Hand Powered Portable Ultraviolet Sterilizing Water Bottle with Active UV Dose Sensing

By

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And

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ABSTRACT

A portable hand powered water sterilization device was created to address a portion of the growing epidemic of global water contamination. As being more supply chain independent and having an active dose sensing component that monitors the water to insure sterilization, our device boasts far more than any current off-the-shelf devices. The device is completely hand powered via a hand crank generator.

A spermicidal ultraviolet light bulb, rated at 253.7nm (UV-C), was integrated with a common Nalgene™ water bottle. Along with the bulb, UV dose sensing electronics and a hand crank generator were incorporated as well, with the generator supplying power to both the bulb and the photodiode circuitry. Results show that eradication of common waterborne bacteria, protozoa, and viruses occurs after cranking the generator for approximately 41 seconds in clear water and up to 65 seconds in turbid water. The total weight added to the water bottle was less than a pound.

Thesis Supervisor: Ernesto E. Blanco

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ACKNOWLEDGEMENTS

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We would also like to thank the Institute for Soldier's Nanotechnology Lab for the initial inspiration for this project. Furthermore, we could have never gotten this far without the initial funding that was given to us to design our initial proof of concept prototype.

We would finally like to thank our families, friends, and our significant others for all their help and support through this adventure over the last 8 months.

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INTRODUCTION

1.1. Background

One of the greatest health problems in the world is the unsafe and inadequate water supply. Almost one fifth of the world's population, 1.1 billion people, lack access to a safe and reliable source of drinking water[1]. These people mostly live in poor developing countries that are struggling to improve sanitation and water conditions. Children are especially at risk with 41,000 deaths occurring each day from water related illnesses. The scope of this problem is so grandiose and the people involved come from such diverse backgrounds that a single cure-all technology is virtually impossible.

Recent national disasters including the 2004 tsunami, Hurricane Katrina, and the earthquake in Pakistan have highlighted the need for a rapidly deployable water solution that can quickly ameliorate poor water conditions. Displaced victims of natural disasters live in crowded camps marked by unsafe water and poor sanitation. That combination creates a recipe for water-borne diarrheal illnesses that quickly sweep through the communities. Humanitarian workers face the same issues in developing countries where water is unsafe to drink. Both groups are at the mercy of a constant supply of bottled water, which is unreliable due to slow or impossible delivery.

Not only are the residents at risk, but people traveling to developing countries fall prey to water borne illnesses. On average, 30%-50% of travelers to high-risk areas will develop Traveler's Diarrhea during a 1- to 2-week stay. Based on the annual figure of 50 million travelers to developing countries, this estimate translates to approximately 50,000 cases of Traveler's Diarrhea each day[2]. For safety and peace of mind, many opt for bottled water.

In 2004, people consumed 154 billion liters of bottled water globally. As a result, water tables now are rapidly shrinking. Fossil fuels are used in both the distribution and production of plastic water bottles. Nearly a quarter of all bottled water crosses national borders to reach consumers, transported by boat, train, and trucks – all requiring fossil fuels. The most commonly used plastic for making water bottles is polyethylene terephthalate (PET), which is derived from crude oil. Making bottles to meet Americans' demand for bottled water requires more than 1.5 million barrels of oil annually, enough to fuel 100,000 U.S. cars for a year. Worldwide, some 2.7 million tons of plastic are used to bottle water each year. Eighty-six percent of plastic water bottles used in the United States become garbage or litter that takes 1000 years to degrade in landfills[3]. Global dependence on bottled water is depleting our natural resources and polluting our world.

Some of the largest consumers of bottled water live in developing countries. The blatant reality is that this is a costly solution that does not scale well. It costs almost 600 USD per year to supply a single person with 1 gallon of bottled water per day. Therefore, 'safety and peace of mind' are costing 1000 times more than that of tap water.[4] Ironically, in most places tap water is readily available but is often of questionable quality. An inexpensive, reliable, and energy

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[1] UN World Water Development Report 2 <http://www.unesco.org/water/wwap/wwdr2/>
[2] Risk Areas for Traveler Diarrhea
http://www2.ncid.cdc.gov/travel/yb/utils/ybGet.asp?section=dis&obj=travelers_diarrhea.htm&cssNav=browseoyb
[3] Facts and figures: Bottled Water <http://www.wateryear2003.org/en/ev.php-URL_ID=5226&URL_DO=DO_TOPIC&URL_SECTION=201.html>
[4] Bottled Water - Pouring Resources Down the Drain
http://www.finewaters.com/Newsletter/March_2006/Bottled_Water_-_Pouring_Resources_Down_the_Drain.asp

efficient technology that could make water safe to drink would be helpful to millions of people around the world.

1.2. Current Techniques

- **Boiling**: This is the oldest method of water purification. It requires a large energy input and is very inefficient, though a ten minute boil will kill 99.9% of waterborne contaminants. The boil culminates in a long cool down time during which there is a high risk of recontamination. The water also acquires a stale flavor.
- **Chemical tablets:** The industry standard, these tablets are manufactured by numerous companies. Once added to the water, the chemicals activate over time and kill the microorganisms which cause disease. However, the unpleasant taste, long treatment time, risk of re-infection, and health concerns with prolonged use, pave the way for a new sterilization method.
- **Mechanical filtration:** An extremely popular purification method, mechanical pumps push water through micron filters, capturing harmful contaminants. However, the filters are severely prone to clogging, contain numerous parts that require maintenance/replacement, and cannot remove viruses. Several companies fabricate and sell these filtrations devices, with annual revenues in the hundreds of millions of dollars.
- **MIOX™**: This Company offers a unique sterilization technology that uses activated sodium chloride to sterilize water. Major pitfalls of the MIOX™ system include supply-chain dependence (batteries and salt) and long lead time for sterilization (30+ min). Additionally, the cost of the MIOX™ system ($150) detracts from widespread market penetration. In FY2004 MIOX™ reported revenues of $7 million.
- **UV water purification**: Our most direct competitors, these companies sell portable UV water purification devices with expensive non-standard replacement batteries.
  - **Steripen™**: The non-enclosed design methodology for this device produces a high risk of re-contamination and without a dosage feedback, offers little to no assurance of purification. Last year Steripen reported revenues of $1 million, equating to about 7000 units.
  - **Aquastar™:** This design of this device is not nearly robust enough for most outdoor activities, or the market they are attempting to penetrate. Requiring a user to remove the bulb twice with every use creates a high potential for breaking the bulb. Unfortunately, once the bulb dies a consumer must buy a whole new Aquastar unit.
- **Biosand**: This sand filtration method offers a low tech and relatively inexpensive way of cultivating good bacteria to destroy harmful diarrheal bacteria. This filter requires heavy maintenance, but may be able to remove arsenic from the water source. It is not portable but scales to home use. It takes hours to filter through the sand and only rids 90% of the bacteria from the water, not suitable for infants or the elderly. This has extremely low to no market penetration thus far.

A Comparision Among Water Purification Systems

Competitors	Supply Chain Independence	Viral Inactivation	Portable	Rapid (<1min)	No Toxic By-products	Low Reinfection risk	Water safety indicator	Durable
Chemical tablets			•					•
Mechanical filtration			•	•	•			•
Boiling		•			•		•	
MIOX		•	•				•	•
Steripen		•	•	•	•			
Aquastar		•	•	•		•		
Biosand	•				•			
TurnPure	•	•	•	•	•	•	•	•

Figure 1 Current Technologies

1.3. Our Solution

We have developed a patent-pending technology that rapidly and effectively purifies water contaminated with bacteria, protozoa, and viruses without using chemicals or battery power. Think of our device as the next-generation water bottle – rugged, lightweight and highly portable with an added benefit: it has an integrated germicidal bulb that is powered via a hand crank generator built into the bottle. Simply pour contaminated water into the bottle, close the top, and turn the generator crank until an indicator light tells you the water is safe to drink. Ultraviolet light causes dimers to form in DNA effectively stopping the contaminant's cells from functioning. To ensure complete irradiation of all water in the bottle, a photodiode is placed in a specific geometry on the diameter of the bottle, actively measuring the UV dose. Our primary innovations are: activating a fluorescent UV bulb from a hand crank generator, encasing the bulb in a UV transparent sheath, and integrating light sensors to indicate when the water is safe to drink.

1.4. Current Status

- Fabricated a beta prototype
- Completed qualitative testing
- Received $11,000 in grant funding from two design competitions
- Completed a full business plan
- Completed a manufacturing plan
- Currently working on production prototype and DFM requirements

2. FUNDAMENTAL REQUIREMENTS

Our basic requirements came from the ISN Soldier Design Competition. We felt that requirements from the less developed nations would be basically the same, robust design, no supply chain, easy maintenance, and straightforward operation. This rationale was supported by IDEAS competition staff during the proposal phase.

2.1. ISN Design Parameters

General Description of Need:
Today's remotely located Soldier uses chemicals (chlorine and iodine pills) to purify water at remote locations along with a mechanical filtration system. This procedure requires the Soldier to carry three separate issues with him, two of which need re-supply for extended operations.

Project Mission Statement:
The existing system has logistical issues that could be resolved by the incorporation of a new water purification system that is contained and powered by renewable energy.

Specific Required Performance Objectives:
Both the size and weight of the newly designed system should not impede the Soldier's performance or stealth in the field.

2.2. NSF/ANSI standard 55 for UV purification

- Required UV dosage of 40 mw-s/cm^2 throughout water volume

2.3. Imposed Design Requirements

- Must be operable for at least 3 months of normal use without re-supply
- Must be one unit
- Must weigh no more than 1 kg
- Must be easily field maintainable
- Must be environmentally robust
- Must work within 90 seconds for reasonable cranking
- Must be able to check the output of the UV bulb

3. PROTOTYPE DEVELOPMENT

3.1. Ultraviolet Light

At a molecular level, ultraviolet light breaks down, or denatures, the DNA of an absorbing medium, in our case, waterborne contaminants. In water, there are three main categories of contaminants: Protozoa, bacteria, and viruses. Each contaminant within the categories, however, requires very different doses of ultraviolet light to denature the DNA. *Figure 2* below shows how the radiation denatures the DNA by breaking the Thymine bonds and causing Dimer formations.

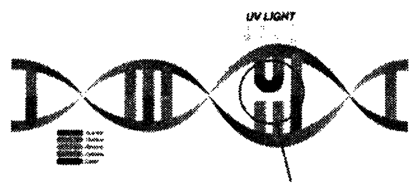

Figure 2: Broken Bonds and Thymine Dimer Formations

Due to the extensive research conducted with germicidal UV-C radiation, we were fortunate to have data on UV doses to denature the DNA of common waterborne contaminants. *Figure 3* below shows the UV dose required to denature each contaminant to differing levels of significance with the NSF/ANSI standard line.

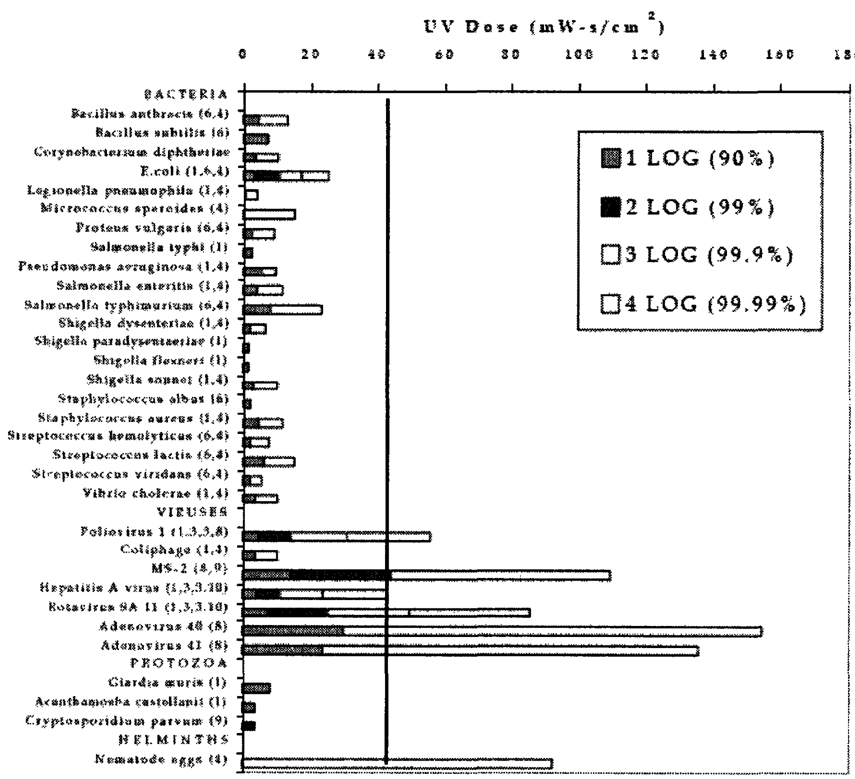

Figure 3: UV Dose Response Data from Various Sources[5]

[5] Cohn, Alicia. "THE UV-TUBE AS AN APPROPRIATE WATER DISINFECTION TECHNOLOGY: An Assessment of Technical Performance and Potential for Dissemination." Masters Thesis. The Energy Resource Group. May 24, 2002. pg 15.

Using the information from *Figure 3*, our bulb will have to reach 40 mW-s/cm^2 in 90 seconds or less to reach our initial design requirements. At this level, all Protozoa are eradicated along with all bacteria to 99.99% and all viruses to 99%.

3.2. Concept Development

With the required dosage information for effective sterilization, we then needed to size the bulb for our purpose. Without an available equation for irradiation with respect to power and distance, we derived the equation taking into account the effect that the absorption medium will have on the dosage time. Please see Appendix A for the complete derivation. *Figure 4* below shows the derived irradiance equation. The distances from the bulb are denoted in spherical coordinates.

$$I(r) = \frac{P_\lambda}{4\pi}\int_{-h/2}^{h/2} \frac{dx}{x^2 + r^2} e^{-(\sigma_w \sqrt{x^2+r^2})}$$

P_λ = bulb power in watts
h = bulb length in cm
x = position along bulb
σ_w = absorption coefficient of water

Figure 4: Irradiance Equation

The germicidal bulb needed to be no more than 5.5" length to fit comfortably inside the Nalgene™ bottle, therefore, the best GE bulb for our needs was the G4T5, rated at 4W. However, the power from these bulbs in UV-C radiation is not the rated amount, the power to radiation conversion is about 20%. Consequently, a 4W bulb gives off 800mW in UV-C light, see Appendix C. Beginning at the smallest rated wattage, we plotted the 4W bulb with differing water absorption coefficients, from clear to turbid water. Water quality usually ranges from .01 – .2 cm^{-1}, with a coefficient of .125 cm^{-1} is considered the threshold of fair quality, most drinking water is in the .01 region[6]. *Figure 5* shows this plot. along with a line representing the radius of a Nalgene™ bottle.

