

III. CONCLUSION

The three subsystems, the eTextile bedding, the smart lighting, and the food tracker appliances, are parts of a larger smart home system that can be used in a variety of environments. This design is more robust to assist users in multiple aspects of their lives including but not limited to treating chronic diseases, monitoring health metrics, improving sleep quality, and tracking nutrition. The smart home system can be scaled for homes, hospitals, and assisted living centers. Each subsystem can be incorporated or excluded from the particular space. In the case of hospitals and assisted living spaces, the subsystems would be able to help doctors and nurses keep track and treat their patients through biometric data, sourcing materials, and administering certain therapies. In all applications, the system level design gives users the ability to live more comfortably and efficiently.

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Pilot Manufacturing Operation Design for an All-inclusive Plastic Processor

Fariha Ahmed
Rensselaer Polytechnic Institute
Department of Mechanical, Aerospace and Nuclear Engineering
ahmedf2@rpi.edu

Through the use of six sigma lean manufacturing tools, this article discusses the early stages of setting up an operation design for Nom-Nom, an all-inclusive plastic processing device. The article first describes the product briefly before discussing the critical customer discovery stage and key takeaways from interviews conducted. It then explains the design's second iteration based on key takeaways and research via prototyping. Lastly, the article utilizes lean tools such as SIPOC, VSM and Customer Workflow to explore the pilot operation design for the product.

I. INTRODUCTION

With the rise of popularity in start-up culture, it is very important to ensure new businesses gain and remain a success, especially when it comes to longevity. The most evident way to be successful is to sell a product or service that is of value, but it can be difficult when it is not marketed properly or even to the right customer base. In fact, if the product is not marketed well, the value of it decreases as the potential consumer may not even be aware of the product. Once, the initial customer discovery is done and a market fit is established, it is important to create an operation design to ensure the business will remain successful and profitable throughout its lifetime. Consequently, another critical way businesses can be successful is by creating a manufacturing model utilizing six sigma lean manufacturing principles. Lean manufacturing principles ensure the manufacturing operation is the most efficient while reducing waste to create an optimal design. This article will discuss the journey of Nom-Nom, an all-inclusive plastic processor, from its initial design to customer discovery, key takeaways, second iteration and finally, how operation design tools are going to be utilized in its production.

II. OPERATION DESIGN

II.A. Initial Innovation Description

Nom-Nom is an all-inclusive, recyclable material processing machine that is automatic and user-friendly. With very few inputs and an LCD screen, it is highly intuitive. The purpose of this device is to intake plastic "trash" that consumers have around and break it down into small components that can be melted and extruded into new objects such as 3D printer filament or plastic for other manufacturing methods. The output material may not be as strong as virgin plastic products since plastics slightly degrade over time as they are reused, and therefore, should not be used for high-modulus applications but rather prototypes and objects that see light use. The goal for this product is to cut down the amount of plastics that end up in landfills and oceans and to reduce the environmental impacts involved in the production of virgin plastic. For further information on the initial design and research of the product, please refer to the article titled *Nom-Nom: An All-inclusive Plastic Processor* within this Journal.

II.B. Customer Discovery & Key Takeaways

After the initial design of Nom-Nom, market research was conducted through customer discovery. This was primarily done through interviews and defining the right market fit for the product. With the initial value proposition in mind, a set of customer interviews were conducted. The initial consumers of Nom-Nom were primarily thought to be students, makerspace managers and 3D printer owners. After interviews, the new customer base of focus was discovered to be educational institutions with sustainability initiatives, makerspace managers, and households. This shift was primarily due to the fact that the device is not as cost effective for students since they will not have as much to recycle on their own. Due to this, a major shift in the consumer base led to educational institutions with sustainable tendencies as they are more likely to pay for recycling pick up currently and could heavily benefit from investing in an in-house recycling device.

Makerspace managers remained as one of the potential customer base for the product as the makerspace industry is currently growing with the rise of rapid prototyping technology and cutting edge innovation in additive manufacturing. The makerspace also includes the growing DIY culture and therefore, could be a great fit for the reusable nature of the product. And lastly, households were another big focus because while students may not be able to afford a recycling device on their own, the number of personal 3D printers are growing along with the DIY culture mindset and this product could really benefit in households where the family owns a 3D printer and utilizes plastic heavily in forms of one time use objects to tupperware in the kitchen.

For this market research, a diverse group was interviewed. Among those interviewed, the most notable include: the Director of Sustainability at the University of Albany, the makerspace manager at the School of Humanities, Arts and Social Sciences (HASS) at Rensselaer Polytechnic Institute (RPI), a sustainability professor at RPI and local business in Troy, NY with sustainable initiatives. During the interviews, many had concerns about the maintenance of the product. Others were concerned about the safety of children and pets when the device is located in a household or an educational institution. There were also some technical concerns regarding the level of humidity when processing the plastic, the composition of the plastic, and finally the quality, composition and strength of the output from the device. And lastly, a major concern was the input for the product and the condition they have to be in for a usable output.

II.C. SIPOC

SIPOC is a design tool used for process improvement as part of the 'Measure' phase of the DMAIC (Define, Measure, Analyze, Improve, Control) methodology in Six Sigma process map. A SIPOC diagram refers to the five levels which are: Suppliers, Inputs, Processes, Outputs and Customers. Based on the customer interviews discussed in the previous section, a SIPOC diagram was created for this device as shown in Figure 1.

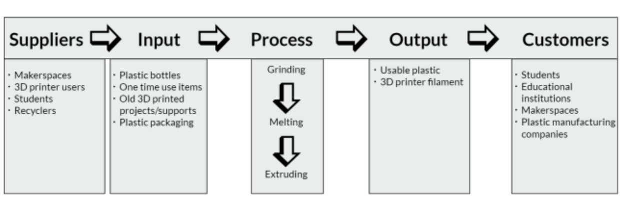

Figure 1. SIPOC Diagram.

II.D. Design Iteration Post Research & Prototyping

The design iterations made to the design of the device all address various concerns from the key takeaways from the potential customer interviews conducted. The most prominent one is the concerns around safety especially when it comes to acknowledging that the product might be around children and pets if in a household. This concern is combated by the addition of a child-proof enclosed lid which will open when the experienced or adult user prompts it to open based on inputs to the LCD screen. Other safety concerns that arose during the interviews were the concerns about off-gases from the device for which an external ventilation system has been designed. The product will also meet many regulations set forth by agencies and regulatory bodies such as the Environmental Protection Agency (EPA), Consumer Product Safety Commission (CPSC) and other as listed in Table 1.

Another concern was the maintenance of the device and ease of troubleshooting for the customer. This was addressed by adding an open source manual to the Value Stream Map (VSM) for the product which will be further discussed in the following section. To combat the technical concerns of humidity level and polymer composition, the addition of various sensors have been included in multiple locations of the device. The drawer of the device, for example, will contain both humidity and an initial material composition sensor to ensure the pellets are of the correct condition to be processed for a viable output. Another composition sensor as well as a filament dimension sensor will be included at the extruder for ensure a consistent composition and size for the entire spool of filament.

Name of Agency	Regulatory Body	List of Safety Requirements	Impact on specification for Nom-Nom
Environmental Protection Agency (EPA)	U.S. Government	• Clean Air Act; controls air pollution • Carbon footprint; excess energy consumption proliferates pollution	• Heating process must capture as much CFC's as possible • Overall system must consume as little power possible
Food & Drug Agency (FDA)	U.S. Government	• Must be safe to be in close proximity with food	• No residue from other plastics can be left in the chamber, as that can result in mixing • Polymers must be given enough time to recrystallize and form cohesive parts
Consumer Product Safety Commission (CPSC)	U.S. Government	• Normal use cannot put consumer in harm's way • Misuse within reason cannot harm the user	• Safety labels on the grinding equipment • User interface mapped to a part of the machine far from the hazards • Fuses for the heat chamber
Occupational Safety and Health Administration (OSHA)	U.S. Government	• Similar concerns to that of EPA and CPSC • Must be safe to operate with multiple bystanders in close proximity, and for extended periods of time	• Ventilation system • Grounded power adapter • Does not require specialized personal protection equipment (PPE)

Table I. Regulatory Bodies and Agencies Considered.

The next big concern was regarding the cleanliness of the input, especially if they are one-time-use items such as plastic beverage bottles and utensils and not just old 3D printed projects or print supports which do not require prior cleaning. For this, an optional cleaning mechanism was designed which can be an add-on to the product or a permanent component for future models. This will also have the added benefit of a sorting feature which can detect different plastics and sort accordingly as to not create polymer blends of incorrect ratio.

And lastly, a design iteration made from personal testing of the current prototype is changing the current mesh design which is placed above the drawer to catch large plastic particles that have not been grinded properly. Currently, the mesh size is too small and captures pellets that are of the correct dimensions to be processed further. More testing will determine the accurate dimensions for the mesh to ensure that the optimal pellet size is passed through for further processing.

II.E. Value Stream Mapping & Customer Workflow

VSM is an efficiency lean tool for combining material processing and work/information flow. It reduces waste as defined by the "7 types of waste" in lean manufacturing and analyzes the series of events from the beginnings of a product or service to the end when it has reached the customer. The VSM for this product can been seen in Figure 2 below.

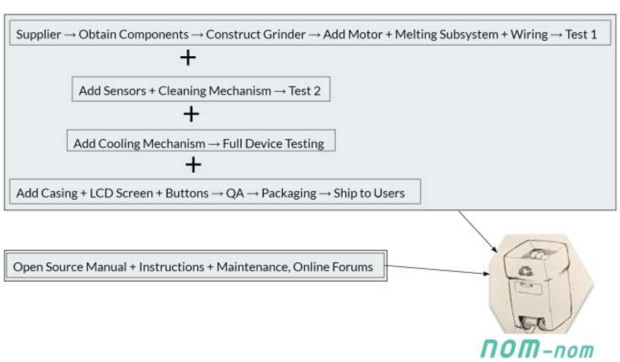

Figure 2. Value Stream Map of Nom-Nom.

The customer workflow for this product as seen in Figure 3 is the step-by-step process by which the user will operate the device for the desired output while Figure 4 exemplifies a high-level overall usage flow for the device.

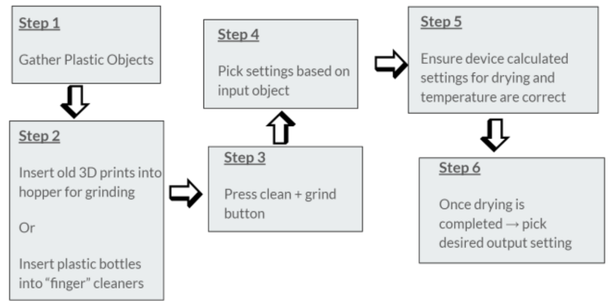

Figure 3. VSM Workflow Steps.

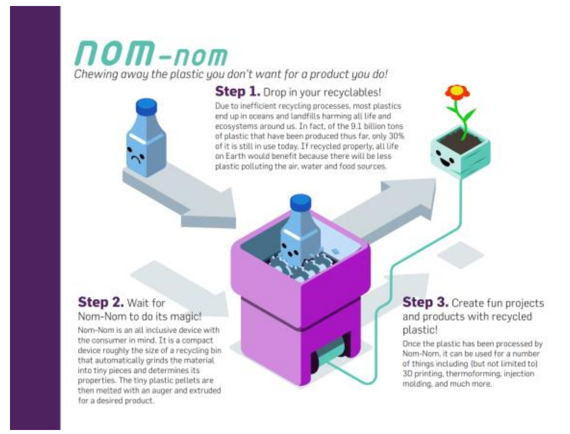

Figure 4. Customer Workflow.

III. NEXT STEPS & CONCLUSION

While current work is being done on the manufacturability of the device as well as an operation design for manufacturing, some future steps include iterating on the size of the product as well as scaling up for future iterations. Furthermore, various output methods will also be considered as the initial prototype and design only focus on 3D printer filament as the primary reusable plastic output. Additionally, more research and prototype development need to be conducted to test the design iterations listed above.

With key input from potential customers and prototyping, the design of the Nom-Nom has been iterated. While it is still in the research and development phase, the manufacturability of the product as well as the components of operation design is being created to ensure the device can be realized once the prototyping is advanced. The ultimate goal of this operation design is to ensure the risks have been considered and reduced to improve efficiency and create a six sigma lean manufacturing operation when manufacturing the product.

ACKNOWLEDGMENTS

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Hybrid Energy Collection for Hypothermia Mitigation

Jacob Alter[1], Lander Arpi[2], Akhil Jacob[2], Morgan Locandro[1]
Rensselaer Polytechnic Institute
1 Department of Mechanical, Aerospace and Nuclear Engineering
2 Department of Electrical and Computer Systems Engineering
alterj@rpi.edu, arpil@rpi.edu, jacoba3@rpi.edu, locanm@rpi.edu

Hypothermia is a major challenge for refugees crossing major bodies of water such as the Mediterranean Sea. Incorporating elements of sustainable design into traditional means of transportation can help reduce the number of fatalities due to hypothermia. A boat design that utilizes wind and solar energy, has UV disinfecting benches, and contains heated blankets offers a robust solution to minimizing the effects of hypothermia on refugees as they make their journey across the Mediterranean and has applications for refugees anywhere in the world.

I. BACKGROUND

In 2017, 172,301 refugees arrived in Europe after crossing the Mediterranean Sea [12]. In total, more than 33,000 people have died attempting to make this border crossing since the year 2000 [12], making it one of the most dangerous borders to cross according to the International Organization for Migration.

Migrants from across the continent of Africa fleeing the ruins of their war-torn nations, often are faced with military servitude and extreme violence. Libya serves as a major gateway for these refugees as they attempt to make the dangerous crossing of the Mediterranean [15] as shown in Figure 1.

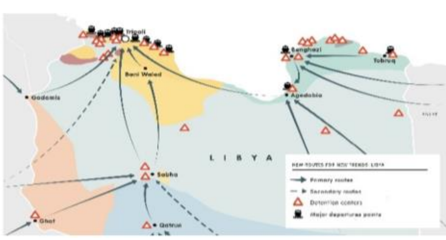

Figure 1: Map of Crisis in Libya [15]

Currently, refugees live in conditions that have many problems. Mainly due to a lack of nutrition, heat, and hygiene. Due to a caloric intake deficiency, many refugees are becoming susceptible to hypothermia [9].

I.B. Characterizing Hypothermia

Hypothermia (a condition characterized by abnormally low body temperature) [2], is one of the most common threats to life during the journey across the Mediterranean [9]. There are several modes of heat transfer from the body. On the ocean, these primarily include convection, radiation and evaporative cooling.

Evaporative cooling can largely be attributed to the wet environment. Evaporative cooling occurs when water on the surface of the body vaporizes and in doing so, removes energy from the body. This mode of heat transfer can account for up to 20% of heat loss [16]. Maintaining dry conditions is critical for minimizing heat loss.

Radiative heat transfer can be minimized by reflecting radiated heat back to the body and thereby reducing loss to the environment. Radiation accounts for 60% of the body's heat loss [16], therefore recapturing this lost heat is critical to assisting the body's thermoregulation.

$$\dot{Q}_{Rad} = \varepsilon\sigma A({T_s}^4 - {T_{surf}}^4) \approx 40W \qquad (1)$$

Convection is the final primary mode of heat transfer, accounting for approximately 15% of heat lost [16] contributing to hypothermic conditions in the Mediterranean. High winds increase the fluid flow across the body and increase the rate of heat transfer away from the body. The high velocity of the wind will contribute to loss of energy, but can also be used as part of the solution, providing power.

$$\dot{Q}_{conv} = hA(T_s - T_f) \approx 10W \qquad (2)$$

The total rate of heat transfer from a person to the environment can be characterized by the following equation:

$$\sum \quad \dot{Q}_{conv} = \dot{Q}_{rad} + \dot{Q}_{conv} + \dot{Q}_{evap} \approx 50 - 65 \quad (3)$$

Note that all rates of heat transfer are determined per person and vary based on surrounding temperatures and environmental conditions.

II. HYBRID ENERGY FOR HYPOTHERMIA MITIGATION

Alternative energy resources are abundantly available in the Mediterranean Sea. These energy sources make them perfect candidates to power solutions that can be used to assist in transporting refugees to Europe and safeguard their health along the way. Wind and solar energy are the most abundantly available resources [18] and can be harnessed for both mechanical and electrical energy. Since wind speeds and solar radiation vary seasonally [1], the power collected also fluctuates seasonally as shown in Figure 4.

II.A. Solar Power Supply

The Mediterranean Sea is in relatively close proximity to the equator, thus making it an extremely viable candidate for the use of photovoltaic cells for renewable power generation [1]. Power output is at its peak in the summer months as shown in Figure 4, but is capable of providing substantial power year-round.

Effective implementation of a photovoltaic cells makes the best use of the available area. On board the area for mounting solar panels is limited, and since the power generated by the cells has a linear relationship to the area of the cells as shown in Figure 3, placement must be strategic. Placement of these cells maximizes their effectiveness by exposing them to sunlight as directly and for as long as possible.

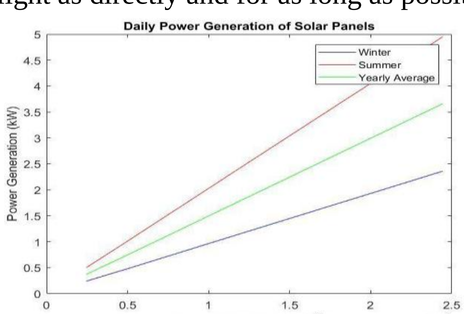

Figure 3: Solar Panel Power Generation [1]

II.B. Wind Power Supply

Solar energy can generate electrical energy to aid in providing hypothermic relief to the refugees, but wind energy can be used for both the generation of electrical energy, and mechanical energy which can be used to help move the boat across the Mediterranean Sea. The wind speeds are highest during the winter and spring months, as shown in Figure 3. Marine-Scale turbines are most effective when wind speeds are at least 15 miles per hour [13].

$$P = \frac{1}{2} k c_p \rho A v^3 \qquad (4)$$

II.C. Benefit to Hybrid Energy Collection

Given that neither a solar or wind powered solution will maintain consistent output throughout all the months of the year, a hybrid approach to power collection will more reliably provide renewable energy to the boat, which can then be used to mitigate hypothermia in refugees.

The power generated in a hybrid system will ultimately see fewer periods of limited power output as shown by the graph in Figure 4. Wind and solar energy have high output over different periods of the year and can therefore work more effectively to power a solution to reduce hypothermia in refugees.

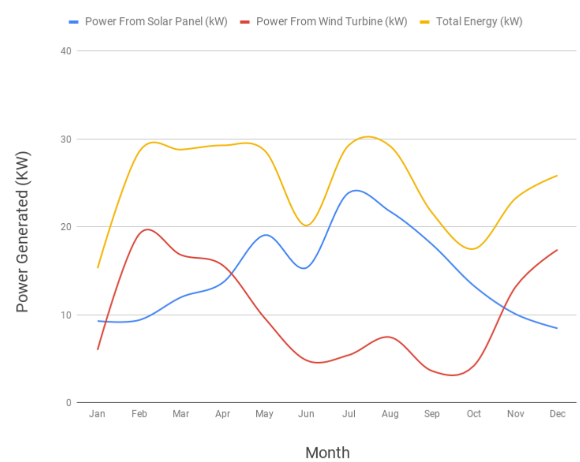

Figure 4: Total Energy Collection Annually [1, 13]

III. SYSTEM DESIGN

Revolutionizing boat design for refugee and crisis situations to effectively utilize renewable resources on the sea will increase safety and efficiency with which people can be brought to the safety of asylum. Combined solar energy and wind energy can be used onboard a vessel as shown in Figure 5.

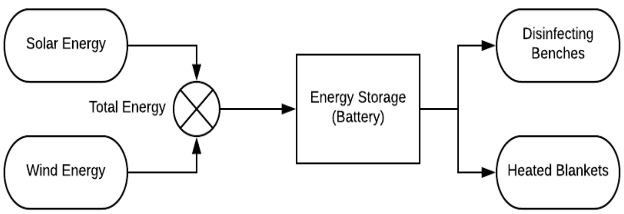

Figure 5: System Design Logic Diagram

III.A. Subsystems Overview

The full boat assembly is comprised of several subassemblies identified below in Figure 6; the main sail, the wind turbine, the UV Sanitation benches, the flexible solar panels and the auxiliary drive.