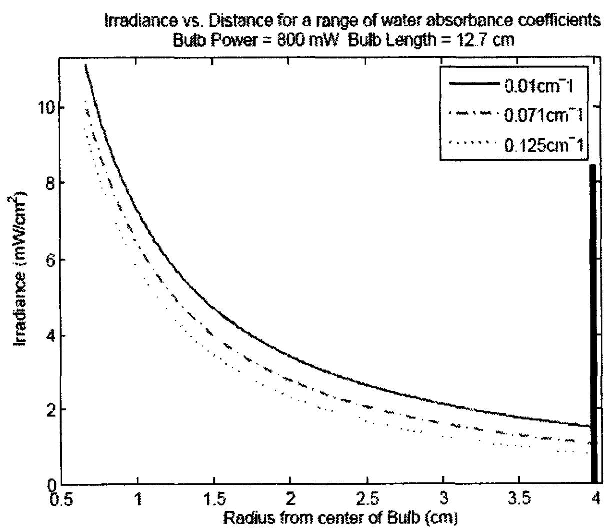

Figure 5: UV Irradiance vs. distance with differing water absorption coefficients

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[6] Cohn, Alicia. pg 15.

From the irradiance plot of a 4W bulb, we found that we could easily reach the 100 mw-s/cm^2 threshold in 80 seconds, and that we could have potable water in less than 27 seconds if it was clear water (.01 cm^{-1}) and about 51 seconds if it was turbid (*Figure 6)*

Water Absorption Coefficient (1/cm)	UV-C dosage (mW-sec/cm^2)
.01	1.51
.125	.787

Figure 6: UV doses at 4 cm

Knowing that we needed to generate 4W of power, we knew we would require a dc gearmotor that had an output greater than 4W, preferably 6W-10W. The reduction needed to be enough to simulate normal hand cranking and we decided that less than 200 rpms would be fine, but 100 rpms would be near optimal. Using eBay, we bought different motors, mostly 24VDC Pittman, that had sufficient output power and gear reduction. Using a fly-back inductor circuit from a dc fluorescent light bulb fixture, we wired the leads and performed our proof of concept test for powering the light with the gearmotor as seen in *Figure 7.*

Figure 7: Proof of Concept Assembly

Successfully lighting the bulb with the motors, specifically a 24VDC Pittman with a 178:1 gear reduction, we then looked to create our first alpha prototype.

3.3. Alpha Prototype

This prototype was aimed to show a second proof of concept in the bottle, with actual water. First, we found plastic plumbing fittings that fit the diameter of the bulb electrodes well. Sealing the bulb to the fittings, we then connected the electrodes to each other with a wire. We then forced one fitting through the one inch hole and capped it off with an end-cap and sealed it with silicone. Using duck tape and some wood as supports, we attached the motor to the side of the bottle, with the motor shaft protruding from the bottom of the bottle. For a crank, we took a piece of ½" x ¼" brass stock, hammered into an L, drilled a through hole for the motor shaft, and made a threaded hole for a set screw to hold the crank in place. We then put a wooden dowel over the metal to make it easier to hold. *Figure 8* below shows our working alpha prototype.

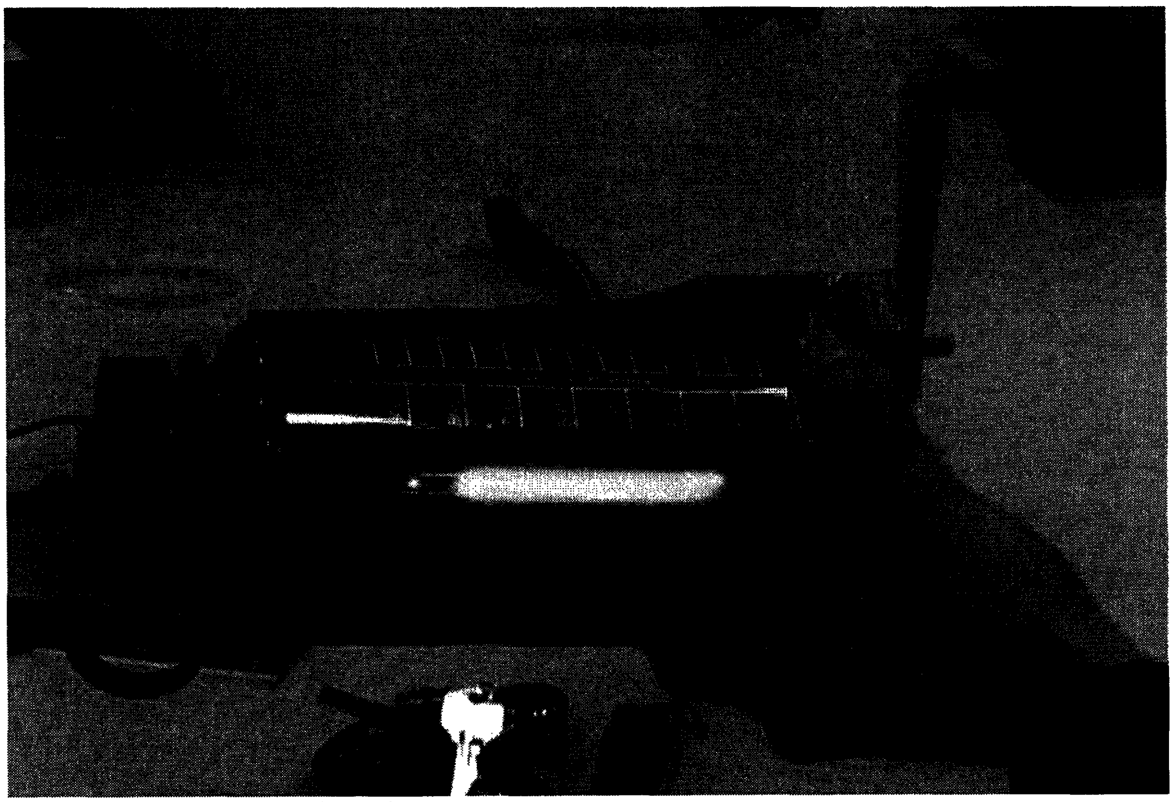

Figure 8: Alpha Prototype in Action

3.4. Beta Prototype

The alpha prototype hit our basic design requirements however we hadn't yet integrated or designed our photodiode circuitry, or a proper sleeve to protect the bulb. This prototype we aimed to meet all the design requirements except for easy maintenance.

3.4.1. Photodiode

The photodiode is used to monitor the instantaneous dose that the bulb emits. Since the diode is very sensitive, it must be placed in a darkened enclosure to ensure that it is only receiving light from the bulb. Once we find a supplier of better UV photodiodes, we can have options for a clear or darkened enclosure since the primary source of UV-C will be from the bulb itself. The photodiode circuitry works as follows. The generator charges an input capacitor that powers Op-amps and supply line. As light falls onto the photodiode, charge enters the V- terminal on a 10x amplifier (Op-amp 1) and a negative voltage develops on its output terminal. This biases the diode correctly and charge flows out of the capacitor. The second op-amp acts as a comparator between the charge on the capacitor and a micro-power voltage reference. The reference set point is fixed with respect to supply voltage (always 1.2v less than supply). When the capacitor drains to less than 1.2v from supply voltage, the comparator output goes from low to high and the gain to source voltage over the N-channel mosfet biases it to the ON position. Voltage can now pass through the LED to ground and the light turns ON. The rate of capacitor drain can be changed by adjusting the discharge resistor (470k) or the size of the capacitor. *Figure 9* shows the circuit diagram and *Figure 10* shows the breadboard version.

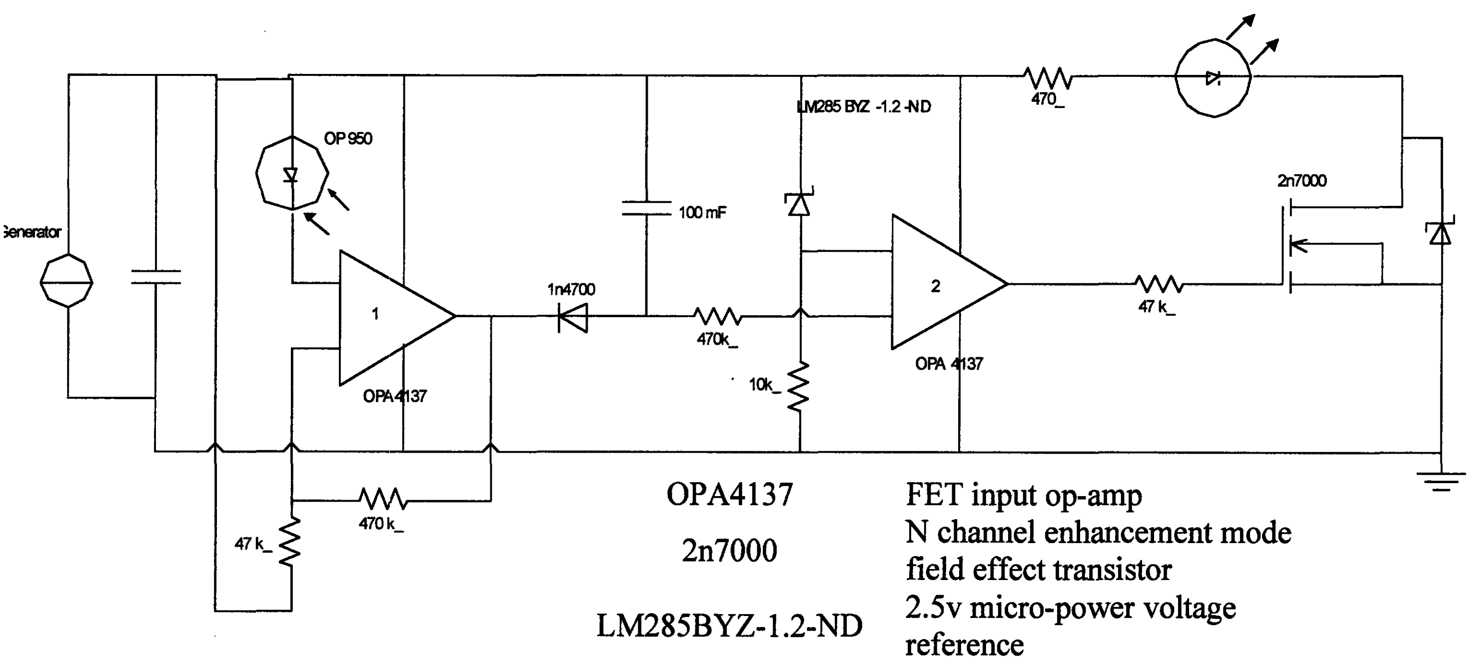

Figure 9: Photodiode Support Circuitry

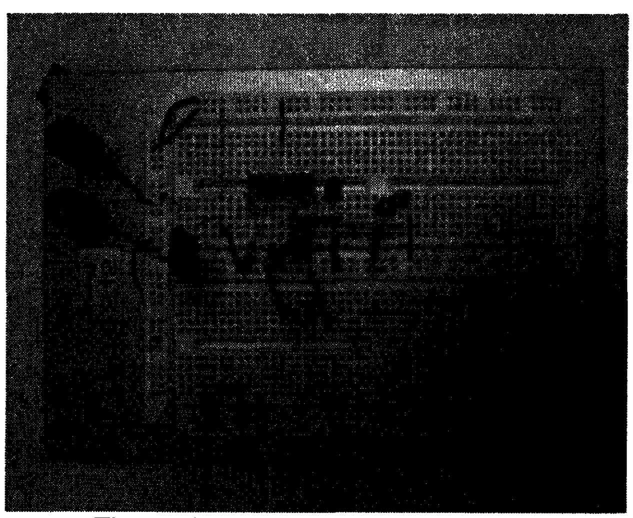

Figure 10: Photodiode Breadboard

3.4.2. Bulb Sleeve

From the onset, it was apparent that a sleeve would be essential for maintenance and bulb life. However, we soon found out that UV absorption would make this a difficult problem. Most plastics, just like crumbling plastic left in the sun for too long, absorb nearly all Ultraviolet light.

Initially we thought quartz would be the best solution, however, found that quartz is extremely expensive and brittle, making it non suitable for our application. The only family of plastics that have high enough Ultraviolet transmittance are fluoropolymers (Teflon™). Zeus Inc. has done vast amounts of research on UV transmittance of fluoropolymers and has a wealth of information on their website.

> Ultraviolet transmittance can be another useful aspect of fluoropolymer tubing. While levels of UV transmittance vary among the fluoropolymer resin family, Zeus tubing is used in applications such as water purification with excellent results. Crystallinity and wall thickness also affect the level of transmittance tubing will allow.[7]

Dupont also has a collection of information concerning fluoropolymers; presently, *Figure 11* is a plot of % transmittance across a wide spectrum of light wavelengths for Perfluoro-ethylene-propylene (FEP).

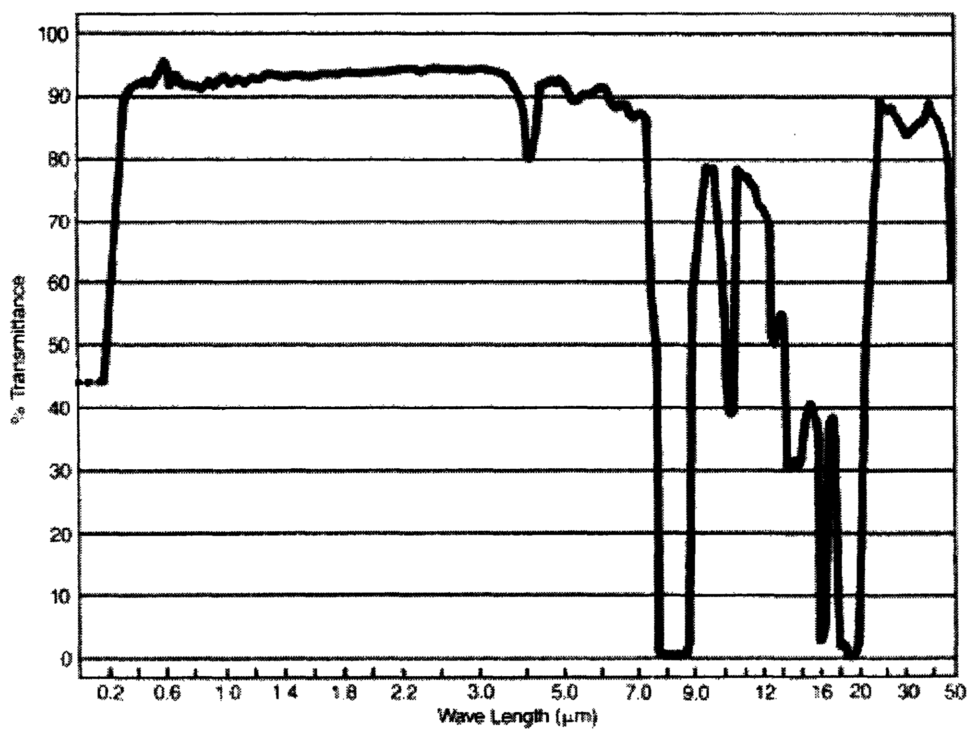

Figure 11: UV Transmittance Across Light Spectrum[8]

[7] Zeus Inc. < http://www.zeusinc.com/uvcompatibility.asp>
[2] Dupont < http://www2.dupont.com/Teflon_Industrial/en_US/assets/downloads/h55007.pdf> pg 8
[8] Dupont FEP. Information Bulletin. <http://www2.dupont.com/Teflon_Industrial/en_US/assets/downloads/h55007.pdf> pg 8

Since Dupont did not offer a definite thickness for the film they used, it was hard to make an accurate approximation for the expected transmission of the tubing at 254nm. However, referencing both conversations from Zeus technicians and Dupont articles we expected to see the 1/32" thick tubing to have an 80% transmittance rate. For our first implementation we decided to use a short length of FEP tubing from Zeus as the sleeve.