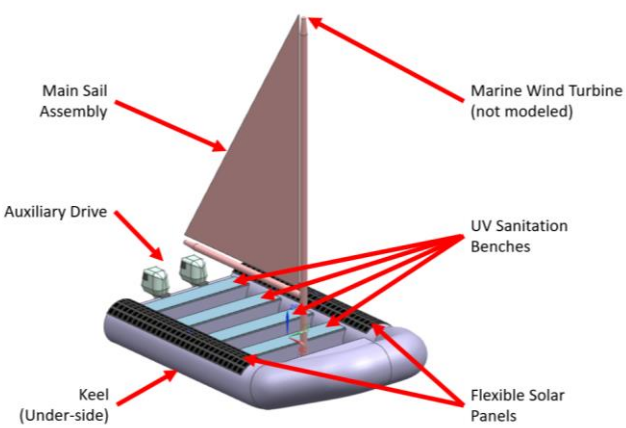

Figure 6: Subassemblies of Boat

Note: Model for Auxiliary Drive from GrabCAD [7]

III.A.1. Electrical Energy Generation

In order to generate a source of electrical energy to power the blankets, two systems are incorporated into the design. The primary method of energy collection includes the use of solar generation through flexible solar panels.

Two flexible solar panels, sized as shown in Equation 5, are placed along the edge of the boat in order to collect 10kW – 15kW each from the sun, for a total of 30kW [3]. The use of flexible solar arrays to conform to the curves of the boat will help to ensure that some portion of the panel is always oriented toward the sun.

$$41.7 \times 21.3 = SolarArray\ Size \qquad (5)$$

In addition to this, a wind turbine will be placed at the top of the mast. In terms of power, this turbine will be able to collect a maximum of 20 kW and a minimum of 5 kW depending on the month [13]. Both the wind turbine and solar panels will be able to collect electrical energy. The wind turbine is strategically placed at the top of the mast in order to prevent refugees from interacting with it, leading to possible injuries.

Table 1: Estimated Power Generation [1, 13]

Energy Type	**Minimum Power (kW)**	**Maximum Power (kW)**
Wind	5	20
Solar	10	30

III.A.2. Harnessing Wind Energy

The Mediterranean Sea has well known winds which have historically been the backbone of trade routes and have powered trading vessels for centuries. The mechanical energy generation via the wind was considered to be the means to power the boat itself. Due to these considerations, the main sail with a height of 14.67 feet is in the middle of the boat. This allows for 0 J of external energy to power the boat and the engines can be saved for emergencies. The boat includes a mainsail as well as a jib (the front sail) that will both be made of nylon [8]. This sail set-up allows for the most effective method of sailing. The mainsail is designed as the main power generation while the jib is used as an airfoil for extra power generation and stability.

III.A.3. Sanitization System

In the wake of humanitarian crises, fleeing refugees often have no choice but to wear the same clothes for days or weeks on end [11]. In light of this potential hygiene problem, each bench in the boat has been designed to include strips of UV lighting designed to kill harmful bacteria. The benches feature a detachable bench seat that dually serves as a flotation device.

When not in use for flotation, the bench can be reattached to the bench frame and forms a storage unit for refugees' clothes. Once reattached and put in the closed position, the bench UV light will turn on and kill potentially harmful bacteria on clothing inside the bench storage unit. This design serves to both not only clean clothes and reduce the number of harmful bacteria, but to also help save lives by having a means to float should the boat capsize.

III.A.4. Main Boat Assembly

The main assembly of the boat will include many aspects to ensure safety and efficiency. The main safety concerns include the emergency engines and the keel underneath the boat.

The keel works as a counterweight when a moment force is created by the wind on the mainsail.

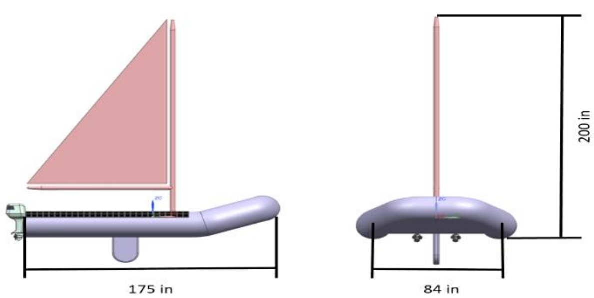

Figure 7: Full Boat Assembly

Capacity of the boat will be considered and upgraded for larger families. After gathering the results of the The boat itself will be made from a lightweight material such as aluminum to improve efficiency by minimizing the total weight.

III.A.5. Warming Blankets

The blankets are the secondary system of this design to generate heat for refugees. This is achieved through conduction coils built into the fabric of the blankets. These coils allow for individuals to be heated continuously. While 60% of an individual's heat is lost to radiation Mylar was the clear material choice as it is relatively cheap and can reflect 97% of a person's radiative heat back. The blanket has a total area of 66 x 90 inches to cover the majority of an average adult male. This blanket will also be designed to be of sufficient weight to conform to individuals to provide both security and comfort.

IV. CONCLUSIONS

Refugees from the Mediterranean Sea have faced many obstacles for the past few decades. Their journey to Europe has been dangerous and has had a huge impact on their health. Hypothermia has negatively impacted these refugees' lives as the number of deaths continues to rise. The boat and blanket offers a solution to tackle the problem of hypothermia.

With the combination of solar and wind energy, the boat will provide sustainable protection from the cold-waters of the Mediterranean Sea. The blanket will use the power generated from the solar panels to warm the refugees on board and maintain their body temperatures above 95 degrees. The use of this product will combat the effects of hypothermia by keeping refugees warm and continue to reduce the number of fatalities from hypothermia. For the future, current product, the same technology can be implemented in eco-homes for refugees in their current locations or eco-homes for when they arrive in Europe to make sure that hypothermia does not continue to plague those fleeing their home.

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Green Glass: Solar Facade Modification for the Home

Kaitlin Chitaman
MANE: Innovation and Rapid Prototyping
Rensselaer Polytechnic Institute
chitak3@rpi.edu

Through research, Green Glass has been developed in order to be a replacement for current ways of generating electricity for our world. We have a heavy reliance on using fossil fuels to power our world, this product seeks to reduce the reliance on using coal, which is approximately two percent efficient, for the electricity in our home. Improvements to an original integrated concentrating solar facade have been made in order for home adaptation, as well as for increased overall efficiency.

I. INTRODUCTION

As technology develops, our dependence on power usage increases, thereby increasing our need for an energy source. The amount of power that we use each day is increasing. With an increase in power usage and a decrease in the number of fossil fuels that we have available to us, we are in the midst of creating an irreparable energy crisis. According to an analysis done in 2011, there will be no remaining coal by the last decade in the 2000s, and out of oil and gas well before that time, as seen in Figure 1. This requires the development and implementation of alternative energy sources in order to keep our society functioning.

One of the biggest reservations that people have about implementing solar technology into their lives is the cost. The price is not cost effective for most households with conventional solar systems due to the low-efficiency rates of the cells. It is just too much of initial investment for the low power output. The research conducted works to help the prevention of an energy crisis. The focus was on creating a product that could be implemented into the home of any individual in order to convert both solar and thermal energy into electricity for the home at a low cost with increased efficiency. The focus of this design was optimizing the product based on the needs of the customer along with generating an initial manufacturing plan and business model for this product.

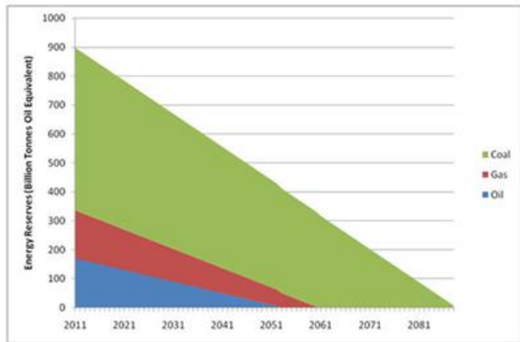

Figure 1: Future Energy Reserves for Main Fossil Fuels

II. THE ORIGINAL SOLAR CONCENTRATOR

The Integrated Concentrating Solar Facade (ICSF) is a building-integrated photovoltaic system that provides interior space with electrical power, thermal energy, enhanced daylighting, and reduced solar gain. It surpasses existing building integrated photovoltaic (BIPV) or concentrating photovoltaic technologies in these benefits, and is applicable to both retrofits and new construction. The system integrates architecturally into facades and atria, harvesting solar energy, while still providing outside views and diffuse daylight for the building users. This product was designed with the goal to be better than all the existing products and has risen above that goal in many respects although, there were some design aspects that were overlooked that can increase the efficiency of the product.

II.A. Principle of Operation

ICSF miniaturizes and distributes the essential components of concentrating photovoltaic technology within the weather-sealed windows of building envelopes. Electricity is produced by an array of photovoltaic cells, while much of the remaining solar energy is transported out of the facade as captured, usable heat. The sum effects of ICSF are these valuable energy resources, reduced interior solar gain loads, which reduces loads on HVAC systems, and enhanced interior daylighting quality, which reduces the need for inferior artificial lighting.

The design and operation of the system allow direct partial viewsheds by building occupants which change and flow over the course of the day, furthering occupants' engagement through the modular design which compliments a range of existing building structures, or, implemented in new designs, offers bold design opportunities. ICSF has been developed through a series of prototypes and is currently integrated into building envelopes.

II.B. Concentrator Specifications

The ICSF uses a unique glass shape in order to bend incoming light directly into a photovoltaic cell that is located at the bottom of the glass. Underneath photovoltaic solar cells, there is a heat sink that is connected to a high-quality heat and coolant transfer loop. This transfer loop works with the building to regulate the temperature inside of the building, accounting for the inside temperature as well. A solar concentrator uses lenses which take a large area of sunlight and direct it towards a specific spot by bending the rays of light and focusing them. Some people use the same principle when they use a magnifying lens to focus the sun's rays to generate fire on kindling.

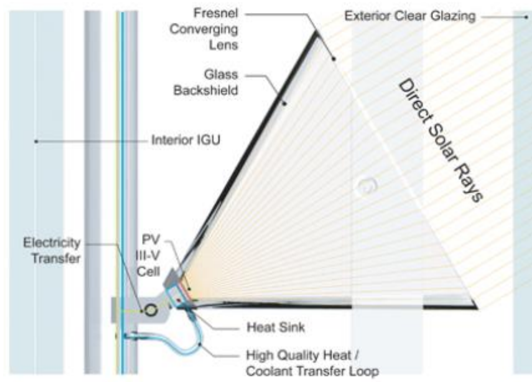

Figure 2: Diagram of the Original Product

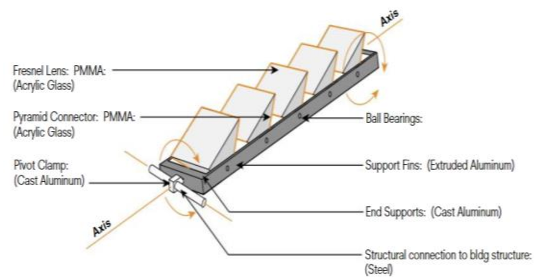

Figure 3: Material Selection

Some of the power that is generated is used to power the overall system. This leads to approximately thirty-four percent of the sun's energy getting converted into electricity. Fifty-three percent of the energy is removed as hot air, but there is still a total loss of about 8% from the external glass pieces. The rest is trapped internally in the system.

III. RESEARCH AND ANALYSIS

It was desired that a product be made that homeowners can implement into their homes with little to no need for outside intervention or assistance. Green Glass takes on the conversion of this industrial and commercial use product into one that can be used in one's home. An important factor of making this product for the home is making sure it comes with high efficiency at a reasonable cost so it is still a reasonable investment in any home.

III.A. Customer Interviews

Through the beginning of this research, over forty customer interviews were done based on the original product and various iterations before coming to the final design of the system. The interviewees wanted a product with higher efficiency, less wasteful by-product, and an ability to customize.

III.B. Adaptations and Improvements

In order to make the design one that could be easily integrated into the home, the shape and size were changed. The new shape is conical, allowing for increased customizability for the user. The size of this cone is five-inches in diameter and height. This smaller size will allow for a light product with less material waste, as well as easier self implementation into the home. The cones are attached in column sizes as defined by the customer in order to fit the needs of their home with a glass backing and clips that allow for attachment to the users' window.

One improvement that is being implemented into the design is the addition of a convex lens. Incorporating a convex lens would reduce the amount of light lost to bending, reflection, and refraction in the wrong direction. Once the convex lens is placed at the correct focal length, the design will be optimized. The calculated ideal focal length for a cone with a diameter and height of 5 inches is 0.5 mm. Experimentation was attempted to test this theory through experimentation, but due to a lack of the right materials, the results from the testing that we were able to perform was inconclusive due to an increase in refraction with the materials used.

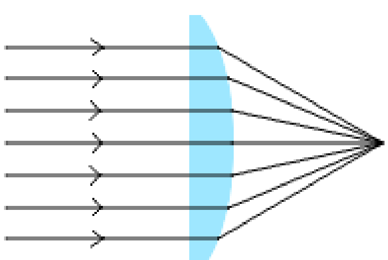

Figure 4: Effect of Convex Lens on Light

A new shape of the entrance of the light was also implemented. This shape allowed for a new way to focus light within the body of the apparatus. Through experimentation, Figure 5, shown below, was developed. There is an increase in the concentration of light particles, as can be seen by the darker red which fades to blue, showing the levels of concentration, with the dark red being a higher concentration. This technology works for any wavelength of light. This is important because solar cells are made out of N-type and P-type semiconducting material that uses all of the visible light spectra in order to generate electricity.

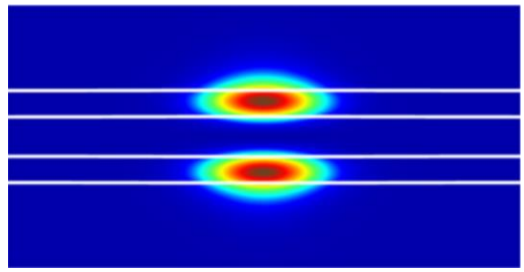

Figure 5: Light through Adjacent Sheets

Through the use of the adjacent plate, there is an increase in the bending of the material due to the exertion of a tiny pressure causing a concentration of the light into narrow tracks. The adjacent plate design can be seen in Figure 6 below. This design used in conjunction with the convex lens will work to focus and concentrate on a higher percentage of incoming light onto the solar cells being used.

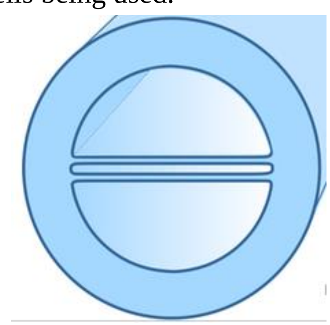

Figure 6: New Entry Design

The final adaptation of this design includes the use of a new type of solar cell. Typically photovoltaic solar cells are made through an expensive chemical process that leads to chemical waste that is harmful to the environment to create, and over sixty-six percent of the silicon created gets thrown away. The new solar cells to be used are grown out of a reusable silicon template with the use of silicon tetrachloride, leading to a ninety-nine percent reduction in silicon use.

III. UPDATED DESIGN

Through the process of experimentation, research, and calculation, it was determined that the addition of a convex lens above the internal solar panels would increase the amount of light that gets absorbed by the solar panel of the system. The integration of the adjacent sheets further concentrates the light. This technology along with the use of a dielectric coating will reduce the overall reflection of the light, increasing absorption.

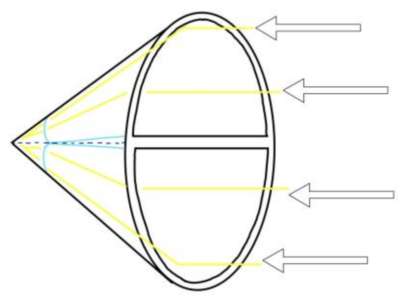

Figure 6: Design of Green Glass

By using this design, we have a theoretical increase in efficiency to about 58% which is a 100% increase over the solar panels that we are using in most residential buildings today.

IV. CONCLUSIONS

Our world needs change and a design like this can help kickstart this change. Having a product with higher efficiency will lead to an increase in buyers as they will be getting an increased flow of power generated for their home. Through this small addition to the home, we are able to optimize any solar and thermal energy surrounding the home. Future work will lead to further analysis of the system as a whole and extended research focuses, including more experimentation in order to optimize the design completely. Another topic of research that will stem from this design is the use of this technology in other applications in order to help our world rely less on fossil fuels that create greater harm to our world.

ACKNOWLEDGMENTS

Much of the content is a result of research done by Anna Dyson and the Center for Architecture Science and Ecology. The research and experimentation done for this design would not be possible without their work. This research was supported by Professor Asish Ghosh of the MANE Department of Rensselaer Polytechnic Institute.

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Clear Voyage - Computer Vision-Based Mobility Aid for the Visually Impaired

Hayley Roy Gil†, John Fantell*
Inventor's Studio 2
hayleyroygill@gmail.com, jcfantell@gmail.com
**Winner of The Inventor's Studio Startup Founder Award*
†Recipient of Lean Design for Six Sigma – Innovation & product Design and Development Certificate

This device includes a headset that features at least one camera, one of which will be stereoscopic; a pair of bone-conducting headphones; and a processing unit. The headset can interface with a smartphone wirelessly. The cameras stream visual data to a processing unit which detects objects in each camera's field of view (FoV) using convolutional neural networks and other computer vision techniques. The processing unit uses binaural recording techniques to create speech-based and sonification based audio notifications which are dispatched to the headphones. A smartphone, via an app, can be used to adjust the settings of the headset.

I. INTRODUCTION

Nearly three-hundred million people on this planet are visually impaired. Of those, forty million are completely blind and twenty million are only children [1]. Visually impaired individuals are more likely to experience depression and social isolation because of the obstacles they face when pursuing standard daily tasks such as navigating their day-to-day environment. Despite the hundreds of available navigation aids designed to increase mobility for visually impaired individuals, the most common navigation aids are still the guide dog and the white cane, both of which have prominent limitations [1]. Guide dogs cannot actually direct a visually impaired individual nor can they judge the color of a traffic light [2]. It is expensive for guide dog schools to train and breed guide dogs, costing upwards of $40,000 - $60,000 per dog, which is why there is a 1-2 year waitlist for new visually impaired applicants[3][4][5]. This may explain why only 2% of visually impaired individuals in the US have guide dogs [6].

White canes, on the other hand, are affordable, but cannot detect any overhead objects such as tree branches and open cabinets, nor can they detect fast moving objects approaching the user [7]. Current electronic navigation aids are too invasive, offer too little utility, or require too much training to justify their use [1].

To mitigate the challenges visually impaired individuals face when navigating their world, Clear Voyage -- a 21st-century navigation aid utilizing computer vision and machine learning to detect objects, street intersections, and other points of interest -- will be designed. It is strongly believed that using Clear Voyage in conjunction with a white cane or guide dog will enable visually impaired individuals the opportunity to navigate their daily world with unprecedented safety and simplicity.

II. PRODUCT DESCRIPTION

II.A. Product Functionality and Overview

The hardware for this system includes a headset such as the design in Figure 1. Each side of the headset will be fit with one wide-angle fisheye camera to capture a user's forward field of view (FoV). The two forward facing cameras will be used to create a stereoscopic view of the environment which is required to compute the distance of objects in a user's forward FoV relative to the user. Each side of the headset may also be fitted with a camera to capture objects in the user's peripheral FoV.

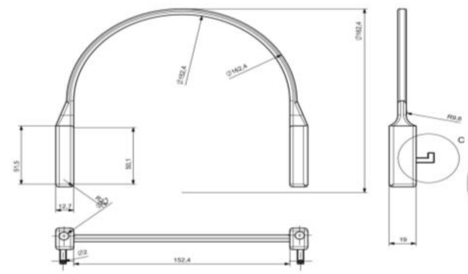

Figure 1. Headset Drawing

After a hazardous object and its location with respect to the user is identified, speech-based and sonification based (non-speech-based) audio cues are used to inform the user of the object's identity and location. Binaural audio cues are used to create an auditory illusion that the object is emitting sound. The user is then able to 'hear' the object and avoid the sound, thus avoiding contact with the object. Audio cues are delivered to the user via bone conduction headphones. The use of bone conduction headphones limits interference with ambient sounds which a visually impaired individual must be able to hear. Additionally, bone conduction headphones bypass the eardrums, making the system more accessible to individuals with eardrum-based hearing disabilities or poor hearing.

A smartphone app is used to configure headset system settings and update the headset software when applicable. The smartphone app interface should be designed so that the app and all of its features are fully accessible to the visually impaired.

II.B. Hardware Components

Table I shows a list of components found in the Clear Voyage system. The functions of each component are listed below. The reasoning and applicability for the component is listed.