An unintended advantage of FEP also comes from its unique physical characteristics[9]

- **Mildew (Fungus) Resistance:** FEP has been shown to be completely resistant to mildew growth by testing both in humidity chamber exposure inoculated with a mixed spore suspension and a soil burial test for three months.
- **Weatherability:** In contrast to most other clear thermoplastic films, FEP remains essentially unchanged after 20 years of outdoor exposure. There is no evidence of discoloration, ultraviolet degradation, or strength loss. This outstanding performance is due to the structure of the polymer molecule and is not the result of chemical additives.

3.4.3. Integration

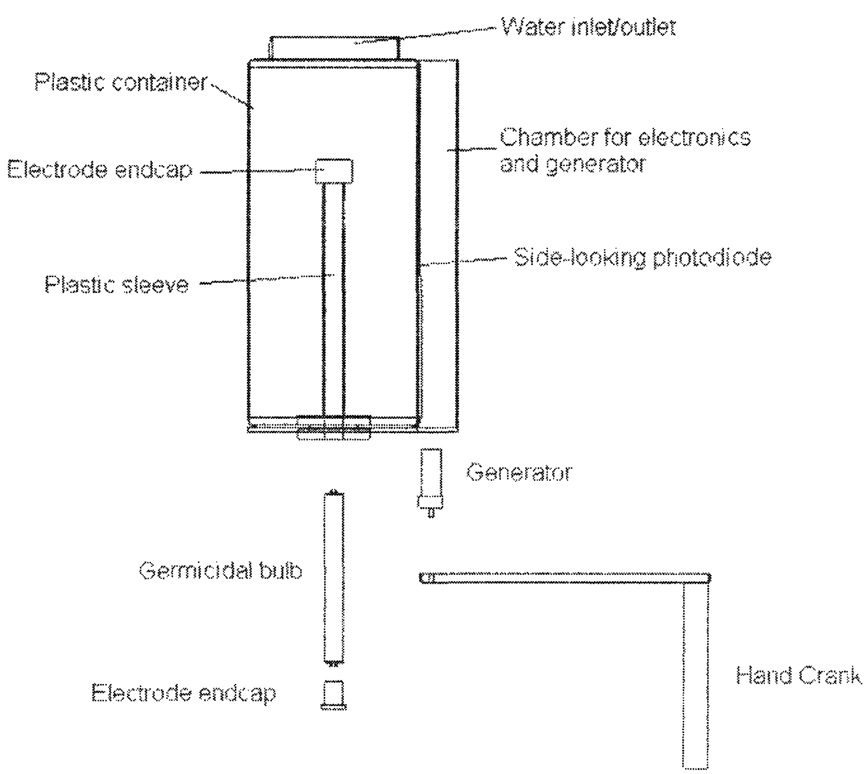

Figure 12: Beta Prototype Assembly

Beyond the assembly detailed above in *Figure 12*, we also painted on a black neoprene layer for the photodiode to work properly and to facilitate better grip. We attached the bulb in a very similar fashion as the alpha prototype, however used barb fittings that held the FEP sleeve in place. Also, we added stability to the motor by machining a brace for the motor that was

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[9] **DuPont FEP. pg 9**

attached to the bottom of the bottle via adhesive. We encased the electronics, motor, and photodiode in a half moon shaped piece of thin PVC that served as the electronics enclosure, seen in *Figure 13* and *Figure 14*. We sealed the enclosure to the side of the bottle via plumber's adhesive putty. The photodiode was attached with a piece of electrical tape, facing towards the bulb through the Lexan™. In this setup it is impossible to measure the actual UV-C radiation, however, we calibrated out across the bulb spectrum and approximated the UV dose as a function of brightness[10]. Concerning long term use, the production model's photodiode must be able to "see" the UV-C light, likely via a small quartz window. The LED for the user feedback was placed through a small hole in the PVC on the side, and illuminates once proper approximated dosage is received. On the top of the PVC we also added a reset button to drain the sensing capacitor to insure proper feedback for each sterilization run.

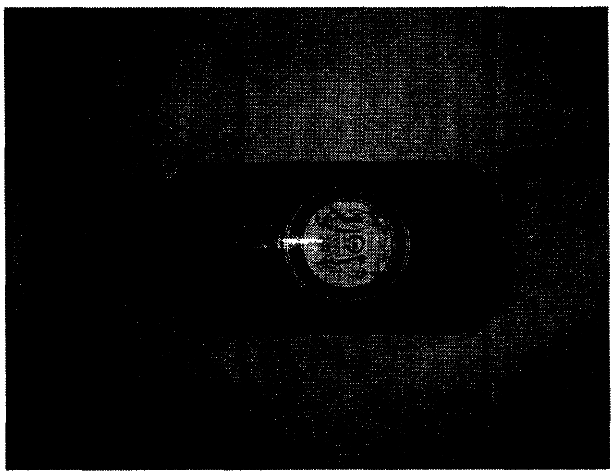


Figure 13: Beta Prototype Front View

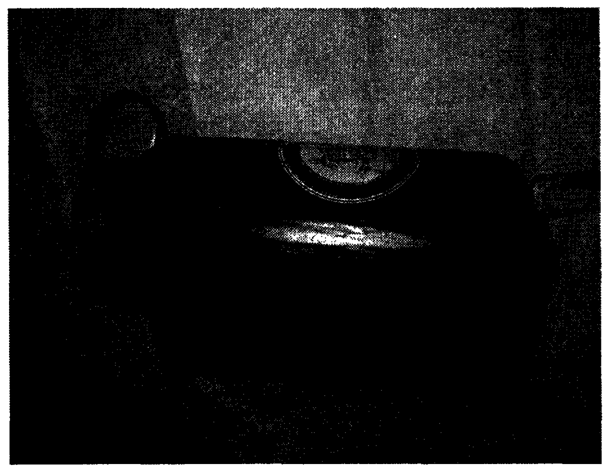


Figure 14: Beta Prototype Side View

Biological testing was completed with this prototype and is explained in the next chapter, however we learned these key design points

- The photodiode circuitry is far too power hungry; the capacitor for sensing drains rapidly without a constant current. This translates to a user not being able to get the LED feedback if he takes a small rest during cranking.
- The black neoprene provides good grip, however, switching to a black Lexan™ would work perfectly for keeping the diode dark.
- FEP is very difficult to work worth in prototyping. Not reacting with anything, the fluoropolymer can not be sealed with any common adhesives.
- Rating the gear reduction for the motor is very dependent on the length of the cranking arm, greater care must be taken in matching these values. However, the motor power output from our current motor is very satisfactory.

This prototype has been very successful for us as a team. We have succeeded in receiving over $11,000 in award money to further our project past this point and make a production model for

[10] This can be done for short term use since UV bulbs degrade first at the shorter wavelengths, making it possible for a bulb to be transmitting a normal amount of visible light, but no UV-C light

full scale manufacturing. We were featured with this prototype on Sunday March 26th in the *Boston Herald* under the title, "MIT innovators' design really holds water," seen in Appendix E.

3.5. Production Prototype Solid Model

Our production prototype model has addressed many of the problems we encountered during our earlier versions. Integrating all of the components with the design and all the Design For Manufacturing requirements has posed very difficult. We feel this design is close to our final production model. However, depending on funding, we plan to make the bottle modular to give a user the accessory options for a battery source or generator source. Furthermore, we also are in the process of weighing the benefits of having all the electrode connectors being placed within the molds themselves, making faster assembly time and less parts. Lastly, as we are still unclear of the transmittance vs. distance of injected mold grade FEP resin we used a sleeve similar to our beta prototype

3.5.1. Bottle Architecture

Instead of retrofitting our product to currently manufactured Lexan™ bottles, we plan to produce a bottle with the required fixtures for our components, please reference *Figure 15*. Like the beta prototype, we plan to place the support electronics, motor, and photodiode on the side of the bottle. The small hole on the fixture side of the bottle is reserved for the photodiode. We plan to seal a small quartz window in the hole, flush with the inside diameter of the bottle, and bond the photodiode to the back side. Our design also uses a threaded extrusion at the bottom center to allow easy removal and placement of the bulb assembly (section 3.5.2) inside the bottle. Along with this, extrusions out the bottom will facilitate proper footing in combination with the crank assembly (section 3.5.3). The bottle will be designed for a simple side pull in two different parts, along with a 3rd part for the bottom threaded extrusion. This bottle will be made of a UV resistant polycarbonate blend (similar to Lexan™).

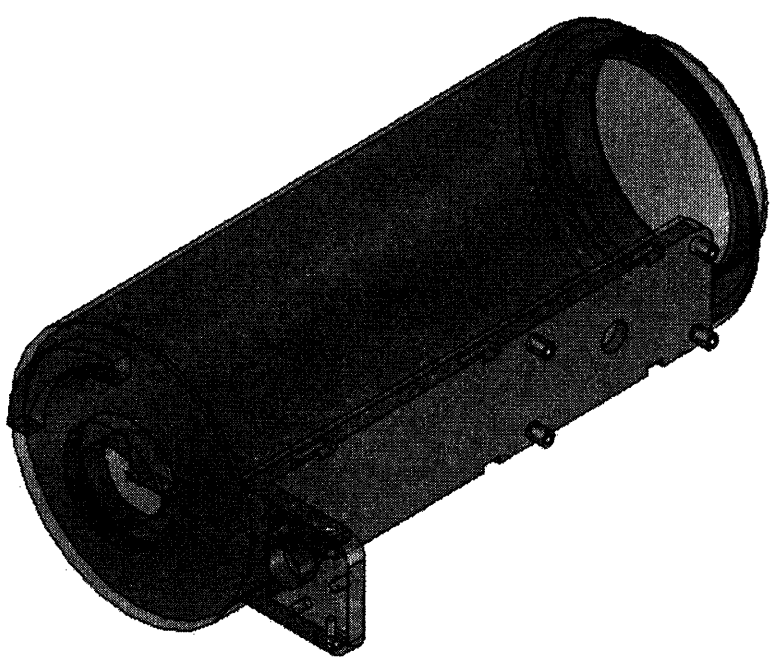


Figure 15: Production Prototype Bottle

3.5.2. Bulb Assembly

Presently, the bulb assembly is very similar to the beta prototype. An important design factor for this came with the cost of FEP resin[11]. Instead of custom molding the sleeve, we custom shaped the connector fittings, since polypropylene (PP) is much cheaper and comes in UV resistant resins[12]. Presently, the electrodes are bridged via a fluorpolymer coated wire that runs outside the sleeve and connects to both barbed fittings. The wire is semi rigged and serves also to keep the fittings together while disconnected.

Our design uses the FEP sleeve, inherently very stiff, as the rigid structure keeping the bulb and fittings stable. However, this also requires the bulb to be loosely attached to the end cap, since under extreme conditions the tubing may bend enough to snap the bulb. The bulb electrodes are therefore attached to a loose contact that can sway with these movements. The bottom connector therefore anchors the bulb in the bottom, effectively a cantilever. Since the shock under extreme conditions could cause bulb breakage, we incorporated a neoprene gasket and shock absorber around the bottom of the bulb. Finally, there is a slot in the fitting to allow for electrical connection to the support electronics.

3.5.3. Crank Assembly

The crank assembly acts not only as a lever arm, but also as support footing for the bottle, please reference *Figure 16.* The cranks bottom directly couples to the motor shaft and rotates inside the bottle's architecture. A simple 1/8" dowel pin will be used for rotating the lever arm. In one direction the lever arm can lay flat, *Figure 17*, while in the other direction it can be translated only to a 10 degree angle from the horizontal, *Figure 18.* This angle keeps the lever arm from hitting the threaded extrusion at the center of the bottle. At the end of the lever arm a rotating knob is attached that facilitates turning.

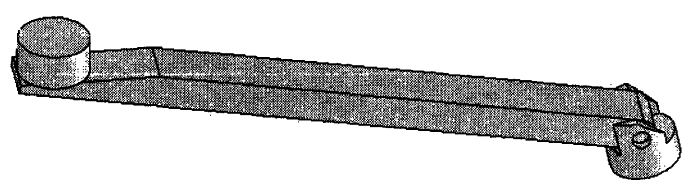


Figure 16: Hand Crank Assembly

[11] GE Plastics <http://www.geplastics.com>
[12] DOW Inc.Saint Gobain Verotex <http http://www.dowtwintex.com/plasticpipes/prod/m5010.htm>matprop/tw_uv_res.html >

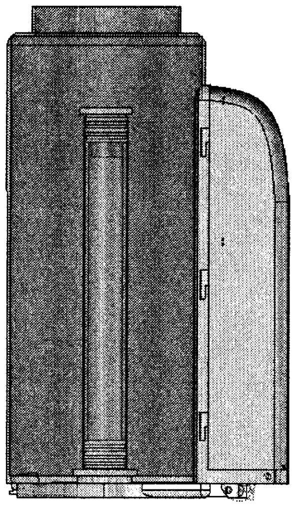


Figure 17: Hand Crank Closed

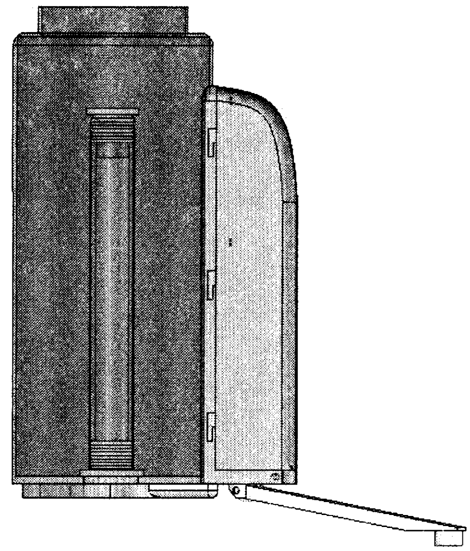


Figure 18: Hand Crank Open

3.5.4. Assembly

Referencing *Figure 19-21, i*ntegration of all the components is designed to be relatively straightforward. The circuit board and motor must both be fastened to the bottle via tapped holes. The hand crank assembly is press fit and bonded to the motor shaft. The bulb sleeve assembly will simply screw down into the threaded extrusion. Since the extrusion is a hard plastic (polycarbonate), the PP fittings will create an acceptable long term watertight seal[13]. After the bulb is in place, the power adapter is then pressed in place, connecting the bulb to the support electronics. The housing enclosure is then slid in and screwed into place.