Table I. Sensor Unit Components

Component	Function	Applicability
Processor	(1) Preprocesses and extracts objects from camera feeds (2) Generates audio notifications for each object (3) Dispatches notifications to headphones	The processor is necessary to connect all of the components of the headset together and generate audio notifications based on objects detected in the camera feeds
Battery	Stores power and powers all devices in the unit	This is the headset's power source
Smartphone App	Controls device configurations	This feature controls device configurations
Bluetooth or Wifi Receiver/ Transmitter	Connects to a user's smartphone	This feature is necessary to update the headset configurations via the smartphone app
Stereoscopic (Forward) Cameras	Aids in depth approximation of hazardous objects	This feature collects data for computer vision analysis
Peripheral Cameras	Detect moving/ approaching objects from peripheral directions	This feature detects dangerous objects (primarily cars) approaching the user
Bone Conduction Headphones	Deliver audio cues while limiting interference with background sounds	This feature conveys information about hazardous objects to the user

II.D. Software Description

The processing unit houses the software that processes visual data from the camera feeds and dispatches binaural audio recordings to the headphones. Figure 2 shows a high-level flowchart of the system software.

data. Then the center point $P = (x,y,z)$ of each bounding box is computed. A decision criteria will be created to determine whether or not a notification should be generated for an object with bounding box center P. If a notification should be generated, binaural recording algorithms will be used to create a binaural recording that is transmitted to the headphones and then played. The binaural recording will include information about the type, location, and distance of an object relative to the headset user.

II.E. Software Flowchart

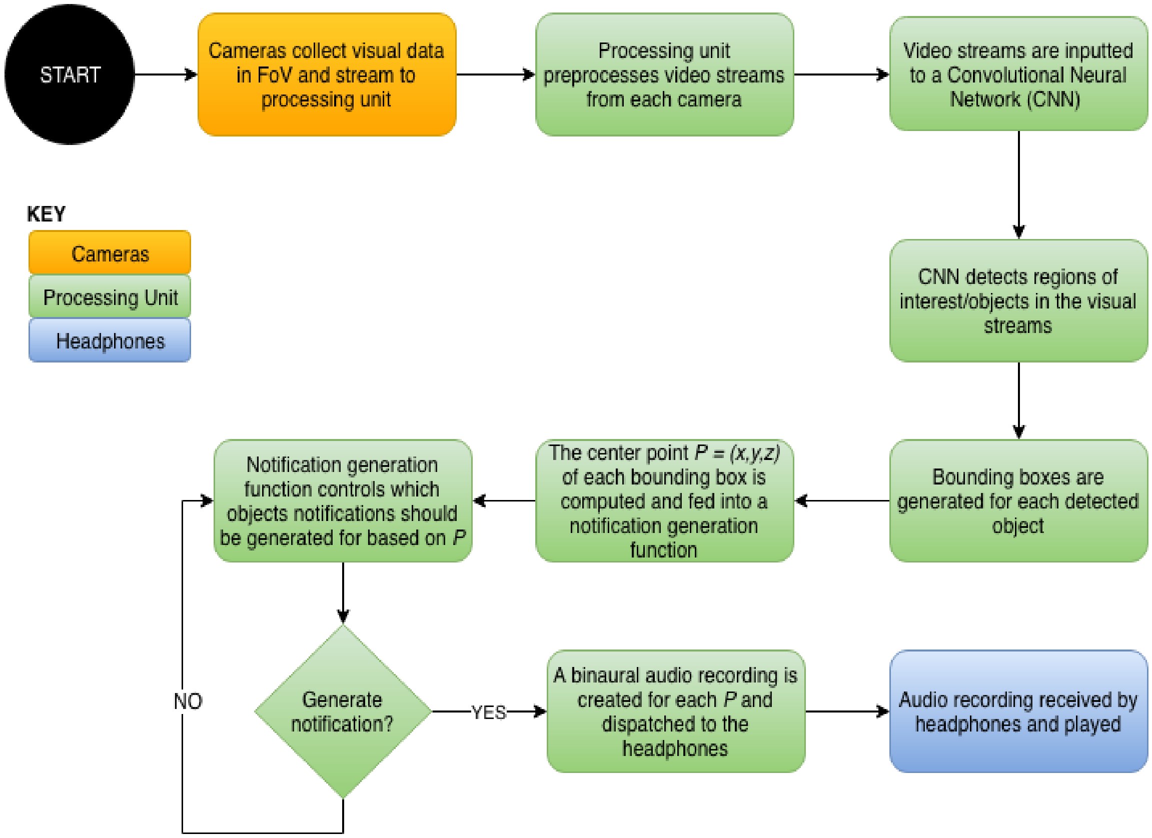

Figure 2. Flowchart of program

III. CONCLUSIONS

The main application of Clear Voyage is its ability to alert visually impaired users of hazardous obstacles in their environment. For instance, if the device recognizes there is a tree-branch 3 feet in front of a user, it will notify the user of this so they can either duck their head or steer clear of the tree branch. If a user approaches a street intersection and wishes to cross, then the device will alert the user when there are no cars coming so that they can cross. Furthermore, if a user is crossing the street and a car makes a right turn on red the device will alert the user that a car is moving towards them from their left, allowing them to quickly move forward and avoid the risk of injury.

The system audio notifications, which will provide a user with information about an object's type, distance, and location for each hazardous object in their vicinity. These notifications are designed to be non-invasive and easily interoperable by the user.

Depending on the user's degree of residual sight, the device can be configured to convey more or less information to the user through a smartphone app that is designed to be fully accessible to the visually impaired users.

The device is not a substitute for the white cane or guide dog. Instead, it is a complimentary mobility aid that will provide a visually impaired user with increased environmental spatial awareness when navigating.

ACKNOWLEDGMENTS

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Open-Application Biosensor System for Live Biomechanical Data Analysis

Hayley Roy Gill†, Sierra Koch, Kathryn Mix†, Harry Zhou*
Inventor's Studio 1
hayleyroygill@gmail.com, kathrynmix@gmail.com, 11sierrak@gmail.com, harryzhou4498@gmail.com
**Winner of The Inventor's Studio Startup Founder Award*
†Recipient of Lean Design for Six Sigma – Innovation & product Design and Development Certificate

This project includes the development of a dynamic biosensor prototype for medical professionals. A variety of attachable biosensor units are used to record data associated with the desired biomechanical motion that the user wishes to capture as well as data such as heart-rate, and body temperature. Data is transmitted to a processing unit such as a smartphone to be displayed and analyzed. Using Inertial Measurement Units (IMU'S) 9-axis biomechanical motion data is recorded. The data is monitored using regional bound movement constraints that can be chosen and calibrated by a medical professional so that any desired biomechanical motion can be captured and analyzed. For instance, a medical professional could choose to study a baseball player's throwing form and set regional bounds that monitor if the player's arm, leg, hips, or some other biomechanical motion, is within a desired spatial range. When the biosensor units are no longer within the established regional bounds, the violation is logged and, if desired, the smartphone issues a warning to the user providing real-time feedback. All data is recorded and delivered back to the medical professional to develop user-centered medical improvement strategies.

I. INTRODUCTION

There are a variety of measurement techniques for analyzing biomechanical motion within a lab setting. A common form of recording biomechanical motion is using visual motion-capture systems, such as those used for capturing the motions for video games or movies. Motion-capture systems consist of a network of cameras positioned around the subject of interest. A software either detects markers that are placed on the subject (marker-based motion capture) or detects the subject's overall shape (marker-less motion capture). The software converts the visual data into 3D motion models. This type of biomechanical motion measurement is often used for medical studies, cinema effects, and even the foundation of computer game models [1]. Motion-capture systems are effective for creating accurate animations that depict human motion, but lacks applicability outside the lab environment or in a dynamic setting because visual motion-capture systems require specific lighting and complex camera setup [2].

Biomechanical motion data can be used to help better understand a variety of medical conditions or states, such as the effect pregnancy has on the back posture of women [3]. Motion data gathered within a lab setting can help diagnose a variety of medical conditions, but has limitations when facilitating treatment outside of a lab setting. Human beings experience a variety of biomechanical movements that may be missed when only analyzing lab-collected data. Additionally, the cost, expertise, and time required to design or run a traditional visual motion-capture system typically requires the motion captured to be of a high enough value to cover those costs, thereby excluding the study of medical conditions that are anticipated to have less, little, or no monetary value [2].

The goal of this project is to create a non-invasive, wearable system for day-long, biomechanical data collection and analysis outside of a controlled laboratory setting. The device will serve as an easy-to-use data tool for doctors, physical trainers, and their patients to incrementally improve biomechanical motion and provide instantaneous harmful motion feedback.

II. PRODUCT DESCRIPTION

II.A. Hardware and Enclosure Description

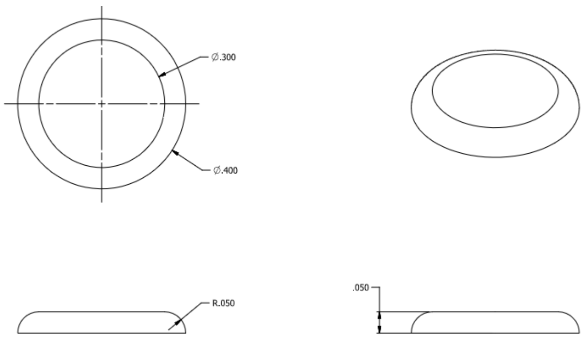

Figure 1. Enclosure Drawing

An ideal biosensor system includes small, attachable biosensor "units" that can be placed on an individual at the points needed to measure a desired biomechanical motion. These points can be placed anywhere on the body that the user desires data from.

The biosensor units include a standard mobile Bluetooth receiver/transmitter. The units collect, encode, and then transmit live data to the user's smartphone. The smartphone collects and processes this data. A warning notification is displayed if the user experiences biomechanical motion that was marked as undesired by a medical professional or trainer during calibration. This warning can be highly customized or disabled. All sensor data is stored in the smartphone app and can be delivered to the trained professional for analysis. Because the type of data that can be collected from the biosensor system is so dynamic, the app provides only basic analytics in the form of 3D motion tracking. However, the data can be easily exported and the user may use that data in whichever way they feel is most beneficial.

The individual biosensor units are not responsible for recording or processing the data, therefore, their size is small, about the size of a U.S dime. The enclosure of each unit would be approximately the size of a quarter and could be attached to using elastic bands or adhesive. The units would need to be placed at specific locations outlined by the trained professional so that the IMU's could accurately model the user's motion.

For example, a medical professional may have a pregnant patient who is experiencing symptoms such as backaches and hemorrhoids. These are classic symptoms of the patient sleeping on their back during pregnancy [3]. The medical professional may decide that this biosensor system is useful tool for the patient to use to avoid sleeping on their back by monitoring their position as they sleep. In this scenario, the medical professional could attach biosensor units near the shoulders using skin-safe glue or tape. If the patient turns onto their back in the middle of the night, the biosensor system processor will recognize the inertial change and wake the patient via an alert on their smartphones so that they may choose a more safe sleeping position.

In another example, a physical trainer might be interested in the healing process of an injury such as an ACL tear. They could place biosensor units at locations such as the ankle, knee, and hip, and have the test subject perform a set of exercises over the healing process. The physical trainer could then compare the biomechanical motion of the test subject over time, and use that data to better design exercises and treatment for recovery in the future.

Overall, the unit could be used by medical professionals to better track live biomechanical motion as well as a variety of other biological data.

II.B. Hardware Layout

Figure 2 shows a potential layout of the internal circuit for each biosensor unit. Each unit will consist of a Bluetooth receiver and transmitter, a heart monitor, an internal IMU, a BiLED, a thermistor, a processing unit, and a power source. These biosensors may all be used, or only one of them: the goal was to make a unit that could be used in as many beneficial, different ways as possible.

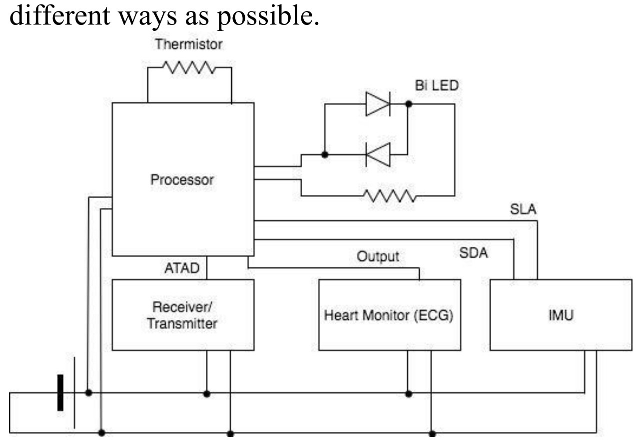

Figure 2. Example circuit diagram for the inside of each biosensor unit.

The user is responsible for choosing whichever subsystems they feel will most benefit their project or experiment. When the unit is attached, the thermistor and heart monitor will be in contact with the user's skin. The IMU, battery, and power source remain on the inside of the unit, while the Bluetooth receiver and transmitter lies on the external surface of the unit to allow for communication with a Bluetooth router and smartphone. The BiLED lies on the external surface of the device so that visual notifications could be communicated to the user about the Bluetooth connection status and power state of the unit.

II.C. Hardware Components

Table I shows a list of components found in each sensor unit. The functions of each component are listed below. The reasoning and applicability for the component is listed. With the exception of the IMU, the other sensors may be interchangeable if the medical professional prefers to collect other data. The sensors listed here were chosen to collect the most commonly analysed medical data.

Table I. Sensor Unit Components

Component	Function	Applicability
Processor	(1) Receives data from sensors (2) Encodes data for transmission (3) Analyses user communication data that is received by the receiver	The processor is necessary to run the biosensor unit's various sensors and exchange data with the user's smartphone
Battery	Stores power and powers all devices in the unit	This is the unit's power source
Bluetooth Receiver/ Transmitter	Exchanges data with the user's smartphone	This feature is necessary to transmit live data
Thermistor	Takes temperature of the body	This feature provides data for the user's body temperature
BiLED	Notifies the user of Bluetooth connection and power	This feature displays the status of the unit
IMU	Determines sensor unit's location, angle, and acceleration	This feature characterises the user's motion
Heart Rate Monitor	Detects the user's heart rate	This feature provides data for the user's heart rate

II.D. Flowchart

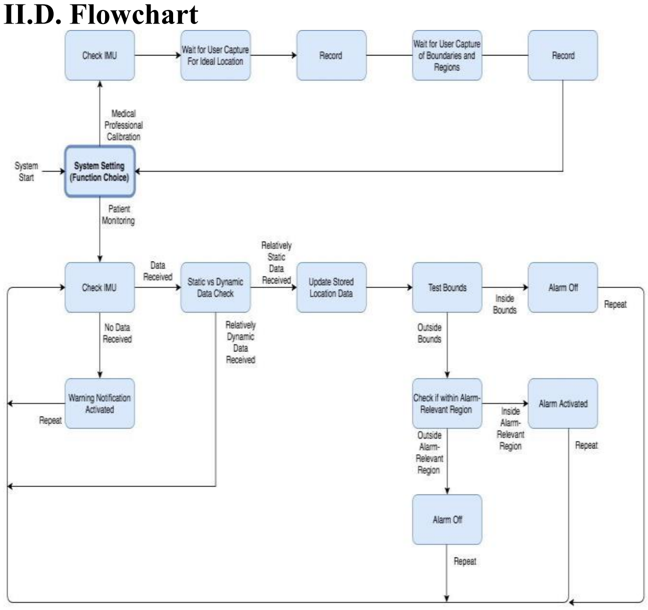

Figure 3: A flowchart that shows how the prototype biosensor system calibrates, monitors and records data.

II.E. Software Description

The main software is responsible for processing the data received from each of the sensors. The software is run by the smartphone which serves as the central processing unit for all biosensor devices. The smartphone would need to receive data from a Bluetooth router, which would connect to all sensor units attached to the user.

Figure 3 shows a flowchart of the prototype program that would run on the smartphone. The current flowchart starts at the "System Setting" box. During the system setting part of the program, the app asks the program user if they are a patient or a medical professional. If the program user is a medical professional looking to calibrate the sensor unit system, the calibration procedure can be started. The calibration procedure includes moving the patient (with the attached sensor units) to the ideal biomechanical position (such as a sitting position for optimal posture). Once prompted, the system will record the IMU data for the ideal position. The medical professional will then be asked to physically maneuver the patient in order to highlight accepted regions and the physical boundaries that can be classified as harmful positions. Once the positions are calibrated and recorded, the system can then be used by the patient to record biomechanical data and monitor for harmful motion.

The alternate software process begins when the patient option is chosen at the "System Setting" box. When the patient option is chosen, a continuous process is activated. This process checks for data sent by the IMU. The received data is analyzed to check if the patient is in motion or has moved to a static position where biomechanical data should be analyzed. If the received data shows a static position, the system will update the stored data. The data is analyzed to see if the IMU's are placed within the physical bounds established by the medical professional. If the IMUs stay within the bounds, the alarm is set to off and the loop repeats. If the location data is found to be outside of bounds, the data is then tested to determine if the user has moved outside of the alarm-relevant region. The alarm-relevant region is set by the medical professional during the calibration process. An example of an alarm-relevant region would be when the IMU demonstrates a sitting position of the user but with poor posture. When data is received as being outside of the alarm-relevant region, the smartphone will notify the user to correct their position. When the IMU far exceeds the bounds, they'll be classified as outside the alarm-relevant region. An example of being outside the alarm-relevant region could include the data that is received when an individual is walking or lying down as opposed to being in a sitting position. When the IMUs are outside of the alarm-relevant region, no notification is triggered and the checking process is repeated.

III. CONCLUSIONS

There are a variety of potential applications for an open-application data collection device for biomechanical motion. The software allows medical professionals to work with patients to customize applications that fit patient needs. An adaptive motion monitoring system is required to effectively fulfill the patient needs. While the most common application of this device may be posture analysis, there exist a variety of applications in the medical and sports fields. After arthroplasties, orthopedic surgeons could use the system to notify patients of potentially harmful motion during joint replacement recovery. Detrimental motion habits can be detected early and preventative action can be taken. Real world data can be delivered directly to doctors to monitor patient recovery processes. Once dynamic motion analysis is added to the system, the device can be a powerful aid for individuals suffering from stroke. Neurologists and occupational therapists can use the system to monitor the walking gait (or other daily actions) of their patients outside the lab. The patient's recovery can be monitored outside the clinical setting. There are also many applications of the system in sports medicine. Proper form is imperative to avoid sport injuries. Currently, player form is visually monitored by a coach or trained professional. Players who independently practice are at risk of injury due to unconscious deviations in form. This device can be used as a form monitoring device for players during personal practice.

Overall, this device is a tool for applications chosen by medical professionals or trainers. The device provides easy to access, live biomechanical motion data to aid in the analysis of human movement and intervention of harmful motion.

ACKNOWLEDGMENTS

The authors would like to thank Asish Ghosh and Tracy Schierenbeck for their guidance and support throughout the development of this project.

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Pediatric Isothermal Sleeping Bag

Claudia Stirpe, Daniel Lannan*, Gino Gasbarro*†, Vijay Yalamanchili
Rensselaer Polytechnic Institute
stirpc@rpi.edu, lannad@rpi.edu, gasbag@rpi.edu, yalamv@rpi.edu
**Winner of The Inventor's Studio Startup Founder Award*
†Winner of Inventor's Studio Innovator Award

Refugees flee from Libya and Syria in an attempt to escape poverty, authoritarian governments and war. Refugees in the Mediterranean most often attempt to flee from Libya via dinghy boats by traveling in the Mediterranean Sea in hopes to reach Italy. The boats that these refugees travel in are not built for the sea conditions that are experienced. Many people end up in the sea and some tend to suffer from hypothermia due to the cold water temperatures. This report outlines the design process of the Pediatric Isothermal Sleeping Bag, a device that uses human waste, specifically urine, to heat the user who is suffering from hypothermia. Babies are labeled as the number one priority in these severe cases and are the intended user of the product. This device utilizes the heat from urine to warm the user in a thermal sleeping bag. The layers of the sleeping bag were specifically designed to keep heat from escaping to the ambient air and trapping it within the sleeping bag.

I. Introduction

The use of barrel bombs and chemical weapons in the countries of Libya and Syria has led to many people fleeing their home countries and sailing to Europe through the Mediterranean Sea. The cold weather of the Mediterranean Sea affects many of these refugees as they travel on dinghies. Under international law, if a non-governmental organization (NGO) finds refugees in international waters it must transport them to the nearest safe port. The two main problems faced by these refugees are waste disposal and hypothermia [1]. A single product that solves the issue of waste disposal and treats hypothermia is very much required. The Pediatric Isothermal Sleeping Bag is one such product that provides a solution to multiple problems faced by these refugees throughout their travel to Europe.

II. Customer Requirements and Product Specifications

Table 1: Customer Requirements and Product Specifications

Customer Requirements	Product Specification	Rank
Thermally Insulated	Mylar sheet	5
Secure and Safe to Use	Threaded cap enclosure of nozzle	5
Easy to Use	Jaw string allows for easy sizing of opening	3
Waterproof	Neoprene outer layer keeps bag waterproof	4
Compact	Infant size dimensions	3
Scalability	Scalable Design	2

There are two main issues at hand: hypothermia and waste disposal. The ideated solution uses human waste (urine) and the heat contained within the waste to heat up infants and small children. This solution needs to be secure as the user should not come into contact with the waste. The temperature of Mediterranean Sea water is much lower than that of a human body which requires the solution to be waterproof. As space onboard is limited, a compact solution is required [2]. The product is currently aimed at infants and small children as they are of first priority on the treatment list of doctors. However, this product needs to be available for all refugees on board the NGO ships.

III. Existing Innovations

The technologies utilized in the Pediatric Isothermal Sleeping Bag are not new concepts. However, no product has utilized the combination of a sleeping bag and a urine collection device to heat the individual inside. The following paragraphs will discuss the existing innovations that have characteristics that are similar to the intent of the suggested prototype.

III.A. Sleeping Bags

The three following inventions are modifications to conventional sleeping bags that have characteristics that are incorporated into the Pediatric Isothermal Sleeping Bag.

The Multi-Purpose Waterproofing Sleeping Bag [3] is constructed from five layers of fabric. The middle most layers is filled with a heat insulating material. Additionally, the outer material and zipper are waterproof.

The Electrically Heated Sleeping Bag [4] is moisture resist and powered by a self-contained electricity generator. The bag is also made of insulated material on the outside of the bag. The next layer inward is a flexible elongated electrical heating element circuit enclosed by a covering. The heating element is divided into two columns and runs transversely. The bag can successfully be rolled and stowed like a conventional sleeping bag.

The Urine Wetting-Proof Sleeping Bag is an innovation designed for children. The interior of the sleeping bag consists of three layers. A toweling urine leaking pad is clamped between a plastic sheet and a plush urine absorbing sheet. A pillow is contained at the mouth of the sleeping bag. [5]

III.B. Urine Receptacles

The following paragraphs shed light on existing innovations that are aimed toward human waste disposal. These solutions all are seen in bag form, yet none utilize the heat of the liquid.

The Disposable Bag for the Collection of Body Fluids [6] collets body fluids within a sealed structure. The bag has a pair of sealing strips adjacent to one another at the flexible funnel opening. A non-return valve is sealed at the bottom of the funnel. A gauge indicates the amount of fluid collected.

The Human Bodily Fluid Collection and Absorption Device is expandable, liquid permeable and insoluble. The pouch contains hydrophilic material that promotes quick absorption. Once the liquid is absorbed, it turns into a gel that contains antibacterial properties. [7]

The distinguishing feature of the Biodegradable Urine Collection Device is that the bag is constructed from biodegradable material. There are additional engagement members that aid in the use of the device for both genders. [8]

IV. Proposed Solution

The Pediatric Isothermal Sleeping Bag is proposed as a low-cost solution to the problem of pediatric hypothermia aboard refugee boats. The solution has been designed to accommodate the needs of fleeing refugees while incorporating well known concepts of effective warming bags such as the sleeping bags described in section III.A.

The proposed solution functions as a heat retaining warming bag which utilizes urine as a method of heat generation. Accessible materials for the refugees were selected for the design. The layers are arranged in such a way that the bag can effectively isolate the urine from the child user while allowing the heat energy contained within the urine to be trapped inside the bag to allow the user to be warmed.

IV.A. Design Choices

The design was chosen based on the following criteria: effective warming process, availability of materials and necessary resources for operation, and human centered design.

IVA.1 Liquid Heating Choice

Very few resources for warming a child facing hypothermia exist aboard a refugee boat. When examining available resources, it was realized that human waste, specifically urine, is one resource aboard these boats. Urine is 95% water [9]. Water has the highest specific heat of all liquids except ammonia, resulting in urine at 98.6 degrees holding a large amount of energy which can be used for the generation of heat [10]. Regardless of how cold someone aboard one of these boats is, their urine will still exit their body at the human body temperature of about 98.6 degrees Fahrenheit [11]. With these properties of urine in mind, it was selected as one of the few resources aboard a refugee boat that could be effectively utilized as a heat source.

IV.A.2 Material Selection

Our materials were selected using common knowledge of everyday available materials. Water bladders were selected as the container for the urine to be used in our design. A cotton layer was selected to isolate the water bladder from the child, both due to the properties of it being widely available and comfortable for the user. A layer of Mylar was selected to encompass the water bladder layer due to the common knowledge of Mylar being effective at trapping heat. The final outer layer was selected as neoprene for the well-known qualities of wet-suits which retain heat even when wet. Being that this solution would be implemented aboard a refugee boat, it is important that it retain its functionality while wet.

IV.A.3 Human Centered Design

The proposed solution, as shown in Figure 1, utilizes a drawstring tightening mechanism to tighten the bag around the user's upper body in order to retain heat. A liquid sealing cap is included to seal the valve in which urine enters in order to eliminate the possibility of spillage while the solution is in use. The solution was designed to resemble that of a child sized sleeping bag which can be rolled up and stored effectively.

Figure 1: Prototype Design Rendering

V. ANALYSIS OF MATERIALS

The functionality of the sleeping bag design was heavily weighted on the materials chosen for the each layer. The design of the sleeping bag was created to trap in body heat from the user, but also transfer heat from the urine to the interior of the sleeping bag. In order to ensure that the heat did not escape to the ambient air, but rather directed to the interior of the blanket, the thermal diffusivity and heat transfer rate of each potential layer was analyzed. In addition to analyzing the thermal properties, a thermal simulation was conducted to simulate the temperature change within the blanket over a two hour period of time.

V.A. Thermal Diffusivity

Thermal diffusivity is the rate of heat transfer of a material from the hot side to the cold side [12]. The thermal diffusivity is represented by Eq. (1).

$$\alpha = \frac{k}{\rho C_p} \tag{1}$$

In Eq. (1), α is thermal diffusivity [m^2/s], k is thermal conductivity [$W/(m \cdot K)$], ρ is density [kg/m^3], and C_p is specific heat capacity [$J/(kg \cdot K)$].

V.B. Heat Transfer Rate

Heat transfer is the transfer of heat from a hot side of an object to a cold side. Heat energy transferred to an object increases the object's temperature, and heat energy transferred from an object decreases the object's temperature [13]. There are three types of heat transfer: conduction, convection, and radiation. The heat transfer that was analyzed for this project was conduction. The heat transfer rate is represented in Eq. (2).

$$\dot{q} = \frac{kA(T_{Hot} - T_{Cold})}{L} \tag{2}$$

In Eq, (2), $\dot{q}$ is heat transfer rate [W], k is thermal conductivity [$W/(m \cdot K)$], A is exposure area [m^2], T is temperature [K], L is thickness of layer [m].

V.C. Calculations and Analysis

Table II shows the material properties and layer thicknesses. This information was used to calculate the thermal diffusivity and conductive heat transfer rate of each material. Table III shows a summary of the values that were calculated. The materials in Table III were listed in the order they would be constructed from the exterior layer to the interior layer respectively. The layers are Neoprene, Mylar, Thermoplastic Polyurethane (TPU), Water (Acting as Urine), Thermoplastic Polyurethane (TPU), and Cotton. In order to calculate the conductive heat transfer rate, a study was created to analyze the heat transfer rate of the given thickness of each material with an area of 1.5' x 2', which converts to $0.2787m^2$.

The study looked at the heat transfer from a T_{Hot} of $98^{°F}$ to T_{Cold} of $60^{°F}$.

Table II: Summary of Material Layers and Properties

Material	**Thickness**	**Density**	**Thermal Conductivity**	**Specific Heat**
Neoprene	3	1230	0.19	1500
Mylar	4	1390	0.15	1172.3
TPU	0.1	1420	0.61	1760
Water	3.175	1000	0.58	4187
Cotton	3.175	1540	0.21	1340

Table III: Summary of Thermal Diffusivity and Conductive Heat Transfer Rate Calculations

Material	**Thermal Diffusivity**	**Conductive Heat Transfer Rate**
Neoprene	1.03E-07	0.373
Mylar	9.21E-08	0.221
TPU	2.44E-07	35.890
Water	1.39E-07	1.075
TPU	2.44E-07	35.890
Cotton	1.02E-07	0.389

The calculations proved the prediction that the Mylar had the lowest thermal diffusivity. In the presence of heat, the Mylar acted as a thermal barrier to trap the heat on the interior of the surface. The thermal diffusivity of the TPU is high compared to the other materials. Since there is a low thermal diffusivity for the TPU, it allowed for the heat from the urine, or water in this study, to transfer to the interior layers of the sleeping bag.

The conductive heat transfer calculations further concluded correct material decisions. The values showed theoretically that the heat will transfer faster from the water to the interior layers within the sleeping bag. Since the Mylar had the lowest conductive heat transfer rate, the heat should theoretically stay within the interior of the sleeping bag.

V.C.1. SolidWorks Analysis

A further test was conducted using the same boundary conditions as the conductive heat transfer rate calculation to ensure the material layer selections were sufficient for the thermal requirements of the design. The results of the simulation are below.

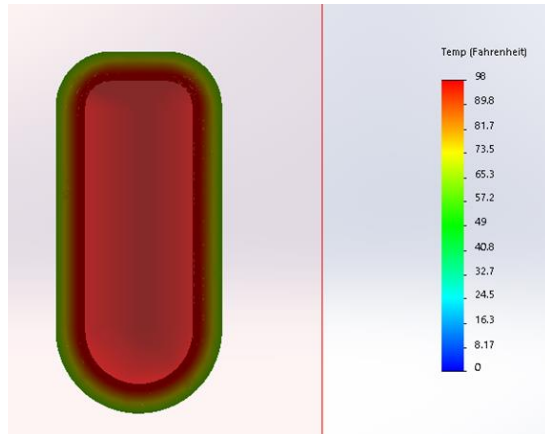

Figure 2: Transient Plot of the Simulated Thermal Testing after 120 minutes.

Steady state results show that the thermal properties of the chosen materials push the heat in the desired direction. The child inside the sleeping bag will get warmer. Selected materials contain heat after two hours. The middle chamber remains at 98 for at least 2 hours.

CONCLUSIONS

The ongoing refugee crisis in the Mediterranean does not appear to be wavering any time soon. Our solution has the potential to ease the dangerous struggles these refugees face while fleeing from their oppressive countries. By proposing a solution which utilizes a source of heat which is readily available aboard these boats, a means of warming of potentially hypothermic child can be achieved.

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Section III:
Engineering Innovation for Society

A Novel Approach to Improve Food Distribution Systems

Wen Fan, Noon Farsab, Rohan Hattangady, Junfu Tian.
Rensselaer Polytechnic Institute
Dept. of Mechanical, Aerospace, and Nuclear Engineering
Dept. of Electrical, Computer and Systems Engineering
fanw@rpi.edu, farsan@rpi.edu, hattar@rpi.edu, tianj3@rpi.edu

A solution to improve food aid distribution systems is presented. The proposed design utilizes an app to provide delivery of food from distribution centers to fresh food vending machine. The current system of food banks to provide accessibility of food is costly and inefficient. The proposed solution addresses these concerns and can be especially useful in situations when a natural disaster occurs or to improve accessibility remote residences. This paper highlights the thorough design process that ultimately was used to create a prototype. Background, design tools and principles, engineering analysis, the prototype, and future work are discussed.

I. INTRODUCTION

I.A. Background and Mindful Reflection

Food insecurity and its distribution in America is a seriously underestimated problem and according to Feeding America nearly 1 in 8 people are not able to obtain enough food to live a healthy and active lifestyle. That means that nearly 40 million adults and 12 million children are not able to obtain adequate amounts of food [1]. Distribution methods to address food insecurity are currently inefficient and outdated. With the development of new technologies in AI and crowdsourcing and cheaper hardware, a new solution has the potential to be very effective.

Natural disasters are a major cause for food distribution issues. While it may seem like an uncommon occurrence, natural disasters such as hurricanes and fires typically affect millions of Americans each year and have the potential to uproot a supply chain. Part of what makes these natural disasters so challenging to handle is the high degree of variability involved. It is extremely difficult to make arrangements in advance and the disaster has the potential to affect all individuals. Grocery stores were low on supplies and had jacked the prices of basic necessities such as a water bottle, upwards of $8.50 [2].

Residence in remote areas is another problem that affects people across the country. Living in a farm in South Dakota, for example, may result in the closest grocery store being an hour drive away. Food banks in California attempted to tackle this problem by simply opening more food banks closer to these locations, however it can be quite expensive to maintain with taxpayer dollars (about $1.5 million) and requires millions of pounds of food to keep in operation [4].

I.B. Mindful Reflection

Food insecurity is a challenge that many Americans face every day. The current system in place makes it very challenging for these families to easily obtain fresh meals in situations where they live in remote locations and may not have accessibility to internet and vehicles for transportation. Furthermore, food banks can be a costly investment for the government making it difficult to expand to new areas, especially in situations where funding is tight.

Natural disasters present a major hurdle when it comes to coordination and supply of food aid sources. In the case of Hurricane Harvey, the food banks ran out of food quickly and many were low on supplies and had increased the prices of basic necessities. Given that it is not feasible to leave the house, it would be nearly impossible to travel far to find a source of food.

While food banks can be an appropriate solution in many cases, it is not feasible if the family lives in a small town such as a farm. For an individual living in these types of remote areas it would be best to keep a large stash of non-perishable foods in preparation for these types of scenarios. Furthermore, an emergency plan would be necessary. This would entail keeping an emergency phone line, shelter, and supplies that could last at least 1 week.

With the development of new technologies for prediction algorithm and AI bringing profits to new tech startups, we see tremendous potential for the government to utilize this for government funded projects.

II. DESIGN PROCESS

II.A. Design Tools and Principles

This Design is generated by the standard of Engineering Design Process which includes several steps: Identify Customer Needs, Establish target specifications: product specification and performance specification, Generate/select concepts, System-level design, Subsystem-level design, Build, Test. The product is designed for customer, therefore it must satisfy customer requirements which means design must meet product and performance specifications.

The product specifications can be seen in the table below. SMART criteria [6] is one principle to identify customer needs in this project. SMART refers to Specific, Measurable, Achievable, Relevant and Time-bound.

Table I Product Specifications

Customer Needs	**Interpreted Needs**	**Technical Specification**
Affordable price	Minimize cost for the funding organization (government).	Cost < $2050
Quality of the food	Can maintain the temperature of food in the equipment and keep it clean.	Fresh 2-3 Days
Security	Only people who are food insecure should be able to obtain food.	ID Scanning, Fingerprint reader
Small Size	Fresh food vending machine can be stored in a small area.	50''x 50''x 36''
Durability	The machine should need few repairs.	Last for 20 years

Table I is the matrix team used to convert Customer needs to Interpreted specification to Metrics. Following SMART criteria, there are five technical specifications that are considered for this product: 1). Affordable price for the customer under 2050 dollars; 2). This product should be able to keep the quality of the food in 2-3 days; 3). This product only provides food for food-insecure people, so the ID scanner and fingerprint reader are necessary; 4). This product should be stored in a small area, therefore the dimension of this product is 50 inches length, 50 inches height and 36 inches width; 5). To achieve a time-bound standard, this product should last for 20 years with few repairs.

The rest of the Engineering Design Process will be discussed in the section *II.B. Innovation Process* for generate/select concepts and Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis and section *III. Solution Design.*

Other tools team used in this project: FMEA (Failure Modes and Effects Analysis), more detail for risk analysis according to this project will be discussed in section *II.C. Technical Details*. Lean Design for Six sigma: Optimize part in DFSS will be discussed in *V. Improvement.*

II.B. Innovation Process

According to the research, in the US, hunger is still one of the most important social problems that need to be solved. According to "Feeding America":

Millions of people struggle to get by because of underemployment, stagnant wages and rising costs of living. In fact, more than 46 million people still turn to the Feeding America network each year for extra support.

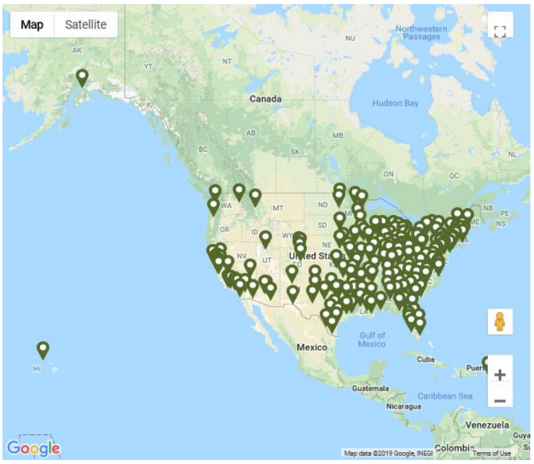

Figure 1: Food Bank Distribution in the U.S.

Among those people, some of them lose their jobs and only need help to get through the hard times. To help these people, “Feeding America” organization has already built a lot of food banks to supply food aid to those people. However, according to “Feeding America” webpage, those vulnerable groups including children and seniors are at greater risk of hunger than others. In that case, how to deliver the food has become a serious problem on food aid. Because for those people who need food aid may have no personal vehicles, it could be a challenge for them to get the food from the food bank while they live far from it.

The team decided to build a innovation product to help the food banks to deliver their food aids to those people who need help. Based on the analysis about the present case, the major problem is the cost to increasing the number of food bank is too expensive to be borne by the organization like “Feeding America”.

The team came up with two ideas. First, the food bank can directly deliver the food aid to individual’s home with a special case to maintain the quality of the food inside.

Second, is to have something like a vending machine to be placed in each community, and people can get their food aid by walking to the machine instead of driving to the food bank.

After analyzing these two methods, the team decided to use the second design as the prototype design for the solution. While the team is concerned about the delivery method for the first design, it will be hard for the company to directly deliver the food to each individual directly, and some of them may be homeless while they need food aid. It will also be a problem for the company to do that since this need high cost on the management and hiring new labor for delivery.

However, the second design will not have these problems since it will be placed in certain locations for each community. The company has no need to hire new workers for delivery. Instead, the delivery can be done by using shared economy method like Uber and Lyft.

II.C. Technical Details

For this project the system design has been completed. The system design included the delivery subsystem and the food storage vending machine subsystem. The team has identified the technical risks within the system solution to enhance the quality of the product by adding risk mitigation components. The technical risks were divided into three categories-low, medium, and high.

The technical risks for the machine include unstable temperature, and this would cause the food to spoil. This risk can be mitigated by Implement a temperature detector and adjust it all the time. Getting the food packages stuck is another technical risk in the machine subsystem. In such a case the user would have to worker using the worker’s contact information on the machine.
The disability to identify ID to get the food is a low risk might occur in the machine subsystem. The user would not be able to get the food, and to mitigate this risk the ID database should be updated frequently. Finally, the highest of the food vending machine is damage in the temperature system. This would be a reason for the food to spoil, and might cause serious illness if customer eat it. This risk can be mitigated by

detecting temperature frequently and dispose of contaminated and spoiled food.

Technical risks can occur in other part of the system design such as the food delivery app. If no driver respond to food delivery request to a vending machine, the application would be programed to increase the payment of this order automatically in order to mitigate such a risk.

III. SOLUTION DESIGN

III.A. System Design

The project totally has two subsystems, one is for delivery and the other is for the machine.

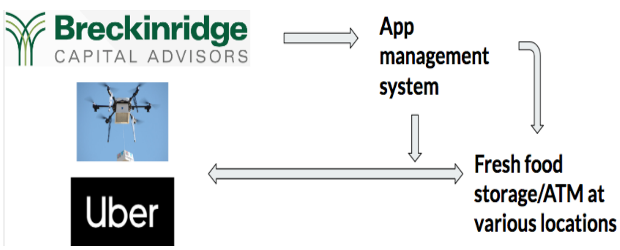

Figure 2: Delivery system

For the delivery subsystem, either vehicle or drone is used to supply the food to local food vending machines that operate similar to an ATM In order to get food from the machine. The app minimizes waste by paying individuals to drop off food from distribution centers that are funded by the government. The users of the app will be able to view the locations of the food vending machine and receive the payment after the food has been delivered. This reduces the number of food banks necessary and reduces hardware cost.

To be more specific, the best choice is to have a protocol with the Uber or Lyft directly and use their application directly. Since they already have great market share and user base in the US. Instead of building a new application for food delivery purpose, it is better to work with them as a new function in their original application. So the food bank and government can reduce the cost of advertisement. Also, the users may be more willing to use a familiar application instead of learning a new software.

To use the food vending machine, the user must show his/her ID to demonstrate they are beneath the poverty line and are facing issues with hunger. Their ID will also contain information on whether they have children, the food vending machine has the ability to maintain the temperature of the food. IOT (Internet of Things) technology will also be used for connectivity with the app and GPS tracking based on the future generation of the internet work.

III.B. Technical Details

The engineering analysis has been completed to ensure that the product will be fully functioning.