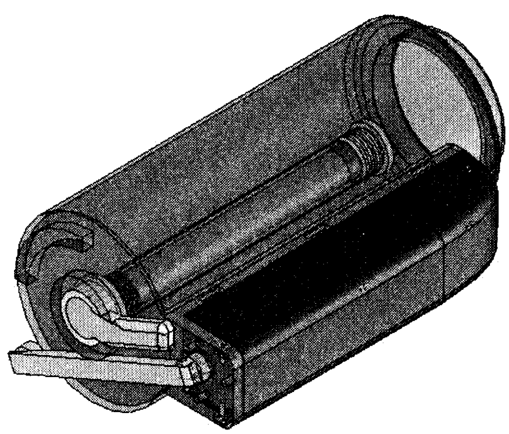


Figure 19: Production Prototype Isometric View

[13] The Nalgene™ bottle cap is made of Polopropylene

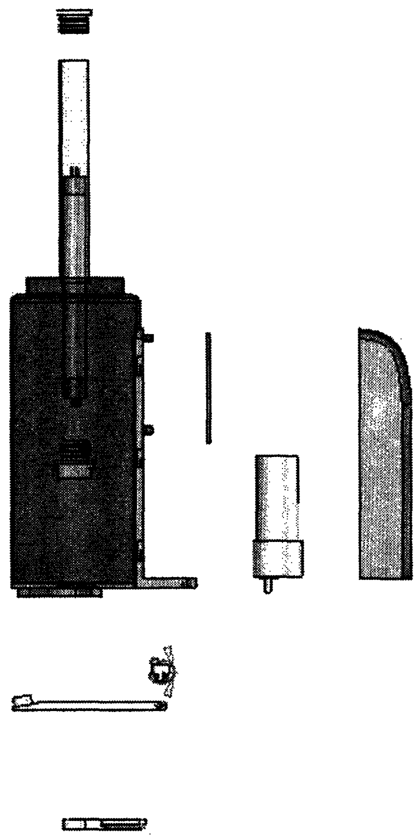


Figure 20: Production Prototype Exploded View

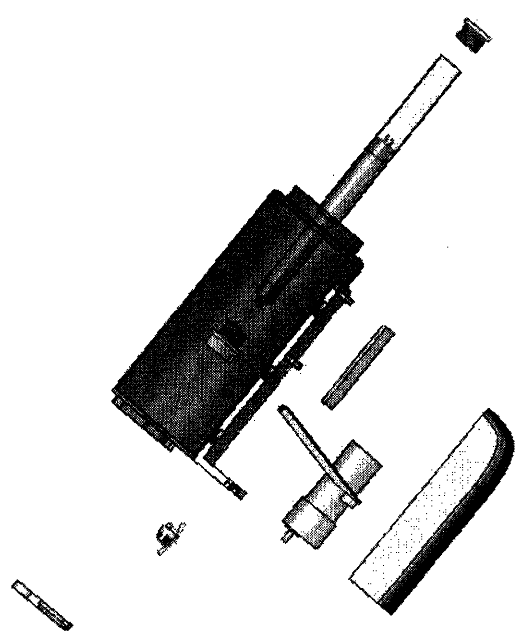


Figure 21: Production Prototype Exploded View 2

4. CONCEPT ANALYSIS

4.1. Introduction

Testing was conducted to evaluate the safety and efficacy of our purifier. Using a variety of methods

4.2. Method

4.2.1. Site Evaluation and Selection

The site selected for water sampling was a community pond in Alewife Brook, MA. The goal of our test was to select a site that was similar the stagnant water sources from which disaster victims and citizens in developing countries are forced to drink. Often sources of water are rich in bacterial and plant growth and are barely clear.

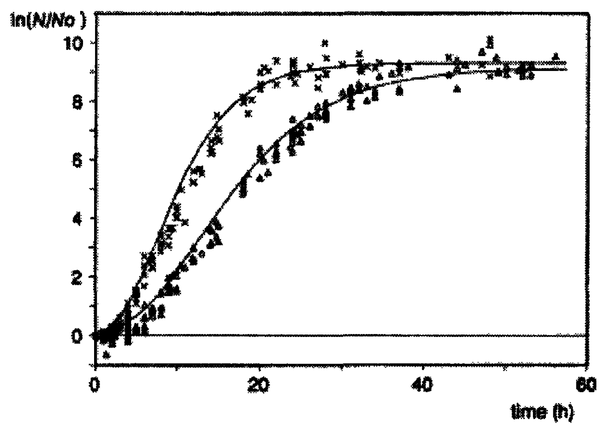


Figure 22. *L. Plantarum* growth curves at 20(△) and 25°C(✕).[14]

Climatic conditions in many of the tropical developing countries can promote accelerated bacterial growth in mesophilic bacteria. Two growth curves are presented in *Figure 22.*

[14] Zwietering MH et al. Modeling of Bacterial Growth with Shifts in Temperature. *Applied and Environmental Microbiology*, Jan. 1994, p. 204-213.

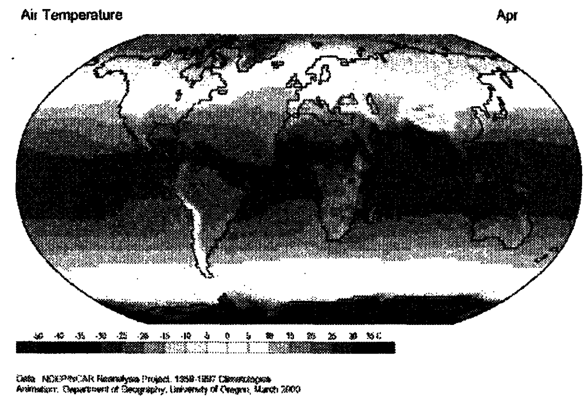


Figure 23. Mean global temperatures during the month of April.[15]

With only a 5 degree difference in temperature, the growth curve is significantly different. With just this in mind, the global temperature charts (*Figure 23*) ensure that the water supplies of many areas with the greatest need for water such as India and Africa, are teeming with infectious agents. India and Sub-Saharan Africa show a mean temperature that is on average 15° C higher in the month of April.

Though we could not account for the temperature difference, the watersheds in Boston are host to several types of bacteria according to a report presented by the Massachusetts state government. Notably, the mean Fecal Coliform colony count was 370,000 CFU/L after rainstorms. In light of this, we waited until rain to collect our samples.

Figure 24. Storm Water Event Mean Fecal Coliform Concentrations[16]

Land Use Category	Fecal Coliform Organisms / 100 mL
Single Family Residential	37,000
Multifamily Residential	17,000
Commercial	16,000
Industrial	14,000

4.2.2. Qualitative Studies

In order to qualitatively gauge the effectiveness of our bottle, we purchased three Watersafe® drinking water test kits. The test is a retail kit that can determine the presence or absence of fecal coliform bacteria. The test utilizes a medium containing ortho-nitrophenyl-ß-D-galactopyranoside (ONPG). This chromogen is cleaved to form o-nitrophenyl-pyranoside(ONP) and galactose by fecal coliform bacterial strains which produce the degrading enzyme ß-

[15] http://geography.uoregon.edu/envchange/clim_animations/index.html
[16] http://www.mass.gov/dep/water/resources/concord3.doc

Galactosidase. ONPG is deep purple in color, but ONP is yellow, so a confirmatory identification of the presence of fecal coliform bacteria can be qualitatively determined in 24 hours (*Figure 25).*

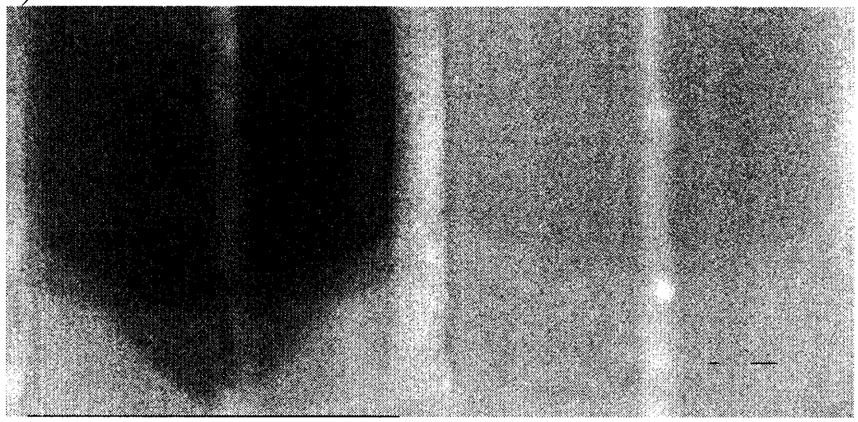


Figure 25. Colorometric changes highlighting differences between infected and clean water.

Procedurally, the test qualitatively compared among samples treated with our UV Bottle, samples treated with chlorine (positive control), and the negative control, samples that were untreated. All the samples were gathered at the same time from the same location and were stored at room temperature for 8 hours prior to treatment and testing.

4.2.3. Quantative Studies

With the large number of studies detailing the efficacy of UV's germicidal properties, our quantitative testing seemed redundant. We instead chose to create additional models for the UV dose delivered. We modified these calculations by factoring in the absorbance of the FEP sleeve. Based on the material information from DuPont[12], we determined the transmittance of UV through the FEP sleeve to be 78%, incorporating this into our model, a graph was generated highlighting the change in dose (*Figure 26-27).* The MATLAB code used to generate the plots is included in Appendix F.

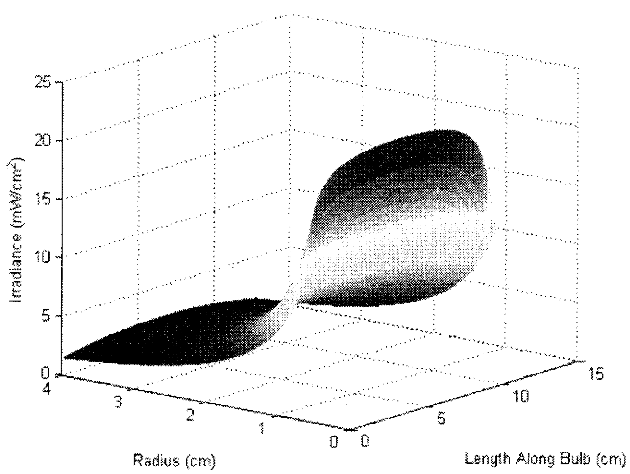


Figure 26: 3 Dimensional Analysis of UV Dose

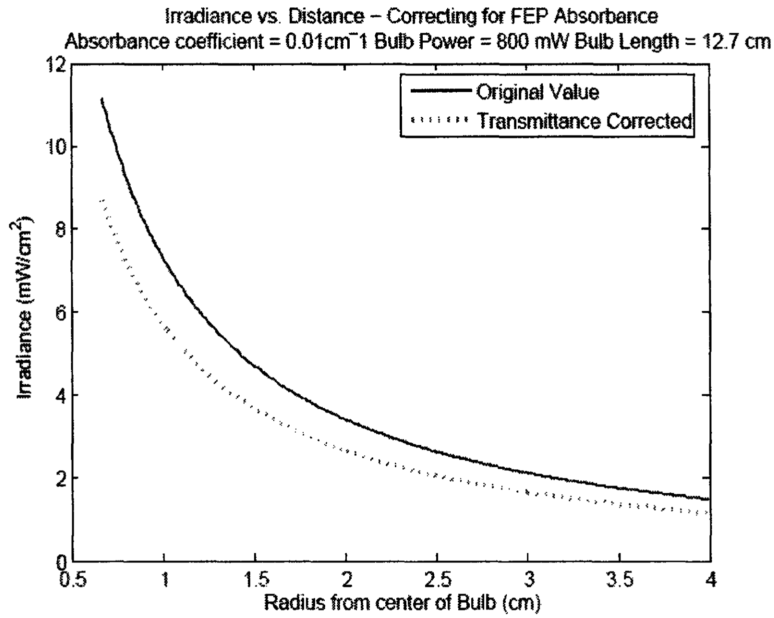


Figure 27. FEP Absorbance Corrected Irradiance

This added reduction in UV transmittance will increase the time that it takes to reach NSF/ANSI standards to 41 seconds in clear water and 65 seconds in turbid water.

4.2.4.Future Testing - EPA Certification

4.2.5. Background

In order to ensure efficacy of microbiological water purifiers, the U.S. EPA formed a multi-disciplinary task force that resulted in a standardization of testing criteria that they are subject to. This effort gradually resulted into what is today the U.S. Environmental Protection Agency's Environmental Technology Verification (ETV) Program. This program accelerates the testing and approval of environmentally friendly innovations, the tests are comprehensive and funded by the EPA, together with the technology developer, there is the opportunity to bring environmentally friendly products to market quicker. The protocol that must be followed is the EPA's Protocol for Equipment Verification Testing for Inactivation of Microbiological Contaminant[17]. We have created a test plan for pre-market testing of our UV Bottle in keepings with EPA regulations.

4.2.5.1.Characterization of Feed Water

Before tests can be performed, a chemical, biological, and physical profile must be constructed. The following areas must be characterized: water temperature, turbidity, UV_{254} absorbance in filtered and unfiltered samples, free and total chlorine, total organic carbon, spectrophotometric color analysis, total coliform with a treated water source or heterotrophic plate count (HPC) for untreated water, aerobic spores, algae, total alkalinity, pH, calcium, hardness, nitrate, aluminum, and finally iron. Most tests will be conducted in a lab, however some will be conducted on-site, according to EPA guidelines outlined in *Figure 28.*

[17] http://www.epa.gov/etv/pdfs/vp/02_vp_microinact.pdf

4.2.5.2. Water Sample Collection and Frequency

Water will be sampled continuously for 320 operational hours and water quality data shall be collected for the feed water and treated water. A strict schedule must be kept for the testing along with documentation, a good initial estimate is that 90 liters of water be processed daily and random samples collected in a statistically significant number of bottles and analyzed (n=30). In addition to the sample analysis; measurements of lamp fouling, UV dosage, circuit functionality, and number of lamp cycles will be recorded.

4.2.5.3. Antimicrobial Activity Testing – Strain and Laboratory Specifications

For anti-microbial activity tests, we will use *Cryptosporidium* oocytes and *Giardia* both obtained from Waterborne Inc., 6047 Hurst Street, New Orleans, LA 70118-6129; *E.Coli*, Fecal Coliform, Adenovirus 41, Poliovirus, and P1 Phage all obtained from American Type Culture Collection, 12301 Parklawn Drive, Rockville, MD 20852. All strains will be subjected to ID_{50} testing, and will have similar host species, isolate strains, and will have been subjected to the same processing techniques. All strains will be shipped with an identical heat killed strain to serve as experimental controls. All strains will be spiked into the water samples collected for evaluation. The species must be allowed to habituate to the test water to avoid false positive results.

Samples for analysis of any microbiological parameter shall be collected in bottles supplied by the analytical laboratory. Microbiological samples must be refrigerated at approximately 2 to 8°C immediately upon collection. Such samples will be shipped at a temperature of approximately 2 to 8°C. Samples will be processed for analysis by an EPA certified laboratory within 24 hours of collection. The laboratory will be required to maintain the samples at 2 to 8°C until initiation of processing. The lab will quantify TC densities and report the density per 100 mL. Methods for assessing the viability of the selected bacteria and viruses will be specified by the laboratory performing the analysis. A peer reviewed methods will be used for assessing the viability of cysts and oocysts. As a backup, assessing cyst and oocyst viability will be verified by animal infectivity studies.

Figure 28. Table of Data Collection Functional Requirements.[8]

Parameter	Facility	*Standard Methods* and Other Method References	EPA Methods
Temperature	On-site	2550 B	
pH	On-site	4500 H+ B	150.1/150.2
Total Alkalinity	Lab	2320 B	
Total Hardness	Lab	2340 C	
Total Organic Carbon	Lab	5310 C	
UV Absorbance (254 and/or other nm)	Lab	5910 B	
Turbidity	On-site	2130 B	180.1
Algae, number species	Lab	10200 and 10900	
True Color	Lab or On-site	2120 B (Hach Co. modification of *SM* 2120 measured at 455 nm)	
Total Coliform	Lab	9221 / 9222 / 9223	
Heterotrophic Plate Count	Lab	9215 B	
E. coli	Lab	9225 or Colilert	
Micrococcus luteus	Lab	AWWARF Surrogate Report by CSU	
Bacillus spores	Lab	Rice et al. 1996	
MS2 Virus	Lab	EPA ICR Method for Coliphage Assay, 1996 or 9224 F	
Algae	Lab	AWWARF Surrogate Report by CSU	
Giardia and *Cryptosporidium*	Lab	EPA Draft 1622, (enumeration only)	
Iron	Lab	3120 B, 3111 B, 3113 B	200.7, 200.9
Manganese	Lab	3120 B, 3111 B, 3113 B	200.7, 200.8, 200.9
Aluminum	Lab	3120 B, 3111 D, 3113 B	200.7, 200.8, 200.9
Nitrate	Lab	4110 B, 4500-No$_3$-F, 4500-No$_3$-D, 4500-No$_3$-E	300.0, 353.2
Free and Total Chlorine	On-site	Hach modification of *SM* 4500 CL G	

4.2.5.4. Inorganic Samples

Inorganic chemical samples, including alkalinity, hardness, aluminum, iron, and manganese, will be collected and preserved protecting against contamination as outlined in EPA Standard Method 3010C. The samples will refrigerated at approximately 4°C. Samples shall be processed for analysis by a laboratory that is certified by the US EPA within 24 hours of collection. The laboratory shall keep the samples at approximately 4°C until initiation of analysis.

5. MANUFACTURING PLAN

5.1. Strategy

Initially, we will use North American manufacturing facilities either in the US or Mexico for fast delivery time to speed up our time to market. Fast injection molding prototype facilities with soft Aluminum tooling offer very competitive prices in the US and will likely be used to produce our very first product line. However, considering cost and demand, we will likely contract out the injection mold tooling abroad to Asia for the next rollout. Depending on demand for each product, we will then plan to shift certain product lines completely abroad, with assembly plants still in the US.

5.2. Facilities Required

We will require simply a building for assembly. In the beginning we plan on using our office space, but eventually we will move the assembly work to a small warehouse. We plan on looking into commercial real estate for our office in Cambridge and eventually renting warehouse space off I-95 or possibly I-495.

5.3. Quality Assurance

Before production we will ensure that each product line is given an EPA certification for microbiological organism purification. On the contract side, we will deal solely with ISO equivalent manufactures abroad. In the assembly plant, we will test each product for quality control in component sets before it leaves our facility. The nature of our safety loop allows us to easily check if each product is in working order before it goes out the door. After traction is gained, we plan to receive ISO 900x compliancy in our own assembly plant to bolster our chances at receiving government and international contracts.

5.4. Organizational Issues

Our Chief Operating Officer is responsible for the implementation of our manufacturing plan. Our CEO will be responsible for securing manufacturing contracts with fabrication plants and securing an overseas partner for DC motors, UV bulbs, fluoropolymer tubing, and any future needs. The COO will ensure that those companies comply with their contracts and that our assembly team is given all the necessary parts without having to wait for lagging deliverables. While being responsible for identifying problems in the supply chain, the COO will also constantly look for more cost effective solutions for the next rollouts. Furthermore, working with the VP of Engineering, the COO will oversee the transition of R&D efforts to full scale manufacturing.

5.5. Resources

We are currently seeking an Enterprises Resource Planning (ERP) inventory management system and hope to have a full business ERP system by August. With regards to money, we have approximated our up front costs for our initial product rollout. Referencing *Figure 29*, our motor design, plus an option for a battery power, will require approximately $29,000 to have the necessary tooling fabricated. This initial investment includes 25 runs for each part, and will be used to insure that all the pieces fit together in the desired fashion and as preliminary product testing before investing in a full scale run. We will require approximately another $13,000 for a run of 1000. Including the front end design and cost, we expect to budget $125,000 for this product line for the first 12 months of being on the market. With the budget we plan to produce up to 6000 bottles in two large runs, an initial run at 1000 units, following up with a run number depending on market traction.

	Initial Investment			
Runs	25	1000	5000	10000
Injection Molding				
Tooling	18200	0	0	0
Assembly Cost		136	678	1356
Processing Costs		502	2510	5020
Motors	113	4500	22500	45000
Uv bulbs	56	2250	11250	22500
Pre filters[18]	38	1500	7500	15000
Electronics	200	1150	5750	11500
Overhead		1048	5242	10484
subtotal	18606	11086	55430	110860
Accessories				
Enclosure M[19]	5000	258	1292	2584
Enclosure B[20]	2600	118	590	590
Subtotal	7600	376	1882	3175
Total w/ 10% addition	28827	12609	63044	125438

Figure 29 Production Estimates for Final Prototype[21]

5.6. Assembly Steps For Proposed Final Prototype

1) Receive parts via freight to our assembly location, add to ERP software
2) Test the UV bulb, photodiodes, support circuitry and gearmotors in sets for QC
3) Place quartz crystal and photodiode on the bottle, possibly snap fit in place, likely bonded
4) Screw electronic circuit board and motor to bottle fixture
5) Connect power leads from motor to circuit board
6) Slide on enclosure and fasten
7) Assemble crank assembly
8) Press fit and bond crank assembly to motor shaft
9) Assemble bulb sleeve
10) Lock bulb sleeve inside bottle fixture
11) Screw on cap
12) Add filter bag and instructions to box, package, ship

[18] Filters are briefly explained in the Future Work section
[19] Enclosure M references the gearmotor design
[20] Enclosure B references a battery powered design
[21] Our initial investment produces the tooling needed for secondary runs. Also, For further explanation of these number see Appendix B

6. Conclusion and Future Plans

A portable hand powered UV water sterilizer offers an affordable, flexible, and technically sound solution to a portion of the global water epidemic.

The production prototype serves to meet all the basic requirements that we aimed for at the beginning of our project. We beat our primary goal of 80 second sterilization by 15 seconds and found that even in the most turbid water, sterilization occurs in about 78 seconds. The weight of prototype beta is less than one pound. The added functionality added a little more than .6 pounds to the bottle.

The most complex problem for the design of this device came at the intersection of maintenance and the high energy properties associated with UV-C light. In order to keep the bulb from contacting the water, the design required a sleeve that transmitted a high percentage of UV-C radiation. Quartz not being suitable for this application forced us to use special fluoropolymer plastics (FEP) that offer high UV transmittance. As a fortunate consequence, the FEP is chemically inert, resistant to build up, and extremely easy to clean.

Through the last two design competitions we have won, every judge and potential user has expressed great interest in our UV dose sensing feedback function. With relatively simple electrical components, the feedback circuitry approximates the dose given to the water and alerts the user when the water is potable with a green LED. Our circuit is in need of optimization to decrease the rate of power drain out of the monitored capacitor. Currently, a one second pause causes the capacitor to drain too much charge to be effective. However, the desired optimization is quite simple and will be addressed with the help of an electrical engineer (not a Mech E!).

Our team is also proud to have completed a full business plan, featured in Appendix G. After the semi-finals of our first competition, we realized the business potential in both developed nations and consumer markets. Concurrently, we are seeking more funding through private angel investors, a Small Business Innovative Research (SBIR) grant from the military, and more "green" design competitions.

With a small amount of funding we feel that we can truly make a difference in the world and at the same time create a revenue generating venture. By establishing our entity as a social enterprise, we will use a portion of profit from the consumer markets to validate the non profit guidelines by donating units to less developed nations, aid agencies, and disaster relief organizations.

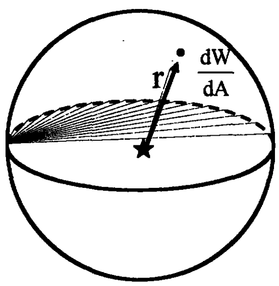
If all goes as planned, TurnPure Inc. will have it's first rollout, deemed PhotoPure World, in the late fall.

APPENDIX A: IRRADIANCE EQUATION DERIVATION

(1) $$I = \frac{\partial W}{\partial A}$$

I Irradiance = radiant flux / unit area incident on a surface
W Watts (joules/sec)
A Area

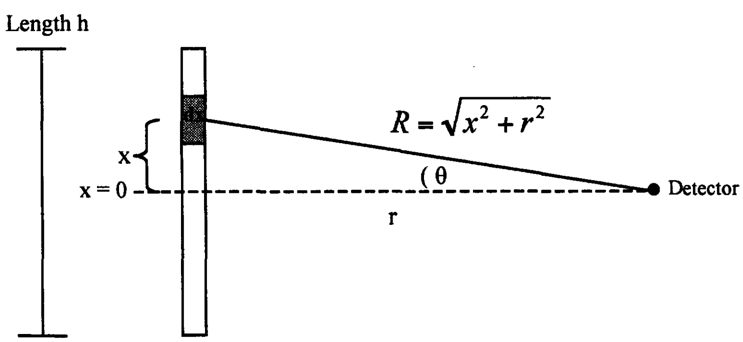
Point Source



A point source in space produces electromagnetic energy at a fixed rate, W_o, in watts. The energy radiates uniformly outward in a spherical shell. Define a spherical surface at a distance r from the source. By conservation of energy, the rate of energy passing through this shell must equal rate of energy production at the source W_o. The irradiance at any point on the sphere is given by equation (2).

(2) $$I = \frac{W_o}{A} = \frac{W_o}{4\pi r^2}$$ Irradiance follows the inverse square law

Line Source



Model the radiation source as a line source of length h. Divide the line up into differential elements dx. If the source puts out energy at a rate of dW, the power output per unit length is expressed in equation (3) as P_o. Each differential element dx radiates energy to the detector and contributes dI to the total irradiance as seen in equation (4).

(3) $$P_o = \frac{\partial W}{\partial x}$$ P_o in watts/meter

(4) $$\partial I = \frac{\partial W}{\partial A} = \frac{\partial W}{4\pi R^2} = \frac{P_o \partial x}{4\pi(x^2 + r^2)}$$

Integrate (4) to find total irradiance incident upon detector

If source produces energy at a constant rate W_o: $P_o = W_o/h$

(5) $$I(r,h) = \frac{P_o}{4\pi}\int_{-h/2}^{h/2} \frac{\partial x}{x^2 + r^2}$$

Light traveling through a medium

Beer-Lambert law
There is an exponential dependence between the transmission of light through a substance and the concentration of the substance, and also between the transmission and the length of material that the light travels through.

```
            | . . . . . . . |
I0   ==>    |. . c,   . . . | ==> I1
            | . . . . . . . |

             <---- l ---->
```

There are several ways in which the law can be expressed:

(6) $A = \alpha l c$ (7) $\frac{I_1}{I_0} = e^{-\alpha l c}$ (8) $A = -\log \frac{I_1}{I_0}$ (9) $\alpha = \frac{4\pi k}{\lambda}$	• A is absorbance • I_0 is the intensity of the incident light • I_1 is the intensity after passing through the material • l is the distance that the light travels through the material (the path length) • c is the concentration of absorbing species in the material • α is the *absorption coefficient* or the molar absorptivity of the absorber. • λ is the wavelength of the light • k is the extinction coefficient.

Apply the Beer-Lambert law (7) to the irradiance equation:

(5) + (7)
$$I(r,h) = \frac{P_o}{4\pi}\int_{-h/2}^{h/2} \frac{\partial x}{x^2 + r^2} e^{-\alpha l c}$$

(10)
$$I(r,h) = \frac{P_o}{4\pi}\int_{-h/2}^{h/2} \frac{\partial x}{x^2 + r^2} e^{-\alpha\sqrt{x^2 + r^2}}$$

APPENDIX B : BILL OF MATERIALS FOR FINAL PROTOTYPE

Component	Purchased Material	Processing (Machine + Labor)	Assembly (Labor)	Total Unit Variable Cost	Tooling and Other NRE, K$ (3)	Total Unit Cost 1000 run	Total Unit Cost 5000 run	Total Unit Cost 10000 run
Bottle		0.42		0.42	3,500	3.92	1.12	0.77
FEP Sleeve		0.03	0.06	0.09	1,800	1.89	0.45	0.27
Pre filter	1.50			1.50		1.50	1.50	1.50
Electronics	1.15		0.08	1.23		1.23	1.23	1.23
UV bulb	2.25			2.25		2.25	2.25	2.25
Accessories								
Enclosure M (1)		0.21	0.01	0.22	3,200	3.42	0.86	0.54
Hand Crank		0.02	0.01	0.04	1,800	1.84	0.40	0.22
Motor	4.50		0.08	4.58		4.58	4.58	4.58
Enclosure B (2)		0.10	0.01	0.12	2,600	2.72	0.64	0.38
Total Direct Costs - Accessories	9.40	0.45	0.14	3.23	5,300	10.78	6.54	6.01
Overhead Charges	0.94		0.11			1.05	1.05	1.05
Total Cost with Enclosure M						**21.67**	**13.43**	**12.40**
Total Cost with Enclosure B						**14.55**	**8.23**	**7.44**

Figure 30 Indented Bill of Materials
Cost estimates for PhotoPure™ World, this is by no means final. The accessories are listed with M and B to denote (1)Motor Power and (2)Battery Power, respectively. Overhead costs were figured as 10% of Purchased materials and 80% of Assembly costs. (3)Tooling estimates were made with price quotes from our initial supplier in soft core Aluminum (suitable for 10,000 units).