The team has built a prototype of the main subsystem which the Food Storage. The prototype is scaled down 1:20. The actual product would the following dimension:
50 in x 50 in x 36 in. The food vending machine has two sides. One for the cold beverages and salads and the other side for hot meals and baby's food. The machine would have 5 shelves in both sides. Each shelf would have 12 boxes of hot meals, and 3 boxes of salads or desserts, and 10 cold beverage. The last shelve of the hot side would be for baby food.

The load capacity for the machine was determined for the actual product. Since the food vending machine will be storing a lot of food, it is important that it will hold the food weight without causing damage. The team has determined the average weight of regular meals and baby's food. The total weight of food with packages will be 170lb when all of the shelves are full. The actual machine would be designed with at least a factor of safety of 2.

A cost estimate analysis was done to determine the final cost of the food vending machine. The total cost is $2045, including $1130 for the electrical components and user interface.

III.C. CAD Design and Prototype

According to engineering analysis for subsystem which is the food vending machine, CAD design is shown in Figure 6. Dimension for a vending machine is 50 in x 50 in x 36 in except the computer screen and ID scanner/Fingerprint reader. Container for each meal is 9 in x 9 in x 9 in and for beverage is 4.5 in x 9 in x 9 in. This vending machine totally contains 48 boxes hot meals for adults shown in orange in CAD drawing, 15 boxes salad or dessert shown in light blue; 12 boxes infant food shown in pink and 30 cans beverage in dark blue.

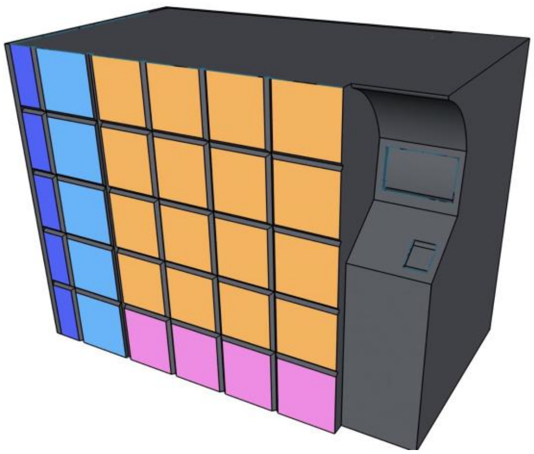

Figure 3: CAD drawing of Food Vending Machine (Front)

Left cross-section is shown in Figure 7. There are 3 boxes after each door and a holder after first box. Holder is used to prevent the user from getting the boxes after the first one. More details about the function of the holder can be found in Figure 5.

Figure 4: CAD drawing of Food Vending Machine (Left Cross-section)

Back cross-section of the vending machine is shown in Figure 8. Due to temperature keeping function of this product, Heater System and Cooling System are considered be added in the back of the vending machine. In this CAD model, orange box indicates the heater and blue box indicates the cooling system.

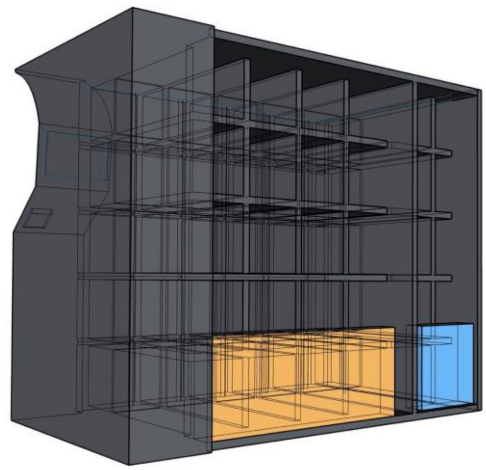

Figure 5: CAD drawing of Food Vending Machine (Back Cross-section)

A 3D printed prototype according to CAD design is shown in Figure 9. For demonstration purpose, this 3D-printed prototype shows all the cross-sections. Different colors on the doors depends on different type of foods, orange for hot meal, pink for infant foods and green for cold food. Cost of 3D printing is 27 dollars which is under team's cost analysis.

Figure 6: 3D printed prototype

V. IMPROVEMENTS

To ensure customers would be satisfied, some improvements can be added to the system design. The food vending machines are going to be located at remote areas where people are affected by natural disasters. Therefore, Uber or others drivers might not be willing to deliver food there unless the amount which are paid is high. To solve this problem the system design can be changed to only include multiple food vending machine which are going to be filled by special drivers hired by the government to deliver food.

In some remote area, access to electricity might be an issue. Therefore, to avoid this issue another improvement would implementing solar panel cells in the machine to generate electricity. A battery system should be added to storage the energy.

The machine is designed to open specific shelves when a customer scan their ID without giving them option. The machine could be supplied with a screen has information about the available option for meals. Also adding more shelves for raw vegetables and meat is a good option for the customers because they can prepare their desire food.
Another improvement is using drones to deliver food in natural disaster. In these times drivers would not be able to drive in such areas, so using drones would be more reasonable.

VI. FUTURE WORK

The first aspect of future work will be to fine-tune and design a detailed plan from the user end. This determining what features need to be included during the software development lifecycle, SDLC, and how the user interface will be user-friendly.

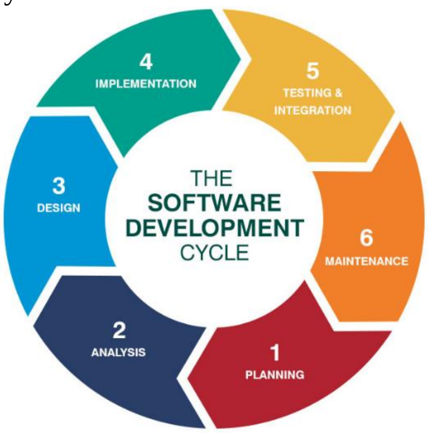

Figure 7: Software Development Life Cycle

In order to develop the software component, a greater understanding will be needed for each of the six steps in this process. Specifically, a closer look at the customer requirements is needed. This involves visiting and conducting interviews with managers of food banks and government organizations that fund them. Another aspect that will need to be examined is the logistics of the model and determining what locations each machine will need to be placed in and how the payment transaction will occur.

A true prototype will then need to be constructed, perhaps gaining assistance from companies such as Amazon and Uber that utilize similar technologies for different applications. One concern that will need to be addressed further is regulatory concerns such as food quality and expiration. There are regulatory bodies such as the FDA that will approve the process based upon the safety and quality of the food being delivered. The FDA will verify both the safety and effectiveness of the solution.

Once a proof-of-concept model is developed, pitches will be given to organizations such as Feed America and private equity investors leading to funding and scaling of the model. The model will progress by initially testing in regional locations with the end goal of expanding globally.

ACKNOWLEDGMENTS

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Waste Disposal in South-East Asia

Noah Dropkin, Zackery El-Mohandes, Nieve Morin, Jack Swift
Rensselaer Polytechnic Institute
dropkn@rpi.edu, elmohz@rpi.edu, morinn2@rpi.edu, swiftj2@rpi.edu

As of the end of summer of 2018, over one million Rohingya have moved into the Cox Bazar region of Bangladesh as they flee prosecution in their home country of Myanmar. These refugees have taken shelter in temporary camps with no permanent infrastructure, including the lack of a proper waste management system. Regular garbage and human waste are disposed of together, typically by handcart. This, coupled with constant flooding from the regions extreme weather, exposes the refugees to bacteria that can cause serious illnesses such as cholera. Existing methods of disposing of waste are ineffective, as waste disposal points are located too close to some shelters, creating additional sanitary issues, and plastic containers distributed to refugees for waste disposal are often sold or stolen rather than effectively used. In response to these issues, a solution has been developed to contain and transfer waste using bioplastic containers. These containers function similarly to the preexisting plastic container solution, however the degradable nature of the bins prevents selling and stealing of the bins as they are no longer permanent materials and as such lose significant value. The solution also utilizes a ClO2 biocide additive to kill bacteria and improve the cleanliness of the system.

I. Background

The Rohingya are fleeing from genocide in their home country of Myanmar, where their villages are burnt to the ground and their people murdered by Myanmar military, in what the UN is referring to as the "world's fastest growing refugee crisis" [1].

As with many refugee camps around the world, the camps in Cox's Bazar, Bangladesh, are composed primarily of temporary structures, partially due to restrictions put in place by the government, and partially due to frequent natural disasters such as monsoons and the resulting flooding and landslides, causing relocation of a large number of refugees [3]. As a result, the human waste management systems in these camps are also temporary, consisting primarily of emergency latrines built by the Bangladesh military that would hardly be considered functioning by those used to the standard US waste disposal system [2]. Latrines such as these are not built to be permanent, and as such they are not particularly sturdy, nor are they connected to sewage systems. As a result, when monsoons hit, these structures are often destroyed, or at the very least flood, and any waste that has not yet been removed overflows into the surroundings [2].

The typical waste produced per capita per day in the region of Myanmar is roughly 0.44 kilograms [4], which is less than one fourth of the typical waste produced per capita per day in the US [5]. Despite this lesser quantity, the waste produced in Myanmar is exponentially more of a threat than that produced in the United States because of how it is handled. In the refugee camps, there is no sewage system. Waste is typically removed from camps by hand to temporary waste disposal sites, where it remains until it can be transported to a more permanent storage location or an incinerator. The concept of moving human waste by hand is the unfortunate reality for the refugees located in the Cox Bazar region.

The lack of separation between types of waste not only adds unnecessary bulk to the waste sites, but also poses risks to the users of the site. The threat to people from the waste sites comes primarily from the risk of disease. Disposal of everyday waste into these waste sites exposes users to bacteria from the human waste that can cause illnesses such as cholera. Flooding, too, can cause bacteria to spread from the waste sites, affecting even those who have not been near them. In this way, both the Rohingya refugees and the Bangladeshi of the hosting communities are affected by the inferior methods of waste disposal. According to Robert Onus, the Emergency Coordinator for Doctors without Borders in Bangladesh, the areas surrounding these waste sites have "all the ingredients for an outbreak" of cholera [6]. While it may seem obvious that one solution to this issue would be the distribution of vaccinations against the waste-spread diseases, it has to be kept in mind that funding for medical supplies is not always sufficient to ensure that all persons receive the necessary vaccines, especially when the number of refugees continues to increase.

II. Comparative Analysis

There are several different solutions in place to manage waste in refugee camps, but almost all have significant drawbacks. Waste collection points vary, from within 15 meters from dwellings and up. Waste collection vessels also vary significantly, from 100 liter metal bins, to concrete pits constructed with 3 or 4 sides or pits without any liner or containment. When waste is collected far from its final intended destination, it is often moved by handcart to trucks or intermediate collection points [7]. Bins and bags can be used to contain waste for easier transfer [8]. When waste is transported in a secondary container, like a bucket or bag, there will inherently be some wasted space in the truck. Waste can also be collected in large containers which feature lids to prevent water ingress, but would need to be cleaned between uses to prevent spreading of bacteria and insects [9].

Most of these methods share several flaws. When waste is left in a way that it is exposed to water, this water is absorbed, providing a breeding ground for disease-carrying insects and animals. This also makes waste much heavier, and subsequently more difficult to move. Moving waste frequently is also very difficult, as waste should be moved at least twice per week to break fly breeding cycles [7]. More permanent methods of waste disposal like sanitary landfills, composting, and incineration require infrastructure, and are usually only implemented after crises have stabilized [8]. When semi-permanent landfills are constructed they are placed far from dwellings, but as settlements expand, they often encroach on these landfills, exposing residents to dangers from insects, rodents, disease, and odors [9]. When landfills flood they carry waste, insects, rodents, and bacteria with them, and exacerbate their issues. Incinerators of all sizes are a common solution to these issues, but are regarded as a last resort [9]. The incinerators documented in use in Myanmar are "often not designed and built according to best practice" [9]. This exposes users to potentially incompletely combusted waste, and presents a fire hazard when built too close to nearby structures [9].

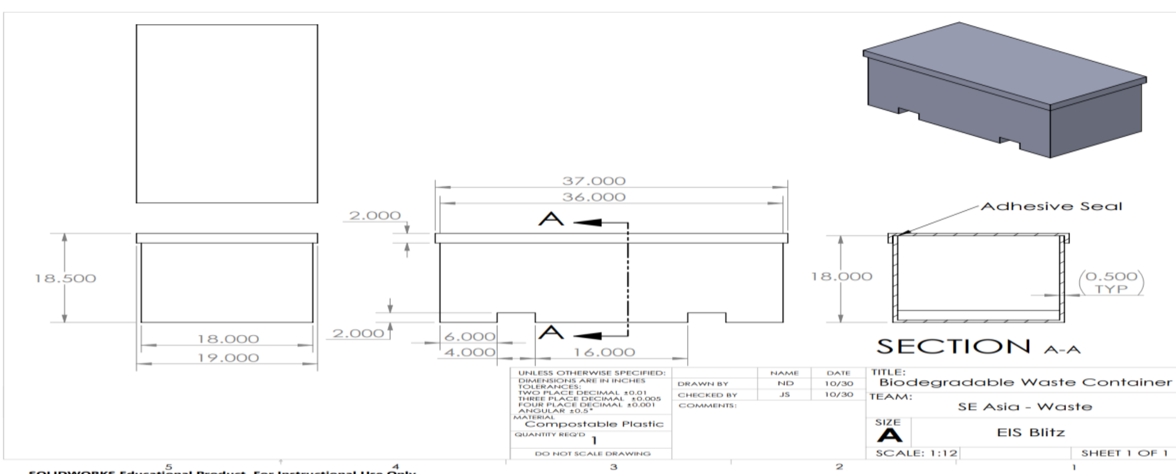
III. Solution

The solution our team decided to focus upon was a compostable or biodegradable crate to be used for storing and transporting waste. The crates are simple rectangular crates, with indentations along the bottom to allow wooden boards to be slid under for easier lifting and carrying. The specific dimensions of the crate can be seen in the technical drawing on the following page. This solution is based in part on an existing solution that we discovered in our research, in which plastic crates were used in the same manner. However, this solution failed because the containers had the risk of being used for alternative tasks in households, being stolen, or even being sold for a small but much needed profit [9].

By deteriorating over time, the crates have less value and are less likely to be stolen or sold. The expected lifespan of each crate is 6 months before deterioration begins, depending on weather.

A biocide additive will be placed in the crate to kill bacteria and minimize the odor caused by the waste. A sensor will be added to the lid of the tank with a level sensor and radio transmitter to alert the responsible party when the crate needed to be replaced. The sensor would be transferred from crate to crate as they are used, as they would be too costly to dispose of each time the crates are replaced.

The solution requires no permanent infrastructure, are resistant to extreme weather and flooding, and limit contact with the waste by animals, insects and users. Finally, because of the simplicity of the product, it should not be overly costly to implement. This, however, cannot be confirmed until a final material is decided upon, and the cost to obtain the material and use it in crate production is determined.



IV. Engineering Analysis

With a volume of 1629 cubic inches each box may weigh a significant amount based on the material chosen to create it. The bioplastics the group looked into had to be sturdy and be not degradable by water. Sturdiness in order to make sure the boxes do not break under the pressure exerted by the trash and hydrophobic because of the rampant flooding in Southeast Asia. A sturdy bioplastic that fit the criteria is Polyhydroxybutyrate. It will not decompose in water because it is hydrophobic and requires the assistance of microorganisms to decompose. Some examples of these are Aspergillus fumigatus and Variovorax paradoxus which exist in soil or decaying matter [11]. Additionally, there are also *Alcaligenes faecalis* and *Pseudomonas* which thrive in anaerobic sludge. The decomposition process if perfect for the refugee situation. Studies using bottles of this polymer had 30% of weight lost to decomposition over a 19 week period while exposed to oxygen and there was a massive weight loss of 80% when no oxygen was present [12]. This means that there will be little to no decomposition effect during the week the box is in use above ground. However, once buried the decomposition process should be complete in under a year. Polyhydroxybutyrate has a density of about 1.22 g/mL [13]. Converting the volume of the box to milliliters yields 26694mL. Therefore the total weight of an empty box is 71.8 lbs. We believe that this is a good weight for the box to be when you consider that by volume it can hold 5.85 cubic feet worth of garbage. When full it will become much heavier. For example, if filled with liquid waste we can use the weight of water as a basis for how heavy it would get. With water's density being 62.43 lb./ft^3, taking up a volume of 5.85 ft^3 would be a weight of 365.2 lbs. When the two weights are added, the total of 437 lb. is in excess of what the average adult male should be carrying [12]. Therefore, the warning labels included on the box should mention to not fill it with liquid waste and instead use the box to dispose of less dense solid waste. As most lifting safety standards max out at around 75 lbs per person per lift any person can lift an empty box alone which is very convenient for moving them where they need to be in order to collect waste. When removing the boxes up to 4 people can lift by placing 2x4s into the notches at the bottom of the box to create handles (2x4s were chosen because it is an extremely common cut of wood and something that can most likely be obtained in the poverty stricken area). With 4 people lifting, the allowable weight according to Chapla is about 300 lbs. If you subtract the weight of the box this moves about 230 lb. of solid garbage safely per box. With this amount of waste exiting the system with ease, the bioplastic boxes are looking as though they can make a significant impact in the betterment of the refugees.

Conclusions

Through analysis of user needs and current solutions we have developed a solution we expect will work well. By developing a solution to contain waste, we are preventing the spread of disease within the refugee communities who are already suffering in a multitude of other ways. We are also keeping the environment around the refugees in mind by creating a product that minimizes waste left in landfills in the long run. Overall, our product will benefit many by providing the refugees with at least minimum of health standards, and by keeping the Bangladesh land that they are currently residing in cleaner and able to be reused once the refugee crisis is solved.

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Intelligent Trash Bin for Waste Management in Refugee Camps Bordering Venezuela

Nichenggong Zhu, Clara Schaffter, Brandon Perez-Gomez, Yiming Fan
Rensselaer Polytechnic Institute
Department of Mechanical, Aerospace, and Nuclear Engineering
zhun3@rpi.edu, perezb2@rpi.edu, fany5@rpi.edu, schafc@rpi.edu

This article addresses the issue of waste disposal in refugee camps in South America, and presents a solution which should help conserve resources and remove some of the hazards associated with trash storage and disposal. The Intelligent Trash Bin accepts trash through a top opening, identifies its material, then sorts it, where it is pre-processed and stored in a sanitary environment until it can be transported for recycling or disposal.

I. INTRODUCTION:

Looking at refugee camps inhabited by the Venezuelans that migrated to bordering countries, large amounts of waste is produced and it must be managed properly. It is important to manage the waste to create a safe, clean, and self-sustaining environment for the refugees as they left everything and seek a better life. Current methods exist, such as communal trash bins and fire pits, however, for long term they do damage to the environment and certain systems like the communal trash bins if not handled properly become a breeding ground for intruders like rats and other critters and potentially spread disease in the camp. In addition, a lot of recyclable materials such as plastic bottles or aluminum cans are dumped instead of recycled and or reused. These systems do not take advantage of the reusable material that are donated or bought for the refugees, and this innovation strives to implement a system which helps manage waste to make the lives of the refugees much easier. To accomplish this, we came up with a solution called the Intelligent Trash bin.

II. REQUIREMENTS AND SPECIFICATIONS

I.A. Requirements

Requirements for an innovation which addressed the problem of waste management in South American refugee camps were determined by considering similar waste challenges around the world, looking at existing solutions, and seeing what factors were the most critical in the disposal of waste. Besides those mentioned in Table 1, the safety of the user and the convenience of the device to the user were also considered frequently during the development process.

Table I: Requirements and Corresponding Technical Specifications for Intelligent Trash Bin.

Requirement	Technical Specification
Easy to use and maintain	Can be used with less than 15 minutes of training and maintained with at most 1.5 hours of training.
Sanitary	99.999% reduction in disease causing organisms [1]
Durable	Require no major unscheduled repairs over a 3 year period of regular use
Power Consumption	Low power consumption, less than 25 watts/day (power usage of a small appliance)[2]
Portable	Can be carried by 2 people- weigh less than 75 lb and be no wider than 1m in any dimension.

III. GENERAL OPERATION DESCRIPTION

The Intelligent Trash Bin works as follows. The user puts trash into the center hole, where it then falls in front of a set of sensors, which identify the material of the trash using computer vision and material tags. The material tags would be included by the producer on supplies given to refugees, so that the device is better able to identify these items and prevent waste.

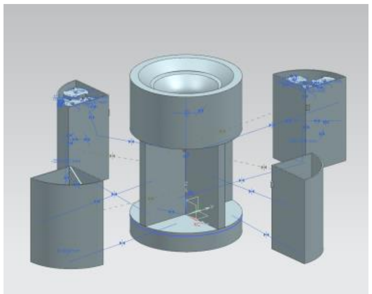

Figure 1: Intelligent Trash Bin CAD Design, Expanded View

Once the material is identified, a rotating chute turns to the bin the material belongs in and dumps it in. The device has four bins, one for plastic, one for metal, one for biodegradable materials, and one for any trash which does not fall into one of the three other categories. A fifth container is present at the base of the device, which collects any liquids which enter the system.