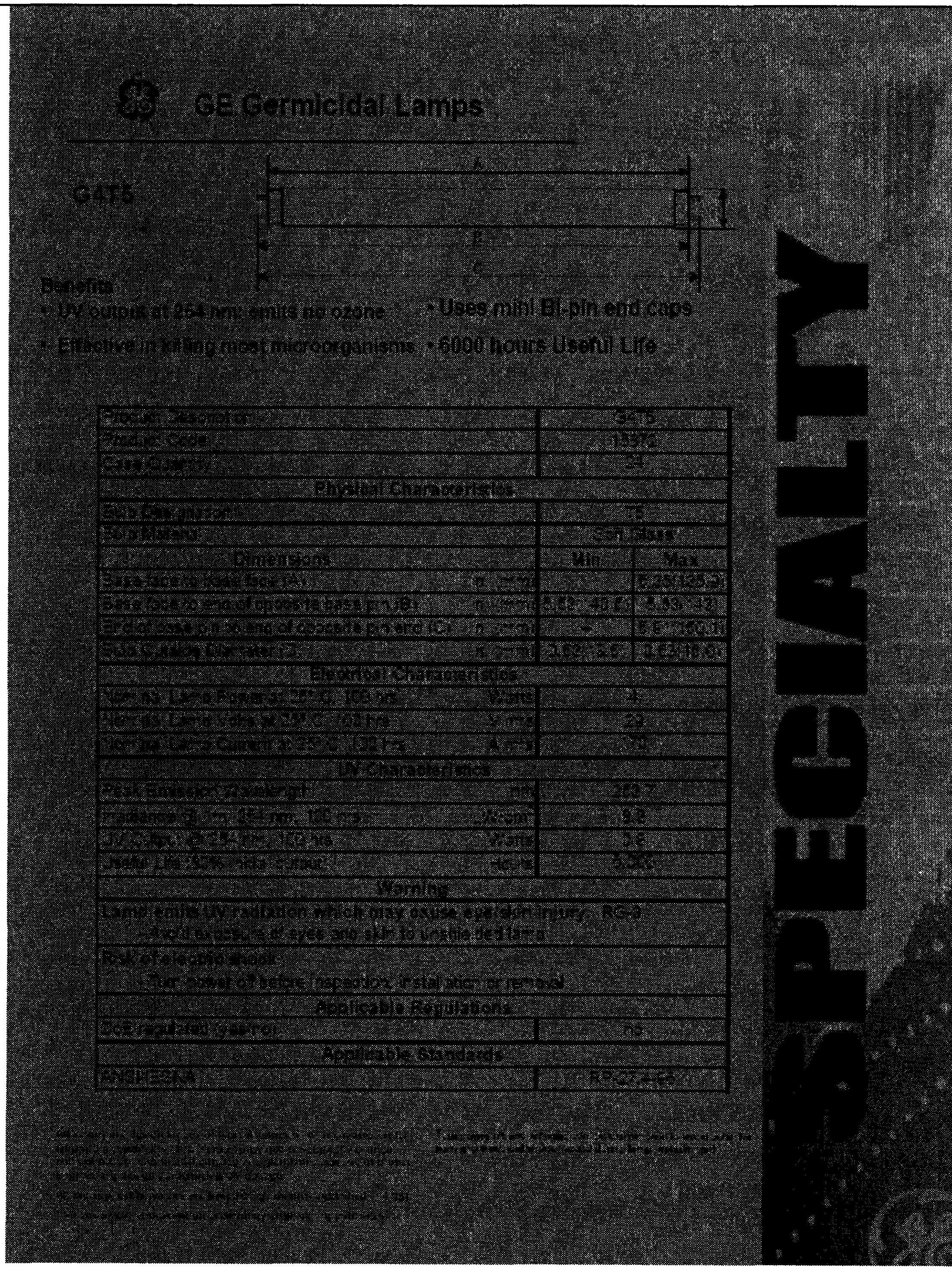
PhotoPure World

Injection Molded	Material	Tooling	Material $/lb	Cubic Inches	Material $/pc	pc/hr	Processing
Bottle	Lexan	5,000	3.50	18	2.73E-03	180	0.42
Hand Crank	PP	1,800	1.50	3	1.58E-04	3360	0.02
Enclosure M	PP	3,200	1.50	9	4.73E-04	360	0.21
Enclousre B	PP	2,600	1.50	6	3.15E-04	720	0.10
Sleeve	FEP	1,800	12.00	0.5	4.66E-04	2520	0.03

Lot Size	Bottle Price	Hand Crank	Enclosure M	Enclosure B	Sleeve	Total IM cost
1000	5.42	1.82	3.41	2.70	1.83	13.36
5000	1.09	0.38	0.68	0.54	0.37	2.69
10000	0.54	0.20	0.34	0.27	0.18	1.36

Processing Cost(2)	75

APPENDIX C: GE G4T5 GERMICIDAL LAMP SPECS



GE Germicidal Lamps

G4T5

Benefits

- UV output at 254 nm: emits no ozone
- Uses mini Bi-pin end caps
- Effective in killing most microorganisms
- 6000 hours Useful Life

Product Description		[illegible]	
Product Code		[illegible]	
Case Quantity		24	
Physical Characteristics			
Bulb Designation		T5	
Bulb Material		Soft Glass	
Dimensions		Min	Max
[illegible] (A)	[illegible]		[illegible]
[illegible] (B)	[illegible]	[illegible]	[illegible]
[illegible] (C)	[illegible]	[illegible]	[illegible]
[illegible] (D)	[illegible]	[illegible]	[illegible]
Electrical Characteristics			
Nominal Lamp Power [illegible]	Watts	4	
Nominal Lamp Volts [illegible]	Volts	29	
Nominal Lamp Current [illegible]	Amps	[illegible]	
UV Characteristics			
Peak Emission Wavelength	nm	253.7	
[illegible]	[illegible]	[illegible]	
[illegible]	Watts	[illegible]	
Useful Life [illegible]	Hours	[illegible]	
Warning			
Lamp emits UV radiation which may cause eye/skin injury. RG-3 – Avoid exposure of eyes and skin to unshielded lamp			
Risk of electric shock – Turn power off before inspection, installation or removal			
Applicable Regulations			
DOE regulated [illegible]		no	
Applicable Standards			
ANSI/IESNA		[illegible]	

22

[22] GE Lighting <http://www.gelighting.com/na/business_lighting/education_resources/literature_library/product_brochures/specialty/downloads/germicidal/germicidal_tech_sheets.pdf>

APPENDIX D: PROVISIONAL PATENT FILED 2 MARCH 2006

INVENTION TITLE

Human powered ultraviolet water sterilization apparatus

DESCRIPTION

[Para 1] A portable water sterilization system contained inside a water bottle that is human powered via a hand crank generator. The device can sterilize bacteria, protozoa, and viruses in less than 1 minute using ultraviolet (UV) light. Current devices are hard to maintain, require battery power, and do not provide feedback to the operator for when the water is safe to drink. Our apparatus can easily accept replacement bulbs, is easy to clean, requires no batteries or chemicals, and includes a light sensor that measures when adequate UV dose is applied to the contaminated water. The light sensor allows our device to operate on water of different absorption coefficients that may attenuate the UV light. Simply timing the bulb duration does not provide a safe and reliable measurement for germicidal effectiveness.

What is claimed is:

[Claim 1] A portable water sterilization system comprising: A Container with an opening on one end encapsulating a volume suitable for storing a liquid.

[Claim 2] A container of claim 1 with a reflective interior coating (aluminum) that promotes light scattering.

[Claim 3] A reflective coating of claim 2 that contains titanium dioxide (TiO_2).

[Claim 4] A container of claim 1 that is made of polycarbonate plastic, lexan, or aluminum.

[Claim 5] A container of claim 1 that is reinforced to provide shock absorption, structurally enhance the bottle, and prevent light from entering or exiting the bottle.

[Claim 6] A uv transmittable plastic sleeve that is attached through the base of the container and capped at the top end. The sleeve encases the ultraviolet light source in the center of the container and keeps the electrodes out of water contact.

[Claim 7] A plastic sleeve in claim 6 that is made of Teflon or FEP plastic.

[Claim 8] A chamber at the base or side of the container that encases circuitry and generator.

[Claim 9] A fly-back inductor circuit for powering the ultraviolet light source that is itself powered from a hand powered DC generator.

[Claim 10] A photodiode and detection circuit for monitoring delivered UV dose.

[Claim 11] A method for indicating when the purification stage has finished.

[Claim 12] A method in claim 11 that is a LED indicator light or progress bar.

[Claim 13] A geared dc motor with a fold up crank that generates power to run the bulb, photodiode detection circuit, and safety circuitry.

[Claim 14] A dc motor of claim 13 that is a planetary drive motor.

[Claim 15] A motor of claim 13 that has a large circular gear that turns as the base of the bottle turns. See figure.

[Claim 16] An alternative means of powering the device as in a battery pack accessory. Another alternative is an ac/dc converter that can power the unit from a standard wall outlet. Converters come in either 220/240 vac or 110/120 vac varieties with appropriate plug adaptors for use in standard or foreign outlets.

[Claim 17] Safety circuitry that prevents the uv bulb from lighting unless the bottle is capped.

[Claim 18] Safety circuitry that takes the form of an electrode at the top and base of the central sleeve that will complete a circuit only when water is present inside the bottle. This can switch the generator power to the fly-back inductor enabling the bulb to be lit.

[Claim 19] An indicator light or series of labeled lights that turn on when the unit is in an improper state. This state can be when the user is cranking the generator but the bulb won't light. If this happens in the presence of water in the bottle, the bulb needs replacement. If no water is present, the unit will indicate that no water is present. Another light can indicate that the top lid has not been secured. Electricity that powers these safety notification systems will come from the hand crank generator output.

ABSTRACT

[Para 2] A portable water sterilization system contained inside a water bottle that is human powered via a hand crank generator. The device can sterilize water contaminated by bacteria, protozoa, and viruses in less than one minute without using batteries. The user turns the hand crank generator producing dc. This, in turn, powers a fly-back inductor generating high voltage ac to light a germicidal fluorescent uv bulb with light output at 253.7nm. The bulb is located at the center of the water bottle and can be easily inserted and removed for replacement through the bottom of the bottle. Surrounding the G4T5 bulb is a sleeve that protects the electrodes, prevents buildup on the bulb, and facilitates easy cleaning while transmitting uv light. A calibrated side looking photodiode monitors the delivered uv dose and indicates to the operator when the water is safe to drink.

DRAWINGS

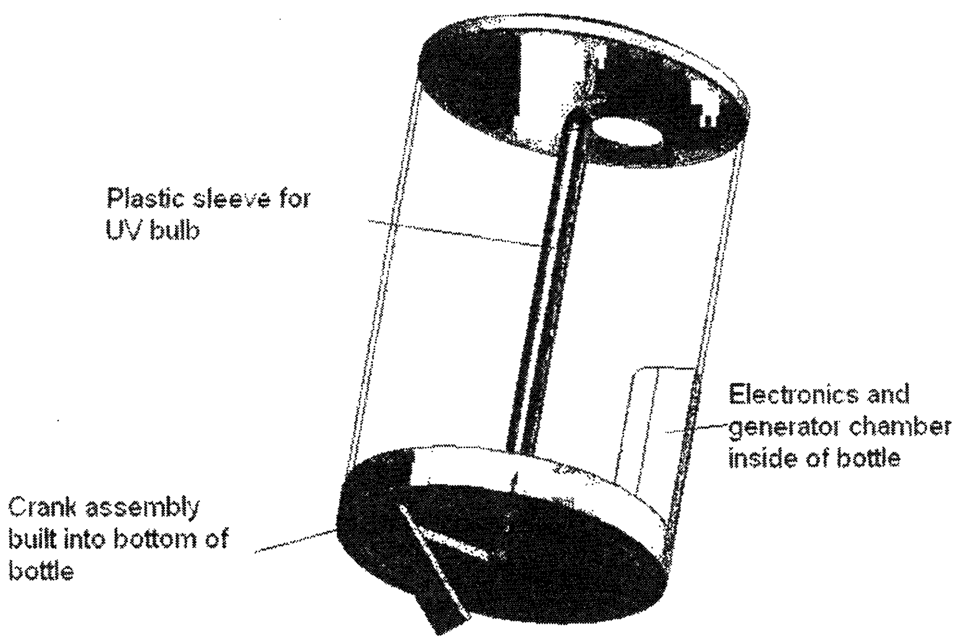


Figure 31 patent diagram 1

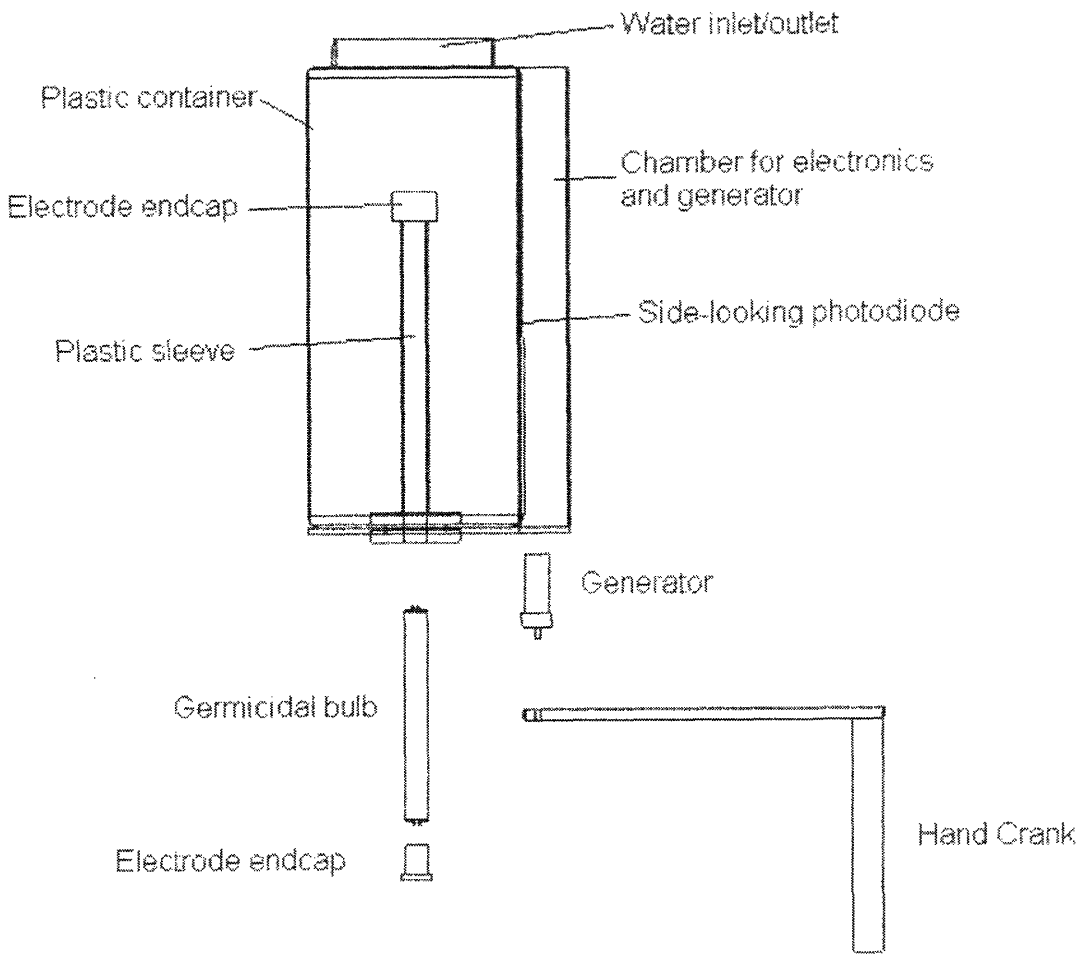


Figure 32: Patent diagram 2

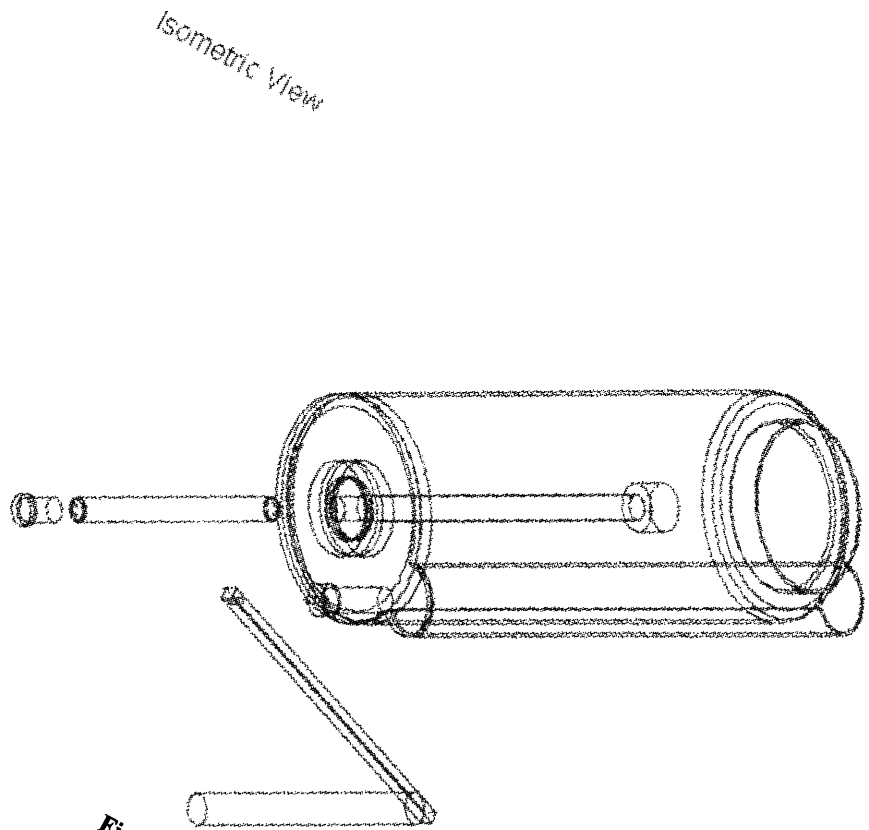


Figure 33 Patent Diagram 3

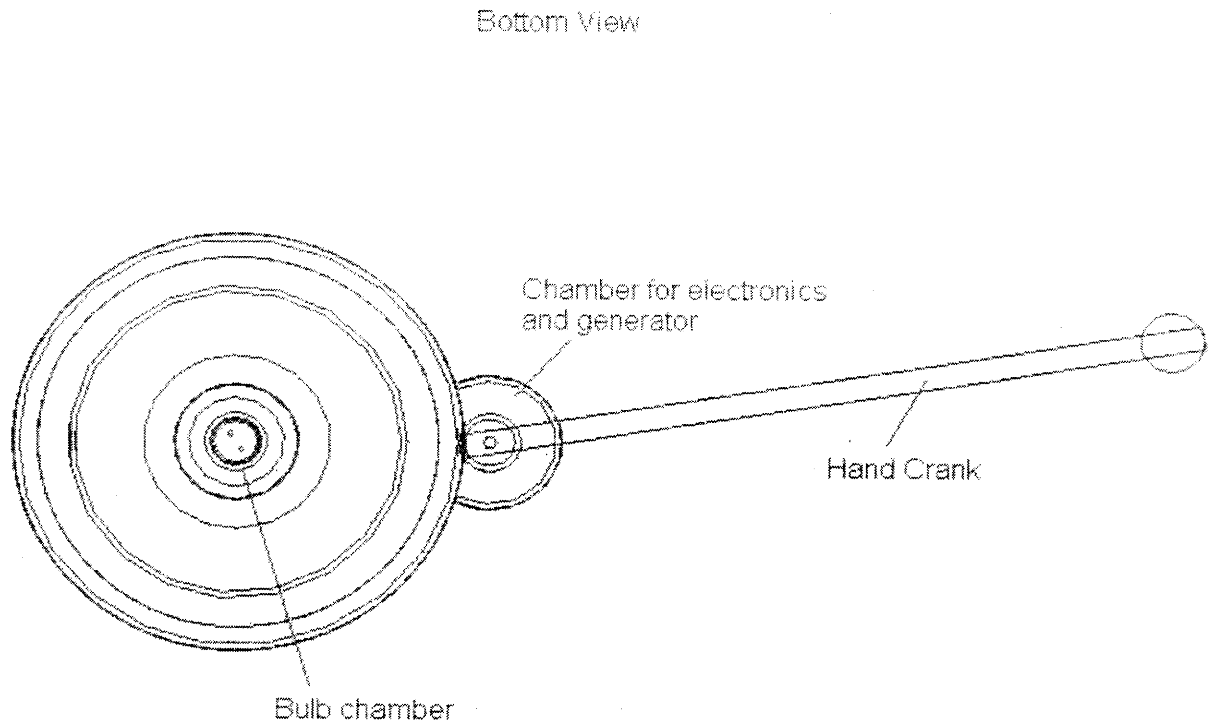


Figure 34 Patent Diagram 4

APPENDIX E: BOSTON HERALD ARTICLE MARCH 26, 2006

MIT innovators' design really holds water

APPENDIX F: MATLAB SCRIPT FOR 3D PLOT

```
bulb_length = 12.7; %cm
% bottle_radius = 4; %cm
bulb_power = 800; %mwatts

aw = 0.01; %cm^-1

dx = 0.01;
%x = -bulb_length/2:dx:bulb_length/2;
%x = (0:dx:bulb_length);
r = 4; %cm
%I in mw/cm2
% I = ((bulb_power/bulb_length)/(4*pi))*sum(0.01./(x.^2+r^2));
% I = ((bulb_power/bulb_length)/(4*pi))*sum( (0.01).*...
%           exp(-aw*sqrt(x.^2+r^2))./(x.^2+r^2));

ictr = 1;
rctr = 1;
for r = 0.675:0.05:4
    for xpos = 0:dx:bulb_length
        xstart = -xpos;
        xend = bulb_length - xpos;
        x = xstart:dx:xend;
        I(rctr,ictr) = ((bulb_power/bulb_length)/(4*pi))*sum(((0.01)./...
            (x.^2+r^2)).*exp(-aw*sqrt(x.^2+r^2)));

        ictr = ictr + 1;
    end
    rctr = rctr + 1;
    ictr = 1;
end


figure, plot(linspace(0,12.7,length(I)),I(1,:));
hold on;
plot(linspace(0,12.7,length(I)),I(2,:));
plot(linspace(0,12.7,length(I)),I(3,:));
plot(linspace(0,12.7,length(I)),I(4,:));
% figure, plot(linspace(0,10,length(I)),I)
title('irradiance along length of bulb at 4cm')

% ictr = 1;
% for r = .1:.1:4
%     Ir(ictr) = ((bulb_power/bulb_length)/(4*pi)).*sum( (0.01).*...
%       exp(-aw*sqrt(x.^2+r^2))./(x.^2+r^2));
%     ictr = ictr + 1;
% end
%
% figure,plot(.1:.1:4,Ir)

[xs,rs] = meshgrid(0:dx:12.7,0.675:0.05:4);
for yy = 1:size(xs,1) %40
    for xx = 1:size(xs,2)
        xstart = 0 - xs(yy,xx);
```

```
        xend = bulb_length - xs(yy,xx);
        x = xstart:dx:xend;
        Imap(yy,xx) = ((bulb_power/bulb_length)/(4*pi))*sum(((0.01)./...
            (x.^2+rs(yy,:).^2)).*exp(-aw*sqrt(x.^2+rs(yy,:).^2)));
    end
end

figure, mesh(xs,rs,Imap);
```

MATLAB Script for 2-D Irradiance plots

```
bulb_length = 12.7; %cm
%bottle_radius = 4; %cm
bulb_power = 800; %mwatts
dx = 0.01;
x = (0:dx:bulb_length);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
aw = 0.01; %cm^-1
%r = 4; %cm I in mw/cm2
%I =((bulb_power/bulb_length)/(4*pi))*sum(0.01./(x.^2+r^2));
%I =((bulb_power/bulb_length)/(4*pi))*sum((0.01).*exp(-aw*sqrt(x.^2+r^2))./
%(x.^2+r^2));
%figure, plot(linspace(0,10,length(x)),I);
%title('irradiance along length of bulb at 4cm')

ictr = 1;
for r = 0.675:.01:4
     Ir(ictr) = ((bulb_power/bulb_length)./(4.*pi)).*...
         sum((0.01./(x.^2+r.^2)).*exp(-aw.*sqrt(x.^2+r.^2)));
     ictr = ictr + 1;
end

figure,plot(.675:.01:4,Ir,'-k','LineWidth',1)

hold on
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%FEP Transmittance Factor...
ictr = 1;
for r = 0.675:.01:4
     Ifep(ictr) = ((0.78*bulb_power/bulb_length)./(4.*pi)).*...
         sum((0.01./(x.^2+r.^2)).*exp(-aw.*sqrt(x.^2+r.^2)));
     ictr = ictr + 1;
end

plot(.675:.01:4,Ifep,':r','LineWidth',2)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%aw = 0.071; %cm^-1 ictr = 1; for r = 0.675:.01:4
%     Ir(ictr) =
%     ((bulb_power/bulb_length)./(4.*pi)).*sum((0.01./(x.^2+r.^2)).*exp(-aw
%     .*sqrt(x.^2+r.^2))); ictr = ictr + 1;
%end
```

```
%
%plot(.675:.01:4,Ir,'-.b','LineWidth',1)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%aw = 0.125; %cm^-1 ictr = 1; for r = .675:.01:4
%     Ir(ictr) =
%     ((bulb_power/bulb_length)./(4.*pi)).*sum((0.01./(x.^2+r.^2)).*exp(-aw
%     .*sqrt(x.^2+r.^2))); ictr = ictr + 1;
%end
%
%plot(.675:.01:4,Ir,':r','LineWidth',1)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%title({'Irradiance vs. Distance for a range of water absorbance
%coefficients'; 'Bulb Power = 800 mW  Bulb Length = 12.7 cm'})
title({'Irradiance vs. Distance - Correcting for FEP Absorbance';...
'Abs coefficient = 0.01cm^-1 Bulb Power = 800 mW Bulb Length = 12.7 cm'})
%legend('0.01cm^-1', '0.071cm^-1', '0.125cm^-1')
legend('Original Value', 'Transmittance Corrected')
xlabel('Radius from center of Bulb (cm)')
ylabel('Irradiance (mW/cm^2)')
```

APPENDIX G: BUSINESS PLAN

TurnPure

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617-407-3752
turnpure@gmail.com

Table of Contents

Executive Summary

Business Description

Turn Pure, Inc. is a privately held, 501c(3) social enterprise founded by two MIT undergraduates and a staff member from Lincoln Laboratories. We have developed a novel hand powered water sterilization system, the PhotoPure PE™, which is capable of destroying 99.999% of waterborne contaminants without the need for electricity. Our business model is simple; profits generated from sales to the military, travel, and outdoor recreation markets subsidize the cost of our products for NGOs and the developing world.

We will offer customers a water purification technology which is faster, safer, and requires less maintenance than any other portable system on the market. Our proprietary SafeMark™ system brings peace of mind to the customer by indicating when the water is fit for consumption. In addition, no power requirement and the very low cost of PhotoPure™ PE makes it ideal for developing countries.

TurnPure, Inc. was recently awarded 1st place in the MIT Institute for Soldier Nanotechnology's annual Soldier Design Competition based on our alpha prototype. Judged by both soldiers/Army personnel and MIT Faculty, every first place winner in the SDC has been awarded an SBIR and in many cases have gone on to secure government contracts. We were also selected as Finalists in the MIT IDEAS competition for socially responsible innovations.

Opportunity Overview and Strategy

We've identified seven potential markets for our device. Four markets have the potential for generating profits, namely customers in the military, outdoor recreation community, travelers to developing countries, and government agencies / employees. Humanitarian aid workers and disaster victims are two markets that would greatly benefit from our technology, but lack purchasing power. The consumer that has access to tap water but chooses bottled water may be placed in either category depending on their income level.

Market Analysis							
		2006	2007	2008	2009	2010	
Potential Customers	Growth						CAGR
Military	0.50%	271,381	272,738	274,102	275,473	276,850	0.50%
Outdoor Recreation	5.00%	31,500,000	33,075,000	34,728,750	36,465,188	38,288,447	5.00%
Travelers to a developing country	5.00%	50,000,000	52,500,000	55,125,000	57,881,250	60,775,313	5.00%
Government Agency	2.00%	100,000	102,000	104,040	106,121	108,243	2.00%
NGOs	1.00%	1,000,000	1,010,000	1,020,100	1,030,301	1,040,604	1.00%
Disaster Victim	0.00%	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	0.00%
Bottled water consumer	10.00%	50,000,000	55,000,000	60,500,000	66,550,000	73,205,000	10.00%
Total	6.48%	142,871,381	151,959,738	161,751,992	172,308,333	183,694,457	6.48%

In the early phases of our company, we will seek out key individuals who can champion our products in each market segment. Most likely, they will be representatives of major players in the markets that will evaluate and provide feedback on our prototypes. Their input will be extremely valuable both in product development and quantification of demand for our technology.

We expect to make our social mission well known through our website, brochures, and labels on the product itself. Socially minded consumers can track our distribution efforts (via our website) and will likely motivate others to purchase our product. Based on the serial number of the device, a consumer can view where we have deployed products funded by his purchase.