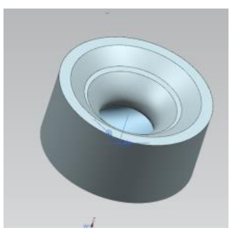

Figure 2: Top of bin, with chute entry. Sensors located around inner ring.

The biodegradable collection bin and plastic collection bin both contain a set of rotating blades which chops the waste into pieces, before it falls into the containment area below. Plastic waste is held until transportation to a plastic recycling plant, while biodegradable material is held until transportation to another location be used as fertilizer, or to be burned for power creation.

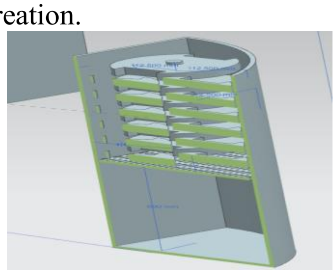

Figure 3: Cross section of biodegradable/plastic collection bin

The metal collection bin contains a crushing device, which sweeps across the bin to crush the metal against the side. Small points on the crushing paddle create holes in the metal, allowing any air or liquid to escape from the container. The crushed metal is then stored within the bin until it can be transported to a metal recycling plant.

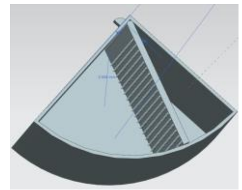

Figure 3: Top view of metal collection bin

The fourth bin is for any other types of trash which are thrown into the bin, so it simply collects these materials until they can be taken to a larger facility to be properly disposed of. This ensures that camps are not running the risk of burning hazardous materials such as batteries by burning their own trash.

Finally, a fifth container beneath the base holds any liquids which are generated by the system. These are sterilized with UV light before being sent to a water treatment plant for further filtration.

There are currently plans in the works for an expansion of this design, where the Intelligent Trash Bin would be the central module in a larger system. There would be four inputs, plastic, metal, biodegradable, and other. Each input would check if the material put into it was of the expected type, and if so, it would fall directly into one of the four processing bins mentioned before. If the system detected the wrong material, the trash would then be diverted into the main input of the intelligent trash bin, where the process would proceed as described before. This modification would allow the more complex sensors needed for the computer vision component of the system run less frequently, therefore improving the overall power consumption of the unit.

IV. SUB-SYSTEM CALCULATIONS AND CONSIDERATIONS

IV.A. Blade Strength and Material

For the blades of the biodegradable and plastic collection bins, the cutting force needs to be considered. Shear force is calculated by the rule of thumb percentage of the yield strength, typically about 80% [3]. Using polystyrene, the most common type of plastic, as a baseline, the yield strength is within the range 4.17 - 6 ksi [4].

$$Stress = Force/Area \quad (1)$$

$$Area = 2rt \quad (2)$$

Here, the area is the area of the cross section of the material the blades are in contact with. Using equation 2, with a radius of 2.76in and a thickness of 0.04in, the area is found to be 0.35in^2. Using the worst case value, the yield strength is considered to be 6ksi, which gives a stress value of 4.8ksi. Applying these values to equation 1, the force required is found to be 1664 lbs.

From this, the motor needed to produce this force is found to have a strength of 15.2 HP, which is then multiplied by the S.F. (safety factor)[3], to find the worst case strength needed. Here, S.F. is 2, so the worst case horsepower is 30.4. This is quite high, but it only used over very short periods of time, which will result in a relatively low overall power use [2].

Considering next the blade materials, stainless steel will be used, due to its strength and general durability. The blades of the biodegradable material bin will be coated with a corrosion resistant material in order to ensure that the blades remain undamaged, as this bin holds the greatest risk for germ growth due to the nature of its contents. This in addition to the naturally corrosion resistant properties of stainless steel will help to mitigate the risk of disease posed by the trash.[6]

IV.B. Crusher Strength and Material

For the crusher, the strength needed to crush the containers put into the device must be considered. Metal waste is usually metal cans, so here they are considered to set a benchmark for the needed crushing strength.

$$\sigma = \frac{\gamma E}{\sqrt{3(1-\mu^2)}} \frac{t}{r} \quad (3)$$

Equation 3 is for the buckling force of the metal cylinder[5], where t is cylinder thickness, r is cylinder radius, μ is Poisson's ratio, is σ axial stress, E is Young's modulus, and γ is gamma, the radius/thickness ratio, which is defined in figure 4[5].

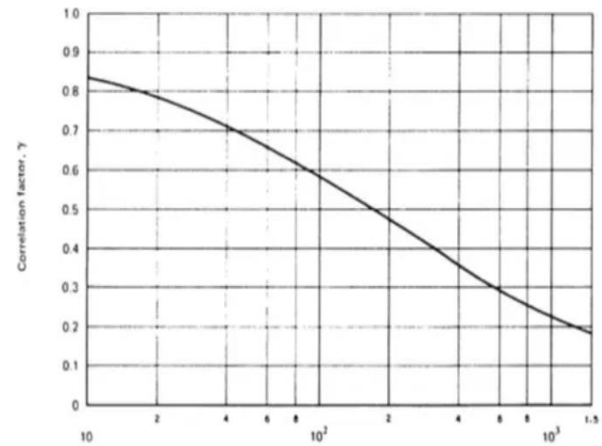

Figure 4: Correlation factor for isotropic circular cylinders subjected to axial compression [5]

The value of young's modulus for aluminum is 10 * 10^ 6 psi, and Poisson's ratio value is 0.35. There radius of the cans considered is t=0.0038 in, r=1.065in, and γ is 0.41 from figure 4. Combining these in equation 3, the axial stress is found to be 9016 psi. Finding the area of the can and converting the axial stress to pound-force, then applying this to equation 1, the force is found to be 229.3lb.

The material of the crusher will be the same as that of the blades, stainless steel, as it is strong and durable, as well as being generally resistant to corrosion. It can also be shaped fairly easily, and will hold its shape well, which makes it an appropriate choice for the crusher as it can support the small spikes on its surface which are used to pierce the metal it is crushing. Finally, it is stronger than aluminum, so it will not distort when trying to crush the other metal.[6]

IV.A. Blade Strength and Material

Each of the containers must be made of material that can resist surrounding weather conditions such as rain, be durable to handle the processing of waste and not degrade too fast overtime, and resist oxidation. In addition, we need a wall that can handle the pressure that the crusher creates when crushing several metals. Therefore, we use an aluminum titanium alloy for the intelligent waste bin. This metal is also relatively lightweight, which helps the device to meet the desired overall weight requirements.

V. PROTOTYPE

As a part of the design process, a model of the device is being constructed, for the purpose of demonstrating the concepts presented. The model will be created at ⅕ scale, and half of it will be built over all, a cross section taken down the middle. The upper ring will be constructed of Styrofoam, carved into the proper shape. The lower frame will be constructed of laser cut PVC sheets, which are then assembled into a three-dimensional whole. Two bins will be produced, one crusher and one blade bin, and these will be produced using 3D printing methods. In order to showcase the internal structure of the bins, each will be printed as cross section, with half present to that the crushing and blade mechanisms respectively can be seen.

VI. CONCLUSIONS

The aim of this innovation is to help improve people's lives in South America, as with overall stress of their situation in the front of their mind, waste management is not a priority. Specifically, the intelligent trash bin can improve the efficiency to deal with the waste proposal made from refugee camps in Venezuela. Following the procedures outlined in Lean Design for Six Sigma, we define the customers' needs and specifications for the product and finally finish the design of the intelligent trash bin that can recognize, sort and dispose off different types of waste in appropriate methods. Due to the cyclical nature of the design process utilized, this innovation is still in development, and further improvements and modifications will continue to be devised for it as the design process moves forward.

VII. MINDFUL REFLECTION

In much of South America, economic, political and natural disorder has come to negatively affect a great percentage of the population of the area. This has prompted one of the largest human migrations in recent history. For this Engineering and Innovation for Society project, the focus will be on the many thousands of people who have taken refuge from Venezuela, to such a degree that over 7% of the population of Venezuela, approximately 2.3 million people [7] of these people, the great majority are fleeing with little to nothing to call their own, with no set end destination. They are simply doing anything within their power to find their way out of the country, taking every opportunity available to them to get away from the situation. They are fleeing to areas in Chile, Ecuador, Colombia, Peru and Brazil [7].

The current situation in Venezuela is quite dire. The economy has collapsed, with inflation running rampant, rising to nearly 1 million percent [8]. This combined with shortages of food and medicine has brought about a health crisis, with people unable to gain access to even the most basic medical treatments. As a result, infant mortality has sharply risen, as has rates of malnutrition in the country. The political state in Venezuela is little better. President Nicolas Maduro is blamed by most for the economic downturn which has ravaged his country, and while his government tries to fix the issues which plague their country, efforts seem to have been in vain. Neighboring nations have taken some action to help mitigate the crisis, but overall, their efforts have also shown few positive results. In addition to this, Venezuela was also hit by 7.3 magnitude earthquake earlier in the year, which only serves to further the already difficult lives of those who are seeking refuge away from a country which offers them nothing but hardships and turmoil [8].

At a personal level, the people who are fleeing the country face further hardships. Due to the rapid rise in inflation, the cost to acquire proper documentation and transportation to the border has become more than most can afford. Families are selling everything they have, house, technology, vehicles, everything but the clothes on their backs, to acquire transport from the country. And once they reach there, they are faced with persecution from now overcrowded conditions, and camps that are little more than collections of tents, thrown together to handle the far above average number of people streaming across the border.

Take the story of Johan Rodriguez, one of many fleeing the country. He and his family managed to make the long journey from Venezuela to Brazil, to a town called Boa Vista, where they have been camping for over a month. Work is scarce, with so many migrants having fled to this area, and without any source of income, many migrants go hungry. These hungry, malnourished individuals then become more prone to illness, which prevents them from working, and which cannot be treated with common, life-saving medicines. This vicious cycle is the daunting reality which faces many South American refugees [7].

Consider the average American. Through our recycling collection, we found that the average volume of recyclables produced per day was approximately 0.45 Kg/day, with approximately 3L/day of fluids being consumed. These numbers are not a great reflection of daily needs, as they do not consider other, non-recyclable sources of waste, so looking at the U.S. average, we find that the average person throws out 4.4 lb of trash per day, eats 3600 calories, and drinks 3 liters of fluid. The minimum amount of calories and fluid intake a human can survive on is about 1200 calories and 1 L water a day, though a human can survive on less for small periods of time.[9] Considering then, that the vast majority of refugees are surviving near the poverty level, with only enough weekly income to afford one or two days of food, thus forcing them to work unfed for the rest of the week, or strictly ration food so they can have a little bit each day. Such things are near unimaginable, yet they can happen anywhere. Not long ago, Venezuela was a booming country, its economy driven by the oil market. People were fed, had access to healthcare and sophisticated technology, the same sort of thing available everywhere in the U.S. today. This didn't just happen in some out of the way place, it happened in a country like this one, one with people who had dreams and opportunities that were taken from them as their country fell apart around them, forcing them to flee for their very lives, seeking resources to survive, leaving everything behind.

What waits for them is seldom better than what they left, at least at first. Jobs are scarce, and refugees are gathered into communities, either official or by need, just to have a place to stay. These refugee camps are also dangerous places though. Not everyone in the areas refugees are fleeing to wish to welcome them with open arms, and even among those who do, the sheer number of refugees coming over the border is straining their resources. Medical centers are unprepared for the volume of malnourished people, especially children and pregnant women, who are in need of care, and external aid is slow and expensive. Fear of refugees has also emerged in some places, with locals blaming them for bringing disease and crime to their towns. Harsher security measures have also been put in place, requiring more extensive, and therefore expensive documentation for migrants [7].

Considering all of this together, it is clear that the situation is delicate, and that in designing anything to ease the hardships of the migrants, we must consider the numerous obstacles which have befallen them, and use our own opportunity and privilege in order to ease the worst of their suffering. As such, the innovation design as a part of this project seeks to alleviate some of the stress present in the lives of these refugees, as with the number of hardships which face them on a daily basis, the idea of conserving renewable resources is likely far from their mind, when they need to fight for survival every day. It is also a point of consideration that though this innovation is designed for assisting with the waste management issue in South America, it has applications all over the world, in other places where refugees are present, or in areas faced with clean up after natural disasters.

ACKNOWLEDGMENTS

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Urban Vending Machine Program

Nathan Peck, Asef Islam, Jina Kwon, Jack Ryan
Rensselaer Polytechnic Institute
Department of Mechanical, Aerospace, and Nuclear Engineering
peckn2@rpi.edu, ryanj12@rpi.edu, islama5@rpi.edu,

The purpose of the homeless vending program is to provide a sustainable source of sustenance to the homeless and underprivileged in urban centers. Through a swipe card program that is easy to enlist in through homeless shelters, underprivileged populations have access to fresh, nutritious meals provided by local restaurant overstock, donations, and subsidies from local administrations. The addition of a trash depository in exchange for credit to the system leads to cleaner environments. This report includes the general solution descriptions, a brief technical overview, and the potential future of the project.

I. INTRODUCTION

Issues in food distribution can be separated into two unique areas with very different solutions; rural and urban distribution. In an urban environment, the food is there, but getting it out to those who actually need it can be an issue, especially with regulations in food quality. In rural areas, specifically undeveloped countries, nutritious food is scarce, and distribution comes down to actually getting it there.

Currently, there is enough food being produced to feed 9 billion people, however much of that food is being distributed to wealthier nations who have resource intensive animal based diets. For example, during a famine in Ethiopia, the country remained a net exporter in food [1]. While switching to a more plant based diet is the obvious solution, it is not practical to expect billions to do so, leading to the necessity for innovations in methods of food distribution.

On the other side of the spectrum, urban food distribution, specifically to the underprivileged and homeless, is more daunting task than most assume. Many cities have strict regulations criminalizing the activities of the homeless, rather than helping them [4]. Not only do cities discriminate against the homeless themselves, but also groups attempting to aid them. For example, "Denver ordinances require a permit for any scheduled event in a city park involving more than 25 people" [4]. Getting such permits require jumping through hoops with city officials and charitable organizations, ultimately diverting people's attention away from the original crisis at hand.

Not only do urban areas have issues with homeless distribution (only 20% eat 1 or more meals a day) [4], densely populated and poorly planned cities may have issues in regards wholesale markets.[2]. A middle man between farmer and consumer is vital, and certainly an area that can be looked at in regards to innovation.

I.A Existing Solutions

Existing solutions do exist for distributing food in urban populations, however they rely heavily on manpower and government support. Some of these solutions include

- Meals on Wheels
  A basic program aimed at driving food around to those in need, specifically the elderly with mobility issues, and to locations with high homeless populations
  - Homeless Shelters
  Physical locations that are sporadically located within a city. They act as convenient locations for those in need and act as hubs for the homeless.
- School Lunch Programs
  Some cities have initiatives to send underprivileged children home with meals for the night

While these programs are great, they can be unreliable, and tailor to specific groups of people. Meals on wheels and homeless shelters can have inconsistent amounts of food, with higher rates of donations and help around the holidays. School lunch programs are great for families with children, but fail to reach the majority of the homeless population; adults.

The urban vending program will not only provide consistent access to food that these programs might not provide, but also provide opportunities to decrease food waste, and lead to cleaner environments and community interaction.

II. INNOVATION DESCRIPTION

The final solution to the identified problem space was a Vending Machine-like design that established a program of wellness and sustainability within an urban community.

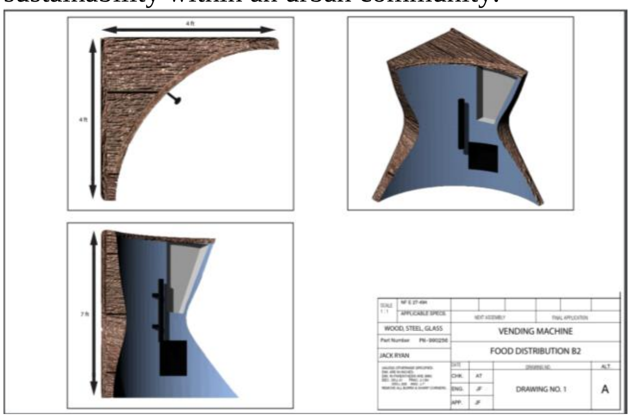

Figure 1. Rhinoceros 5 Render of the Design

The device is approximately 7 feet tall, 3 feet in the x direction, and 4 feet in the y direction. The object is designed to rest in the corner of a high traffic thoroughfare of a low income, food deprived, and demographic location. The device will be equipped with three major components. The first is the trash/recycling receptacle. This part would function similar to a library book drop off. Ideally, users would open the tray, insert their goods, and deposit it into the body of the machine. Using scales or radar, the machine would recognize the trash and then translate that input into a credit which would then be exchanged for a food product.

This leads to the second major component of the device: the pantry. The pantry occupies the entire left-hand side of the body and is indicated by the door handle near the center of the body. This would be stacked with shelves, each featuring an array of healthy but affordable food items which could be obtained through depositing trash into the machine. The incentive this system propagates is that by taking pride in the cleanliness of their surroundings, users can reward themselves with ample nutrition. The final feature of the device is the touch screen located in the upper left hand corner. This screen facilitates the entire interaction, helping the user keep track of their remaining credits and the corresponding food options available to them. It is also where the card swipe interaction occurs, reminding users of their swipes remaining and how valuable these swipes are in terms of acquiring pragmatic nutrition

Overall, this design is intended to be approachable and casual, making it accessible to underprivileged users suffering from the consequences of poor food distribution. It's also designed to be aesthetic and geometrically interesting so that it doesn't negatively stigmatized the user. Ideally, this system would imbue a routine and pride in its surrounding community, improving overall nutrition and net standard of living. Furthermore, the screen and software design could be made to focus users on certain types of trash or debris, meaning city planners and elected officials could communicate directly with their constituents in the context of cleaning the city and surrounding areas.

From an engineering standpoint, there are a few areas of interest to look at. First would be power draw and impact on the city. The standard power draw of a vending machine is 10 kWh. Due to size and scale of this machine, power draw would likely run closer to 20 kWh daily. Taking New York as a test city running at 19.6 cents per kWh in February 2019 [6], we can make the following cost calculations.

Rate per year (kWh) * Cost/kWh=Cost per year (1)

$$7300\,kWh * \$.196 = \$1430.8\,/\,year$$

While cost of electricity is often overlooked. This would put a financial burden on whatever entity is running the machines.

Storage for the food is also a concern, especially for the shape of the pantry. With a circle radius of 3.5 feet, a usable height, width, and length of 7 feet, 3.5 feet, and 4 feet, interior storage can be determined as such.

$$L * W * H - (1/4) * (4/3 * \square * r^3) \quad (2)$$

Applying the numbers, this yields 53 cubic feet of storage, not accounting for the thickness of the walls. Accounting for such, the vending machine might only hold 40 cubic feet. Most home refrigerators only hold 20-25 cubic feet, and this machine would be serving much more. Either constant restock or a change in design would be necessary to meet demand

The weight and strength of the machine need to be taken into account for vandalism and installation purposes. Because much of the exterior will be wood, it will be rather light, at a standard density of $0.67\ gm/cm^3$. However, the interior steel and electronic components would add weight. Maybe changing to an alloy would keep cost and weight down.

A large concern for the machine is vandalism. To alleviate this concern, the machine would use Plexiglas to show off pantry and the touchscreen. With an impact resistance 5 times higher than standard glass, and a tendency to bend when hit, it is an ideal material.

III. DESIGN PROCESS AND STRATEGIES

Throughout the entire duration of the project, the Human Centered Design process as well as the Lean DFSS process were both heavily referred to. The Human Centered Design process was consistently executed throughout the development of our innovation in order to make sure that our product was successfully catering to the people that it was intended for. In our specific case, people who used the device as well as people who lived in proximity of the device would be beneficiaries and this design process ensured that the different components of the innovation achieved this.

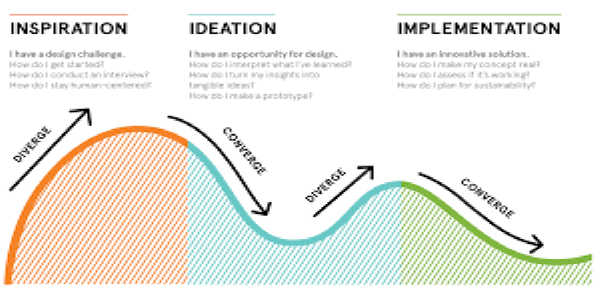

Figure 2. HCD Process

The design of this innovation can be divided into two levels. In order to organize the different components of the design and the necessary steps, a visualization was conducted. This visualization showed the potential designs of the vending device that could be implemented in the areas we were focusing on, in our case urban cities. In addition to creating several concepts and designs, the visualization created several scenarios of how the users of the device would interact with it and benefit from the purpose of the machine. The second level is deeper, in which the logistical components were sorted through and studied as well as the external factors that would affect the innovation. A crucial part of this analysis was the risk mitigation plans that were developed. This was crucial in the fact that during this process of analyzing the potential risks that could arise from the implementation of our innovation, we discovered new avenues to further develop our initial concept. This led to several updates to the initial design idea and made our innovation more complete as a result.

High
Medium
Low

Risk	Subsystem Affected	Severity of Risk	Risk Mitigation
Machine not able to handle extreme weather conditions (heavy snow/rain, very hot days in the summer)	-Sensors -Power -Mechanical components	Can cause the whole device to break, costing money to repair as well as taking away a viable source of food for the people that use it regularly.	Machine is designed in such a way that it can adapt to weather conditions and remain functional. Weekly regulation by the company that supplies the machines for frequent maintenance.
Vandalism	-Structure -Surface	Heavy times of use would be late hours and could prevent machine function or have derogatory imagery	Light and cameras, as well as strategic machine placement would prevent vandals
Too many members of program	-Internal program	Too many members would defeat the purpose of the program, and people wouldn't be able to get food at all times	Only allow those in need to join through homeless shelter
Compartment that is responsible for placing the recyclables/trash getting jammed due to overflow of items placed in it	Component of the machine that allows user to place items	Halts the machine's functionality and makes it unusable. May cause a chain effect and break connected components. Takes away viable food source for dependent users.	Build in sensors that detect when the compartment for placing items is at capacity which displays warning to user to finish current action before continuing.
Lack of space for food and recyclables	-Pantry -Trash Holder	A lack of food would create divisiveness among members over best and current food options, lack of space for recyclables and trash would prevent responsibility aspect.	Volunteer program to fill and empty frequently and off work schedule
Food within vending machine running out/expiring	Quality/Safety of food	Can cause negative health effects to consumers.	Regular maintenance to take out expired foods and replace them with fresh items. Select foods that can stay safely consumed for longer than one day.
Glitches and Software Malfunctions	Touchscreen Display and corresponding components	Could hinder the usability of the device making it hard for users to complete their transactions	Simple and clean software with regular updates to mitigate malfunctions
Incorrect assessment of trash input	The radar that reads the trash input to the depository	Would frustrate users because their hard work cleaning wouldn't be recompensed	Regular cleaning of the radar and Software updates

Figure 3. Complete Risk Analysis

IV. CONCLUSIONS

Inclusive to users and surrounding community members, the urban vending machine embodies human-centered design methodologies. The urban vending machine program addresses uneven food distribution in urban areas. The vending machine will provide affordable and nutritious meals, consisting of leftovers from local restaurants, to people experiencing homelessness, in return for recyclables.

This innovation may be improved in the future by adding some advanced technologies such as facial recognition identification instead of swipe cards, or more effective food collecting methods (i.e. self-driving vehicles, drones, or robots), which could be supported by government subsidies or donations.

People experiencing homelessness suffer from hunger and malnutrition. The urban vending machine works to improve access to safe and nutritious food for the vulnerable members of society.

ACKNOWLEDGMENTS

The team thanks Professor Ashish Ghosh, Tomas Rojas, and Professor Casey Jakubowski for guiding and giving advice.

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Water Sourcing in Lwala Nyakongo, Kenya: Design of the Portable Purification System to Provide Clean Water

Louis Catalano, Hunter Hoffman, Priscilla Kozdroy, Angelo Pasco
catall@rpi.edu, hoffmh@rpi.edu, kozdrp@rpi.edu, pascoa@rpi.edu

Lwala Nyakongo is a village in Kenya that lacks a reliable source of clean and drinkable water. The Portable Purification System (PPS) is a solar-powered device designed to collect water from a saline borehole in the community before desalinating, purify, and store potable water.

I. Introduction

Lwala Nyakongo is a small community of about 3,700 people located along Lake Victoria, the largest freshwater lake in Kenya, Africa. Nevertheless, the community's borehole wells contain saltwater, likely due to an ancient evaporate deposit found in inland dry basins. Without a reliable source of freshwater, the community suffers from a decrease in health conditions [1].

The PPS was designed to assist the community members in providing a sustainable source of potable water.

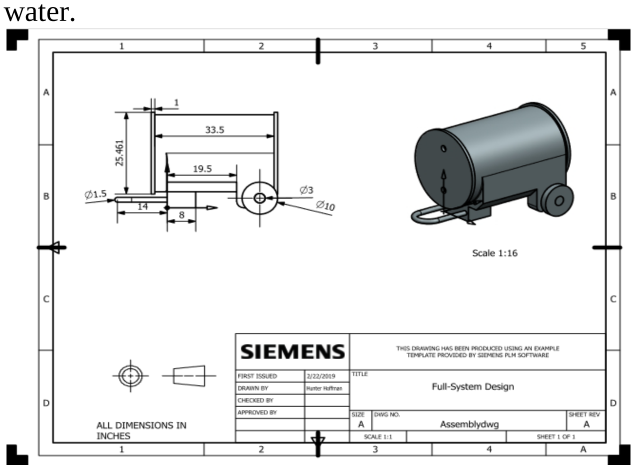

Figure 1. Schematic of the PPS

II. System Design

The Portable Purification System (PPS) is made up of four subsystems: filter, tank, chassis, and power. Each subsystem was designed and intended to play a specific role in the overall system.

II.A. Filter Subsystem Design

The filter subsystem looks at two different aspects of water treatment: desalination and water purification. Both processes are responsible for making the water that enters the system fit for consumption.

II.A.1. Desalination

The desalination portion of the filter subsystem utilizes still distillation (SD). This method of desalination was determined to be best suited for the PPS due to its simple but effective design; capable of desalinating water with salinity levels of up to ~3,500 ppm [2].

In order to separate the salt from the water, a 12V DC silicone heater (See Table I) evaporates the freshwater from the saline and condenses the vapor into a separate tank. Overtime, the salt brine that remains from this process will collect and therefore require monthly cleaning. Other than this regular maintenance, the desalination system is completely autonomous.

Table I. Silicone Heater Specifications

Max Operating Temp.	250°C	Highest Working Temp.	230°C
Best Working Tem.	150°C	Insulated Resistance	≥50MΩ
Compressive Strength	1500v/ 5s	Voltage	220V/380V
Wattage Deviation	±6%	Common Used Max Size	1200*2500 mm

II.A.2. Water Purification

The water purification method used is boiling. Boiling was deemed the best method of water treatment because of its effectiveness and simple integration with the desalination system. During the desalination process, the silicone heater boils the water at around 100°C killing most bacteria, parasites, and viruses in the water [2].

II.B. Structure Subsystem Design

The structure subsystem is composed of the tanks and chassis of the PPS (See Figure 1). This subsystem is concerned mainly with the transportation and storage of both the saltwater and freshwater.

II.B.1. Tanks

The PPS has two tanks; one 55 gallon drum that holds ~25 gallons of saltwater set to be treated, and the another 30 gallon drum which sits inside the 55 gallon drum and stores the freshwater post-treatment. Both tanks are made of High Density Polyethylene (HDPE) plastic due to their high durability and relatively low weight [3].

II.B.2. Chassis

The chassis is comprised of the frame and wheels which are both designed to support and carry the entire system at maximum weight (See Table II).

Table II. Chassis and Tank Specifications

Max Tank Capacity	30 gal	Chassis Drive Arrangement	Rear Wheels
Wheel Diameter	8 in	Handlebar Durability	>88.55 lb
Axle Diameter	3 in	Total Force on System	>125.25 lb

II.C. Power Subsystem Design

The power subsystem includes the solar PV panel and charge controller needed to power the silicone heater. Applying Equation 1, the community receives approximately $4.5\, KWh/m^2$ per day. Using the average solar radiation of Kenya (H), total solar panel area in $\square^2$ (A), solar panel efficiency in % (r), and performance ratio (PR) to find the energy produced in kWh (E); should support the heater needed to treat the water for a day [4].

$$E = A \times R \times H \times PR \text{ (Equation 1)}$$

III. CONCLUSION

The Portable Purification System (PPS) provides an effective way to source potable water from other undrinkable water sources. Whether it's saltwater, brackish lake water, or even snow; the PPS can not only be used as a sustainable source of freshwater, but also be deployed in areas for humanitarian aid. It's easy use and cheap production makes it a valid water treatment device in virtually any part of the world.

ACKNOWLEDGMENTS

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Waste Disposal in the Mediterranean

Ishita Agarwal, Curtis Basa, Nicholas Kern, Christopher Kyle Ordonio, Quanting Xie
Inventor's Studio I
Rensselaer Polytechnic Institute
agarwi@rpi.edu, basac@rpi.edu, kernn2@rpi.edu, ordonc@rpi.edu, xieq@rpi.edu

Developing a product innovation to assist in combating the issue of waste disposal in Mediterranean refugee camps. The result is a multi-step system that heated and compressed plastic waste to repurpose into sheets, utilizing organic solid waste as a fuel source for heating.

I. INTRODUCTION

The migration across the Mediterranean Sea has taken a vast toll on both the refugees and the host countries that they find themselves in. Socio Political conflict like the Arab Spring force many people to flee Syria and other parts of the Mediterranean. Famine and other militaristic conflict cause displacement from northern Africa, as well. The journey itself from these countries is quite perilous, as it includes not only miles of travel by land on foot, but many people risk their lives to crowd onto old boats and small rubber dinghies. Large portions of the masses of refugees that undertake this trip are unable to make it out alive to set foot on European soil. As of early 2018, with more than one-and-a-half million refugees finding themselves on Europe's shores, almost 12,000 lost their lives along the way [1]. Many countries that result in being hosts to these displaced people's struggle to provide the proper support and infrastructure to cater to the needs and well-being of so many individuals. A popular destination for many of these weary travelers is Lesvos Island in Greece. Greece as a country struggles to support its own people. Thus, refugee camps tend to become little more than dirty, cramped shanty town-like housing for its residents [2]. Thousands upon thousands of refugees apply to stay in these host countries seeking asylum; however, only fractions of them receive refugee status and are able to stay for longer [3] [4]. While it would be in the best interest of all of the refugees for them to be able to stay in these European host countries, it is not economically viable, as each individual fleeing to Europe requires so much more help and support than is able to be provided to them. That being said, small percentages of people should still be allowed to stay and integrate into society, with the number slowly increasing as time goes on. However, if every person seeking asylum in Europe is accepted, it might further perpetuate the conflicts and problems that everyone was running away from in the first place; those conflicts should not be entirely avoided, or else no change will come to those regions. Hopefully with time, surrounding countries and governing bodies with strong support and infrastructure can help in ending these issues and allow people to return to their homelands.

Due to thousands of refugees migrating per year to refugee camps around the Mediterranean, with thousands of more people already there, the environment within and around these refugee camps are put at risk. Although the host countries have allowed the refugees to stay within these camps, the sheer amount of people puts strain on the waste disposal system. The majority of waste found is plastic safety equipment from the refugees, however there is not enough landfill capacity found around these camps to hold all this plastic, nor is there a way to effectively process and recycle plastic in a majority of the host countries [2]. This leaves the plastic waste, if not already collected, to be left out in camps and wherever the refugees may have landed. The second majority waste found is municipal solid waste, with anywhere between 7 to 30 tons of solid waste produced by refugees per day [2]. With some host communities already being small, the amount of waste is unable to be processed and is simply dumped with the residues left from water treatment plant.

Within the camps, refugees have expressed a great many negative views, from fear to confusion. With a great influx of people, incidents are bound to happen, from assault to sexual violence. The many stories of people getting stabbed or sexually abused have refugees questioning the safety of their asylum. Along with the cramped population of refugees, there is also a lack of facilities and a lack of workers to provide essentials, such as food and water. In most cases, refugees wait for four or more hours in order to receive a basic meal of bread and water. As for facilities, dozens of refugees have to wait to use a single shower or toilet, and even then have to face the build-up of raw sewage and other waste in these facilities [5].

Refugee camps all across the Mediterranean face issues of disease, mental illness, and nutritional deficiencies due to overcrowding, lack of clean water and food, inadequate healthcare services, and trauma experienced in their home countries and throughout their journey. Their forced displacement gives them no options except to take their families on such a perilous journey across the Mediterranean. Thus, they must live in and endure squalid conditions at these refugee camps as they wait for host countries to accept them as their own. Many diseases circulate through the camps such as tuberculosis, HIV, hepatitis B, hepatitis C, measles, and skin conditions [6]. Refugees are also plagued by mental illnesses from PTSD to depression to drug abuse [6] [7].

Camps also lack security safeguards to protect the refugees in camps. Widespread child abuse, rape and smuggling occur every day [8]. More than 5,000 people have lost their lives in the Mediterranean in 2016 and that number grows every year [9]. In 2017, an EU audit stated that at least 23,000 unaccompanied child refugees are stranded in squalid and unsafe Greek and Italian refugee camps with no place to go [8].

The sudden influx of refugees into Europe has caused several issues in the host countries, as well as benefits. A few citizens of host countries are happy for the influx of a large number of active, cheap laborers, while others see the newly adopted refugees bring in crime and a decline of public security [4]. Tensions between some host countries and their neighbors have grown or developed due to the refugee crisis, for example, Greece, a host country that is commonly the first country these refugees reach in their migration, is having tension with the European Union over their policies on the newly incoming refugees [4] [10]. Additionally, signs of xenophobia and racism are growing in countries that are hosting the refugees [4]. Many of these people are afraid that the refugees will destabilize their way of living and use up resources that are already scarce for the hosting country [10].

With the proposed solution outlined in the following report, the frame of the grinder can be made from ABS plastic, this material has a strong resistance to corrosive chemicals and physical impacts. It is very easy to machine, is readily available and has a low melting temperature making it particularly simple to use in injection molding manufacturing processes [11]. The furnace and compressor should be made of metal with a high melting point and high corrosion-resistance, such as stainless steel. Every piece of the design is very easy to build, the plastic sheets that are created can also be used as material to make additional grinder parts; thus, mass production would be achievable to a certain level. The ABS plastic for grinder has a strong resistance to corrosive chemicals and physical impacts [11], thus the grinder frame is highly sustainable. For the blades in grinder, weekly lubrication will help it last a very long time. The stainless steel for the furnace is able to endure the corrosion of organic plastic degeneration [12]. So the entire system is capable of being long lasting and will not need much daily maintenance.

II. PROBLEM DEFINITION AND REQUIREMENTS

Every year, more than five thousand [13] people fleeing warfare, poverty, and persecution attempt the treacherous journey from the Middle East and Africa across the Mediterranean Sea to reach Europe. These people seek refuge in makeshift camps waiting to be let into the EU for years on end; however, Europe's infrastructure is not able to accept or support such a growing influx of people. With the refugees taking up the already diminishing space available and due to the number of refugees, the daily production of solid waste related to the refugees' flow ranges between 7 to 30 tons, with a daily cost for collection [10]. In addition, another large source of waste in the Mediterranean is plastics from the life jackets and inflatable boats that the refugees used to get to Europe [10]. The volume of lifejackets accumulated from 2015 to April 2016 alone totaled to about 16,000 cubic meters. Once there, living with at least 12 people in one tent, illnesses such as cholera propagate due to the lack of access to clean water. Water supplies that do exist are only available for a few hours each day, so refugees are given water bottles for drinking and sanitization. Thus, the waste created by excess of water bottles and containers can become another large contributor to the plastic waste produced. As a minimum estimate, 105,000 [13] refugees could produce about 147,000 [14] bottles per day. Also refugees are not usually conscious of recycling; thus, a large percentage of those water bottles go immediately to the trash and landfills, and basic plastic usually takes 450 [15] years to decompose. The best way to tackle this waste is to create a self-sufficient waste management system so the refugees create less of an impact on their host countries and the environment. The solution must meet a few important criteria:

- Easy to use for refugees from all backgrounds and educations
- Safe for refugees to use and for the environment around them
- Non-intrusive to the refugee community
- Sterile so it does not cause more illness

III. COMPARATIVE ANALYSIS

Many of the current patents and solutions for proper waste disposal require a solid infrastructure for an entire system to be implemented within a stationary community. Patent application JP2012521293A [16], for example, proposes that an automatic waste collection pipeline be installed that collects, sorts, and fluidizes waste to be transported through the pipe and disposed of at a remote location. This method works to reduce the space taken up by trash by turning it to a liquid and immediately disposing of it; however, for this system work, its network has to already be in place. This cannot apply to migrating refugees who run the risk of further displacement. An innovation that can be applied wherever the refugees find themselves can be much more beneficial to them.

In addition, many current solutions only rely on the breakdown of materials, more specifically, plastic. For example, patent number CN107778892A [17] proposes to create a method of waste decomposition with peptide polyolefin plastic. This material is biodegradable, but durable; however, most biodegradable materials still take at least 3 to 6 months to fully decompose. Furthermore, patent application US20080223758A1 [18] offers a solution to breaking down plastic with a heat generator plastic garbage disposal. The generator takes in small volumes of plastic scraps and heats them to melt them down and repurposed into other plastic products. While these heat generators are more compact, the energy required to power them is not easily available in the camps and makeshift communities that the refugees find themselves living in; thus, this solution cannot be applied to the target consumer base. Ultimately, because of the limited amount of support and resources available to the refugees in the Mediterranean, a better solution for them would exist in the form of a solution that prevents the creation of waste in the first place.

With the preliminary set of customer requirements determined, it was found that most of the current innovations do not align with what is currently believed to be the most imperative needs for migrating refugees in the Mediterranean with their waste disposal and management. Many solutions take too long to be effective or are too complicated and cumbersome and emphasize the use of a community's already existing socio-economic infrastructure to operate properly.

IV. SOLUTION AND VALIDATION

The solution for plastic waste in the Mediterranean refugee camps is a multi-step system of taking in plastics and converting them into sheets for repurposing. Refugees will dispose of their plastics into a bin that grinds them into little bits using a gear system from a hand-crank. Then, the bits get deposited into a large tray that will be heated by methane gas created by the decomposition of solid waste in order to meld the bits together. The solid organic waste that refugees produced will be gathered into a tank that will have archaea species break down the waste and produce the needed gases. The malleable plastic created will be compressed by plates powered by a gear system from a hand-crank. These plates will create plastic sheets that would be removed and cooled so that they can be used by the refugees for their homes, storage, and/or privacy.

This solution meets all the previously outlined customer requirements. The recycling system is easy to use for refugees of all backgrounds and education because their involvement includes moving trays and using simple hand-cranks to operate the grinder and the compressor. This process can easily be taught visually to the refugees in their time at the camp. These recycling systems would be relatively safe for the refugees as the moving parts would be man-operated and could be easily stopped at the users command. Also, the gases created by the decomposition of waste will not come into contact with the refugees. The solution is environmentally safe as well because it reduces plastic and organic waste creation and keeps refugees from using the limited materials from the host county. Furthermore, this solution is non-intrusive because it takes less space than the waste they create and is sterile because the plastics are being heated enough to remove bacteria. Overall, this solution will allow refugees to be self-sufficient in creating a cleaner environment for themselves and the host country.

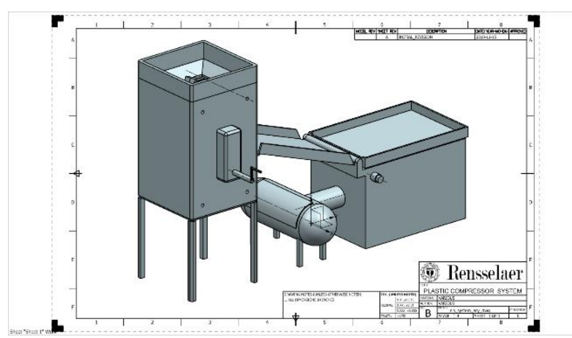

Figure 1: System Level Design

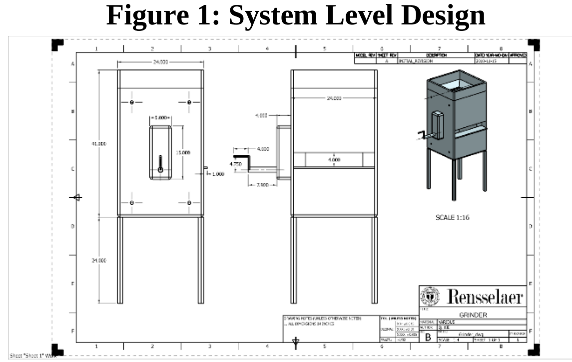

Figure 2: Grinder Drawing

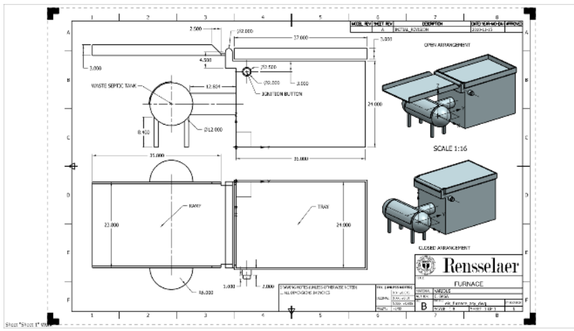

Figure 3: Furnace Drawing

V. ENGINEERING ANALYSIS

The solution proposed requires mechanical, thermal, and chemical knowledge to build and design the systems involved.

These equations below outline the ratios needed for the gear system used in the hand-cranks for the grinder and compressor in terms of force applied and velocity of the gears against one other.

$$R1F1 = R2F2$$

(R = radius, F= force)

$$r1\omega1 = r2\omega2$$

(r = radius, ω = angular velocity)

Equation of shear force in gears:

$$\sigma = \frac{mY}{I}$$

(σ = shear stress, m = mass, Y= distance of the shear where applied, I = moment of inertia)

These equations below are needed to understand how much heat and energy is required to melt the grinded up plastics and how heat will be transferred from the methane chamber to the tray of plastics.

$$\Delta E = mCp\Delta T$$

(Heat Capacity of Polyethylene: C = 2300 J/kg°C)

$$T_1 - T_2 = \frac{bQ}{KA}$$

(Fourier's Law of Heat Conduction)

$$Q = UA\Delta Tm$$

(Heat Transfer Equation)

$$Q = hcAdT$$

(Convection Heat Equation)

For A Single Sheet using the equations above it can be approximated how much heat is required for a single sheet:

- Area: 864 in3 (14148.4 cm3)
- Melting point: 93 degrees Centigrade
- Density: 0.92g/cm3
- 2,786.2 kJ of heat 13 kg per plastic sheet

These equations below describe the process of methanogenesis, or the production of methane within archaea, a domain of single-celled microorganisms, through the decomposition of organic waste.

$$4H2 + CO2CH4 + 2H2O$$

(Production of Methane from the Reduction of CO_2)

$$4CH3OH \rightarrow 3CH4 + CO2 + 2H2O$$

(Production of Methane from the Oxidation of Methanol)

$$CH3CO - 2 + H2O \rightarrow CH4 + HCO - 3$$

(Production of Methane from the Fermentation of Acetate)

$$CH4 + 2O2 \rightarrow CO2 + 2H2O$$

(Methane burning Chemical equation)

Two genera of archaea, *Methanosarcina* and *Methanosaeta*, use acetate in order to produce methane. Two species from the *Methanobrevibacter* genus, *M. smithii* and *M. stadtmanae*, produce methane from CO2 and methanol respectively. Both have been found in samples of human stools, with *M. smithii* having a presence of up to 97.5% in isolated methanogens of the human gastrointestinal tract and *M. stadtmanae* having a presence of up to

23%. Using these archaea, up to 0.02-0.28 g of gas per kg of wet human feces can be produced. Burning 1 g of methane produces 51.6 kJ of energy that can be used.

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Solving the Waste Crisis in South America by Assisting Existing Waste Disposal Groups

Gavin Allcorn, Karen Baltazar*, Patrick Madden, Joshua Yurkofsky
Rensselaer Polytechnic Institute
Inventor's Studio 2 - Engineering Innovation for Society
allcog@rpi.edu, baltak@rpi.edu, maddep2@rpi.edu, yurkoj@rpi.edu
**Winner of The Inventor's Studio Startup Founder Award*

With the large volume of refugees leaving South American countries, like Venezuela, in favor of more hospitable nations, there are a number of crises that develop from the migration, such as waste management. Luckily, many of these countries have existing populations of waste-pickers that happily collect garbage and recyclables to make some extra money. To make their lives easier, The Backpactor is a solution that will allow them to collect more waste as a mobile, manually-operated compactor backpack which hopes to enhance the lives of these waste-pickers.

I. INTRODUCTION

With the recent earthquakes that have plagued Venezuela, many citizens have fled their homes and tried to seek refuge in neighboring countries. Whether the cause is political, economic, or a natural disaster, the point of the matter is that many people are displaced; this causes trash to overflow and create landfills in refugee camps. In order to begin to think of a way to combat this problem, the group collectively started to track and analyze their daily disposal rate in order to then extrapolate the data and connect with the situation for the refugees.

In the United States of America, an average of 4.4 pounds of trash is generated per person with only 1.51 pounds of the trash being recycled and composted [4]. With this data, the problem with disposing trash is noticed; since there is no proper waste service for most refugee camps, the trash is thrown in a landfill area or a new landfill is created. This creation of a landfill provides a very unsanitary condition to the refugees who have to live around it for their daily lives. With the number of refugees reaching into the millions, the quantity of trash generated per area can quickly accumulate to an unsustainable amount. Though the primary concerns with refugees may be housing, clean food and water, and medicine, waste accumulation plays an important role in guaranteeing the security of these other needs. With more garbage comes the increased concern for disease spreading or unstable living conditions or tainting water supplies, which worsens the other existing problems. Though it may seem like this problem could be easily solved by educating the refugee population on how to create less waste, refugees typically do not have the time to be concerned with changing their waste disposal habits. As a result of this, the solution generated for this problem has to be one that is pseudo-autonomous and capable of operating without much intervention as the manpower to operate it may be scarce. Compared to ordinary life for most people in the developed nations, this trash solution directly affects the livelihood of these refugees as they would be surrounded by it and their health would be impacted by it. Also, electricity and available landfills are resources that must be considered as these would not be readily usable as well. This solution is of dire importance, though, as it not only negatively impacts the environment, but human life as well.

There were many specifications that could be looked at, but the most important of them were: Increasing sanitation, landfill volume reduction, and ease of recycling, composting, and disposal. For increasing sanitation, the best way to achieve this specification is to achieve the other specifications because increasing sanitation is the head of the effect of each specification. To reduce the volume in a landfill, the best solution is to sort the disposal of trash. Whether it be using sensors to determine what was thrown away and then determine what to do with that material, is an easy solution to solve this. Ease of recycling, composting and disposal will fall under reducing the landfill volume. Overall, the specifications and requirements for this system revolve around the ease of use (either by refugees or trained assistance personnel), system efficiency, and sanitary aspects of it. Whatever the solution, it needs to be able to operate under a variety of conditions and work to benefit refugee and natural disaster situations across the globe. These specifications, and many more, led the driving discussion and brainstorming behind this life and environment saving solution.

II. BACKGROUND

Across South America, waste pickers are taking to the streets to clean up trash being thrown around, and to also provide a basic income for their household. In Lago Agrio, Ecuador, refugees from Colombia pick waste along the streets. Preventing contamination of rivers, animals and of the environment is of top priority [2]. Even though the work that is done by waste pickers is lengthening the lifespan of dumps while slowing the depletion of natural resources as well as making it cheaper to remove pollution and trash from the city, the work is very hazardous for the waste pickers. Problems that the waste pickers experience during their daily work is: mosquitoes, shar metal, broken glass, stray animals, feces, and medical/other toxic waste in the garbage dump [2].

In Brazil, more than 500,000 people survive by collecting and making income with solid waste in large Brazilian cities; many also work in dumps where there is a big exposure to health risks. Using carts, they are able to pick up an average of up to 300 kilos a day in crowded streets, trying to make a living [3]. Currently, many waste pickers that work individually or in small groups do not have access to protective equipment or training, nor do they have the tools for basic hygiene. Even with bare materials to use, the waste pickers reduce the volume of waste dumped in the cities by up to 20% [3]. This is a huge cultural phenomenon, and there needs to be a solution to help solve the problems that these people face day in and day out.

III. PROPOSED SOLUTION

In order to lessen the burden on the environment and also help improve the lives of the waste-pickers, the ideal solution is the Backpactor. The Backpactor is a mobile, compact, and human-powered compactor that is worn as a backpack. It features a canister where trash is held and compacted by a flat plate that is lowered manually using a crank, rack and pinion mechanism, and a removable bottom plate that both collects excess liquids from the trash and allows for easy removal of the compacted trash.

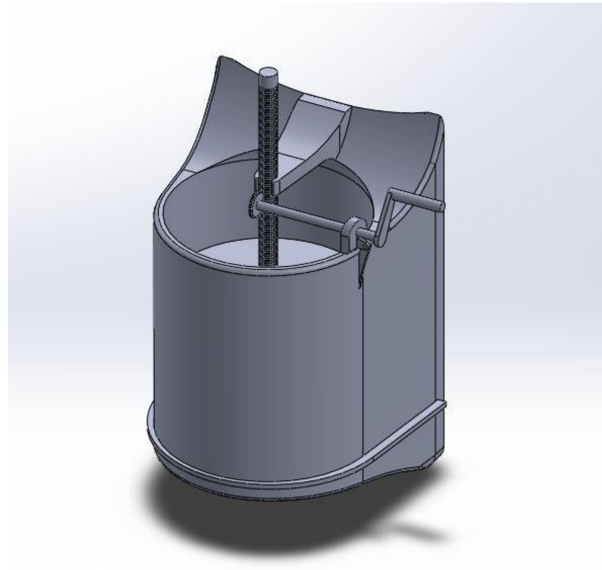

Figure 1: CAD drawing of Assembly

For the comfort of the user, the Backpactor features padding covered in breathable fabric all along the back of the device, along with adjustable, padded straps that are worn over the shoulder as with normal backpacks, as well as adjustable, padded straps that go across the user's hips to help distribute the weight evenly. The adjustability of the straps ensure that many different sizes of adults can use the Backpactor.

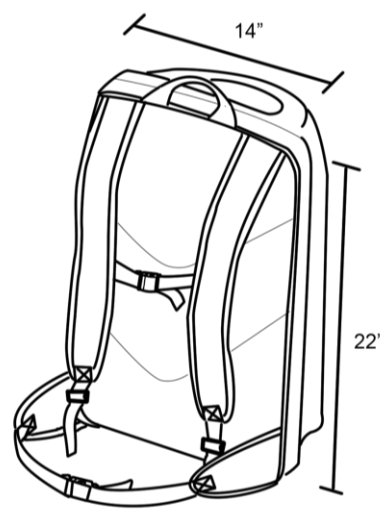

Figure 2: Sketch of Rear

The Backpactor is lightweight and does not require electricity, only the physical ability to carry a backpack and turn the hand crank. It works by taking the user's input torque to the crank and multiplying it and translating it into a downward force exerted over the area of a flat plate. The design is easy to manufacture as it is simply a backpack with a simplistic mechanism mounted on it, and is easy to use due to its simplicity. This design is meant to make the lives of the waste-pickers easier, while employing the gloves and/or grab sticks that they already use for sanitary reasons. Because the users are able to compact trash, they are able to store more trash within a given cart or bag, or can transport the same amount of trash as they did before, but will take up less volume. This and the ease of use of the device, in turn, allows for more migrants and refugees to work as waste-pickers and therefore can even lessen the social stigma around waste-picking as an occupation since it is easier and helps keep the community clean.

III.A. Mechanism and Use

The mechanism of the Backpactor has 4 main components: the canister that holds the trash as it is collected and compacted, the plunger or top plate that moves up and down to compact the trash, the hand crank and gears, and the removable bottom plate.

The canister connects all of the components in the Backpactor. It is cylindrical and works with a circular top plate such that there are fewer points of concentrated stress or failure when the device is being used to compact.

The plunger is made from a cylindrical rack that is connected rigidly to the top plate and the plunger unit is removable. It connects to the canister via the C-shaped tip of a beam that protrudes from the wall of the canister towards the center of the opening. This beam serves to both stabilize and center the rack as it moves up and down. The C-shaped opening allows for enough flex to snap the plunger in and take it out, and grips it in place as it moves. Because of the snap mechanism, the plunger can be stored upside down when not compacting, or simply taken out entirely.

The hand crank and crankshaft are connected to a small gear that is mated to a larger gear that will transmit a larger torque than put into the crank. The larger gear comes in contact with the rack at a position in line with the stabilizing beam, so that the reaction forces are seen by the beam instead of causing the rack to bend. These gears are mounted to a hinged section of the canister such that they can be put in place when the Backpactor is used for compacting, and put away (to the side of the canister) but still connected to the device for storage or when trash is being collected.

In turn, the bottom plate is prevented from moving vertically by the canister, but may be slid in and out of place horizontally through a slot cut horizontally through the canister. The portion of the canister that is below the slot takes the form of a gusset, to take advantage of the added strength and support of triangles. This plate is actually a thin, hollow cylinder, with one end perforated. This bottom plate provides a rigid boundary during compaction, while also collecting any excess fluid remaining in the trash.

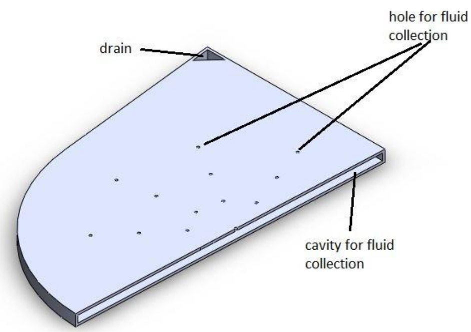

Figure 3. Cross Section of Bottom Plate

When in use, trash can be put into the canister until it is full. Then, the plunger is snapped into place and the gears and crank are put into position. This device works by employing a rack and pinion gear system, which is used to translate rotational motion into linear motion. Here, a hand crank initiates rotation of a smaller gear that mates to a larger gear. The pinion, which is the larger gear, is also mated with a linear rack such that when the pinion turns, it pushes the rack up or down, depending on the direction of rotation. Thus, many turns of the crank will result in one rotation of the pinion, but the force exerted downward by the movement of the rack is high. This rack is connected rigidly to a plate, meaning that as the rack moves downward, the plate will also exert pressure downward on any trash that may be underneath it, compacting said trash. After the trash is compacted, the bottom plate can be taken out of the device to easily release the compacted trash and allow for the fluid collected in the bottom plate to be drained.

III.B. Technical Specifications

The crank handle of the backpactor is designed to swing in an arc with a radius of 5”. The handle assembly will be printed out of PLA with 40% infill. According to data sheets published by The Canadian Center for Occupational Health and Safety, an average human can exert 100 lb.f in this cranking fashion. Using these values, the handle will apply up to 41.67 foot-pounds on the shaft.

$$\tau = F \times r \times \sin(\theta) \qquad (1)$$

The shift will be constructed of #45 steel in order to withstand the shear force. This shaft will be rigidly attached to a gear of .5” radius. A second gear, 2.5” radius, will be used to multiply the force exerted on the rack. The rack will be constructed from 7075 T6 Aluminum round rod. This alloy is strong, lightweight, inexpensive and possessed good corrosion resistance. The teeth will be lathed in. The center support for the rack will be a custom, 3D printed part using PLA with 40% infill. An estimated 1250 lb.f will be transferred to the top plate through the gear and rack. The canister has a top diameter of 11.8” and a depth of 17.43”. The total volume is 20 liters. The canister material is polyethylene as it is lightweight for its strength and very cheap. The top lid and bottom plate will be made of a more durable Plexiglass GS 0F00 as they will experience the greatest shearing stress.

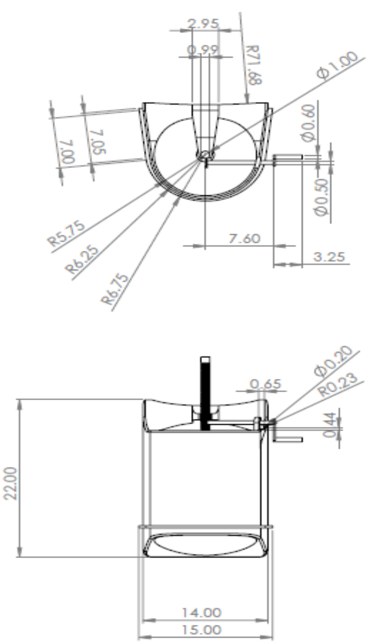

Figure 4a: Design Dimensions from Top and Front Views

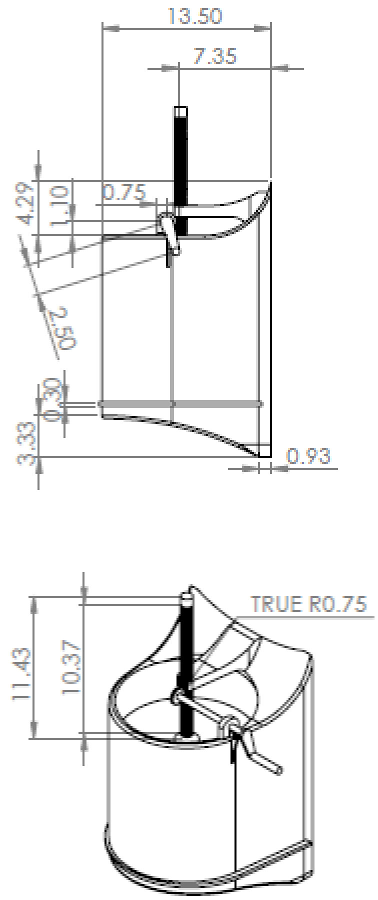

Figure 4b. Figure 4a: Design Dimensions from Side and Isometric Views

III.C. Risk Analysis

As with any product, the Backpactor design does not come without some risks associated with its design and the environment it will be used in. Many of these risks can be mitigated through careful design and constraint to the proper specifications, however, there are some risks that are difficult to account for in the final design of the product.

One of the first, and most severe, risks is that the device containment will break down or fall apart, leaving the wearer in contact with the disposed waste and potentially causing negative health effects from this contact. Many of the waste pickers are picking up trash that could be contaminated with rotting food remains or event potentially human waste. The device has to be able to shield these workers from this hazard and it does so using a uniform, singular body can design. This system makes it so that the main holding compartment for all the waste is in one area and has a much smaller chance to break at any point. The container will also be made of a sturdy, high density plastic that is resistant to wear and chemically resistant to corrosion or breakdown. In addition, both the plastic and the metal components will be safe to clean so that they can be sanitized when necessary.

Another potential risk is found in the performance of the product and if it were to fail to perform the intended action. In this case, the failed action would be that the crank system fails to compress the waste in the bin or fails completely in another way. This is a risk as it pertains to device failure, however, it is not a severe issue as its failure would not seriously impact the structural integrity of the overall device or the health of the operator. Should the crank system malfunction, it can be detached to operate the Backpactor solely like a waste bin, able to hold up to its top limit in trash. To mitigate this small risk, though, the crank system will be fully contained, preventing the possibility of the operator or another party interfering with the geared mechanical system. Also, all components will be internally mounted together to ensure they are held in place through operation. Lastly, the device could have sturdier hinges and latch points installed to ensure that at no point will the failure exist solely as a result of poor attachment.

One of the last major risks associated with this product has nothing to do with device operation and, instead, solely pertains to acquisition and manufacture of the device: the cost becoming too great. With this being a product intended to be distributed in low income areas, the cost cannot be a significant burden to the relief groups or local governments that intend to purchase it. If the cost becomes too high, it will be unfeasible to purchase them in mass quantities which will reduce the effectiveness of the device. To mitigate this potential failure point, all components are going to be manufactured as cost efficiently as possible while still ensuring build quality. Though the cheaper manufacturing runs counter to the improvements in design discussed in the previous risk mitigation plans, it is likely one of the most important aspects to keep in mind with regard to construction. The plastics will likely be injection molded and made from the most common, sturdy plastic available and all the metal components will likely be from a manufacturer that already has the tooling in place or has the product ready, reducing the manufacturing price. All risks associated with this device are potential points of failure that could lead to hazards for the supporting group or the operator, however, most of these risks can be mitigated to improve the efficiency and return on investment of this device.

IV. CONCLUSIONS

The Backpactor is a simple, affordable, and beneficial solution to a lesser known problem in South American countries with refugee and migrant populations that both need work and want to contribute back to the countries they now reside in. Many countries already have populations of waste pickers in lower socioeconomic circles that happily collect waste and either dispose of or recycle it to clean up their homes and make some extra money on the side. This job is easy enough to perform by anyone, however, it could always be improved for better efficiency. The Backpactor solves this issue by providing these waste pickers with a better system to collect trash by compacting what they are holding in a more concise load that they can then support on their shoulders instead of carrying in hand or pushing on a cart.

This device poses a number of advantages over other waste management ideas in these countries. First, it supports an existing workforce which means that more local residents will have meaningful work, and there will be less of a need to hire outside, full-time waste management employees to handle the situation. Second, this system requires no external power which means it will not place any further strain on an already underdeveloped power grid. Lastly, this device is relatively small in size compared to a full size compacting system and is much cheaper to manufacture and distribute in large quantities. Overall, the backpactor is a revolutionary solution that could significantly impact and improve the lives of those that are actively trying to make their home countries a better place.

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Rensselaer Polytechnic Institute
110 8th Street Troy, NY 12180

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