We are on our way to securing patents for our devices. Intellectual Property protection will give us the right to exclude other from making, selling, importing, or offering for sale similar products.

Competition and Competitive Advantage

- **Boiling**: The oldest method of water purification. Requires a large energy input and is very inefficient, though a ten minute boil will kill 99.9% of waterborne contaminants. The boil culminates in a long cool down time during which there is a high risk of recontamination. The water also acquires a stale flavor.
- **Chemical tablets:** The industry standard, these tablets are manufactured by numerous companies. Once added to the water, the chemicals activate over time and kill the microorganisms which cause disease. However, the unpleasant taste, long treatment time, risk of re-infection, and health concerns with prolonged use, pave the way for a new sterilization method.
- **Mechanical filtration:** An extremely popular purification method, mechanical pumps push water through micron filters, capturing harmful contaminants. However, the filters

are severely prone to clogging, contain numerous parts that require maintenance/replacement, and cannot remove viruses. Several companies fabricate and sell these filtrations devices, with annual revenues in the hundreds of millions.

- **MIOX™**: This Company offers a unique sterilization technology that uses activated sodium chloride to sterilize water. Major pitfalls of the MIOX™ system include supply-chain dependence (batteries and salt) and long lead time for sterilization (30+ min). Additionally, the cost of the MIOX™ system ($150) detracts from widespread market penetration. In FY2004 MIOX™ reported revenues of $7 million.
- **UV water purification**: Our most direct competitors, these companies sell portable UV water purification devices with expensive non-standard replacement batteries.
    - **Steripen™**: The non-enclosed design methodology for this device produces a high risk of re-contamination and without a dosage feedback, offers little to no assurance of purification. Last year Steripen reported revenues of $1 million, equating to about 7000 units.
    - **Aquastar™:** This design of this device is not nearly robust enough for most outdoor activities, or the market they are attempting to penetrate. Requiring a user to remove the bulb twice with every use creates a high potential for breaking the bulb. Unfortunately, breaking the bulb requires a user to buy a whole new Aquastar unit.
- **Biosand**: This sand filtration method offers a low tech and relatively inexpensive way of cultivating good bacteria to destroy harmful diarrheal bacteria. This filter requires heavy maintenance, but may be able to remove arsenic from the water source. It is not portable but scales to home use. It takes hours to filter through the sand and only rids 90% of the bacteria from the water, not suitable for infants or the elderly. This has extremely low to non existent market penetration thus far.

A Comparision Among Water Purification Systems

Competitors	Supply Chain Independence	Viral Inacti-vation	Portable	Rapid (<1min)	No Toxic By-products	Low Rein-fection risk	Water safety indicator	Durable
Chemical tablets			•					•
Mechanical filtration			•	•	•			•
Boiling		•			•		•	
MIOX		•	•				•	•
Steripen		•	•	•	•			
Aquastar		•	•	•		•		
Biosand	•				•			
TurnPure	•	•	•	•	•	•	•	•

First Product Offering

Our primary mission is to save lives. 41,000 children die each day from symptoms caused by drinking contaminated water. As aid organizations and nations struggle to improve sanitation and water conditions around the world, millions of people are dying. Our team has developed a patent-pending technology that rapidly and effectively purifies water contaminated with bacteria, protozoa, and viruses without using chemicals or battery power. Think of our device as the next-generation water bottle - rugged, lightweight and highly portable with an added benefit: it has an integrated germicidal bulb that is powered via a hand crank generator built into the bottle. Simply pour contaminated water into the bottle, close the top, and turn the generator crank until an indicator light tells you the water is safe to drink. Our current prototype can make 1L of water safe to drink in less than 1 minute.

The beta prototype for PhotoPure™ World is currently under development. This prototype is being built for testing the modularity of our product, so we can serve both military and volunteer customers simultaneously in our first rollout. The two accessories in this rev are a motor assembly enclosure and a battery powered enclosure. The PhotoPure™ product line consists of four main functional components, a UV bulb, a UV photosensor unit, a Flourpolymer sleeve, and support/power supply electronics. Additionally, the power supply accessories consist of four AA batteries and an inline DC motor. Currently, the main work is focused on developing better circuitry for the photodiode sensor, completing DFM criteria on the parts, and finding overseas ISO9001 suppliers for motors and UV bulbs.

Financial Forecast

Pro Forma Cash Flow			
	FY 2007	FY 2008	FY 2009
Cash Received			
Cash from Operations			
Cash Funding	$578,225	$758,075	$1,022,000
Subtotal Cash from Operations	$578,225	$758,075	$1,022,000
Additional Cash Received			
Sales Tax, VAT, HST/GST Received	$28,911	$37,904	$51,100
New Current Borrowing	$0	$0	$0
New Other Liabilities (interest-free)	$0	$0	$0
New Long-term Liabilities	$0	$0	$0
Sales of Other Current Assets	$0	$0	$0
Sales of Long-term Assets	$0	$0	$0
New Investment Received	$0	$0	$0
Subtotal Cash Received	$607,136	$795,979	$1,073,100
Expenditures	FY 2007	FY 2008	FY 2009
Expenditures from Operations			
Cash spending	$25,000	$414,000	$510,000
Bill Payments	$309,960	$232,507	$223,460
Subtotal Spent on Operations	$334,960	$646,507	$733,460
Additional Cash Spent			
Sales Tax, VAT, HST/GST Paid Out	$0	$0	$0
Principal Repayment of Current Borrowing	$0	$0	$0
Other Liabilities Principal Repayment	$0	$0	$0
Long-term Liabilities Principal Repayment	$0	$0	$0
Purchase Other Current Assets	$0	$0	$0
Purchase Long-term Assets	$0	$0	$0
Dividends	$0	$0	$0
Subtotal Cash Spent	$334,960	$646,507	$733,460
Net Cash Flow	$272,176	$149,472	$339,640
Cash Balance	$323,176	$472,648	$812,288

Founders

Gary M. Long –*CEO* –

Gary has led many interdisciplinary teams in engineering design competitions, winning an Advanced E-Team grant from the National Collegiate Inventors and Innovators Alliance for $11,000. Holding a B.S. in Biomedical Engineering from Johns Hopkins University, Gary has been working as an associate staff scientist at MIT Lincoln Laboratory for over 3 years. His creativity and diligence, as well as his unsurpassed engineering abilities make Gary an irreplaceable part of the team.

Chandan Das –*COO* –

As much a entrepreneurial businessman as an MIT engineer. Chandan will bring his experience in running operations for two past startups to TurnPure Inc. Currently a B.Sc. candidate in the Mechanical Engineering Department, his ability to grasp new ideas and his creativity in solving problems are great assets.

Justin Holland –*CTO* –

Justin is a B.Sc. candidate in Mechanical Engineering and Management at MIT. He has worked in the past for a national laboratory and a private defenese R&D contractor, focusing on product design. His unique ability to engineer without losing focus of the business potential makes Justin an integral part of the team.

1. THE BUSINESS & OUR VALUE

1.1 Description

Turn Pure, Inc. is a privately held, 501c(3) social enterprise founded by two MIT undergraduates and a staff member from Lincoln Laboratories. We have developed a novel hand powered water sterilization system, the PhotoPure PE™, which is capable of destroying 99.999% of waterborne contaminants without the need for electricity. Our business model is simple; profits generated from sales to the military, travel, and outdoor recreation markets subsidize the cost of our products for NGOs and the developing world.

1.2 Value Proposition and Social ROI

We will offer customers a water purification technology which is faster, safer, and requires less maintenance than any other portable system on the market. Our proprietary SafeMark™ system brings peace of mind to the customer by indicating when the water is fit for consumption. In addition, no power requirement and the very low cost of PhotoPure™ PE makes it ideal for developing countries.

Financial			Social		
Miltary	**Outdoor Recreation**	**Travel**	**Aid Groups**	**Disaster Victims**	**Bottled water**
• Improve soldier health reducing medical costs • Reduce water costs by $300 per soldier • Military version can run off vehicle power, purify large quantities at a time	• Sustainable access to water • Remove bacteria protozoa and viruses 30x faster than competing technology	• 50,000 cases of travelers' diarrhea occur each day. All are preventable using our device • Convenience and flexibility able to use water from tap	• Prevents Travelers' diarrhea • Save $400 per volunteer per year • Eliminate depende	• Sanitation and drinking water infrastructure breaks down compromises potable water • Receive aid faster	• Our home unit provides a cost effective alter-native to bottled water • Provide safe drinking water to entire families saving > $1000 USD per year • Reduce negative

Figure 35: PhotoPure Advantages

PhotoPure PE will:

- never require battery replacement
- never clog or require expensive filter replacement
- never make water taste like chemical tablets

Our product pipeline contains several other products based around the same core technology for the military, retail consumers, and travelers.

The possibility for our product to save numerous lives is our greatest value proposition. A few disaster refugees displaced from their homes will no longer be left with potable water. A few children forced to drink contaminated water will now have an option. Our product will save lives, and etch away a small piece of this world wide epidemic.

1.3 Current Status

TurnPure, Inc. was recently awarded 1st place in the MIT Institute for Soldier Nanotechnology's annual Soldier Design Competition based on our alpha prototype. Judged by both soldiers/Army personnel and MIT Faculty, every first place winner in the SDC has been awarded an SBIR and in many cases have gone on to secure government contracts. We were also selected as Finalists in the MIT IDEAS competition for socially responsible innovations.

1.4 Current or Committed Funding Sources

We have been awarded $11500 in cash to progress our prototype as well as in-kind services totaling $5000.

2. THE MARKET OPPORTUNITY

2.1 The Problem

Improving access to safe drinking water is probably the greatest health issue in the world. 1.1 billion people, almost 1/5th of the world's population do not have access to a safe and reliable source of water. Though our technology cannot solve the world's water problems, there are specific groups that we can help.

2.2 Identification of Customers

A. Earned Income Markets

i. Military

U.S. active military personnel deployed overseas represent a market of over a quarter of a million people. Remotely located and often at the mercy of lengthy supply chains, the military needs a portable water purification technology that does not consume scarce resources. The Institute for Soldier Nanotechnology inspired our company to come up with a solution to this problem during the 3rd annual Soldier Design Competition. Our technology was well received, winning first place in the competition. Influential contacts were formed giving us an entry to a solid first customer. [1]

ii. Government agency

We will offer our product for purchase from government agencies under the GSA purchasing program (general services administration). GSA provides assistance to federal employees, vendors and citizens. Employees working for the Department of Homeland Defense, for example, may want to purchase our purification unit as part of their disaster first aid kit.

For more information on products available for GSA purchase, visit http://www.gsa.gov and https://www.gsaadvantage.gov

iii. Outdoor Recreation

According to the Nationwide Survey on Recreation and the Environment (NSRE), 37 percent of Americans participated in some form of adventure outdoor recreation. In 1994, almost one in four Americans went hiking, a total of almost 48 million people. 15 million Americans participated in backpacking, almost 8 percent of the population. Backpacking saw a 73% increase in participants between 1983 and 1994. Rock climbing and mountain climbing, both highly technical and specialized activities, were performed by 7.5 million and 9 million Americans respectively. The hiking community saw the greatest increase in participant out of all other human powered activities between 1983 and 1994 at 93.5 percent.

Sadly, most of our country's surface water sources - our lakes, rivers, and streams - are unsafe to drink. This forces outdoor enthusiasts to either carry bottled water with them or resort to a water purification technology. [2]

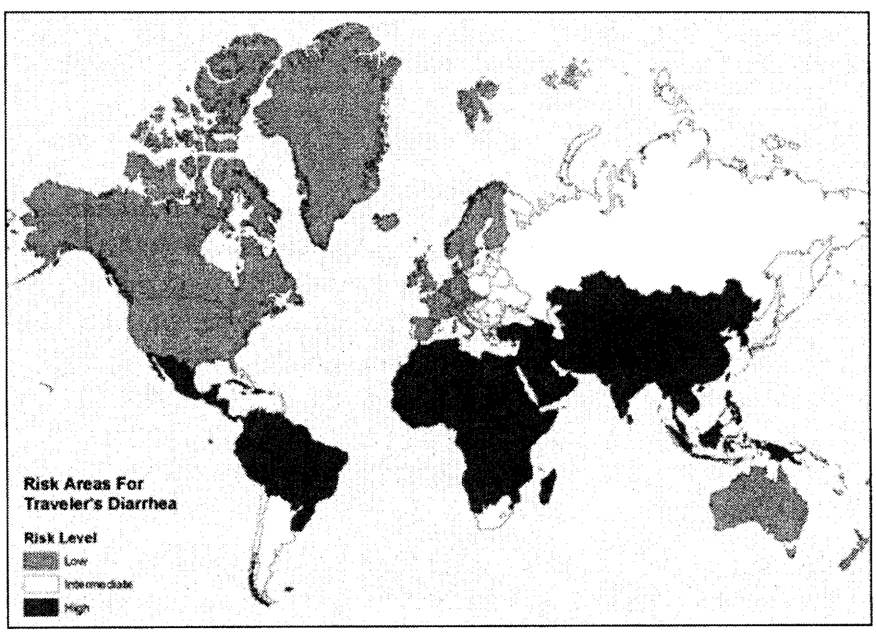
iv. Foreign Travel

The economic impact of travelers' diarrhea (TD) is substantial, because fear of sickness is one of the major deterrents to tourism. According to the World Tourism Organization, 698 million people traveled to a foreign country in 2000, spending more US$ 478 billion [4]. This makes tourism a major influence in a nation's economy. For a developing nation, tourism takes on an even greater importance.

Traveler's diarrhea usually begins abruptly while traveling or shortly after you return home. Exposure to food or water contaminated with Enterotoxigenic Escherichia coli (E.Coli) or ETEC is to blame. ETEC attaches to the intestinal lining and releases a toxin that causes a number of symptoms. These symptoms include loose stools, cramps, nausea, and vomiting. Most cases take three to four days for symptoms to subside without medical treatment. However, you can have multiple episodes of traveler's diarrhea during one trip. Residents of high-risk countries are not affected in the same way because their bodies have become accustomed to the bacteria and have developed an immunity to them. [5].

Certain members of the population have a higher risk of infection than others. They include children and young adults, travelers, people with weakened immune systems, antacid users, and people with diabetes or inflammatory bowel disease. [6]

On average, 30%-50% of travelers to high-risk areas will develop Traveler's Diarrhea (TD) during a 1- to 2-week stay. Based on the annual figure of 50 million travelers to developing countries, this estimate translates to approximately 50,000 cases of TD each day. In more temperate regions, there may be seasonal variations in diarrhea risk. In South Asia, for example, during the hot months preceding the monsoon, much higher TD attack rates are commonly reported. [3]



B. Developmental / Social Market

i. Aid Worker

Aid workers provide disaster relief, health services, peacekeeping support, and education to millions of at need people around the world. Like the military, these individuals are often stationed overseas, far removed from supplies and reliable water sources. They also face similar supply problems that put a heavy strain on their operational budgets. Aid organizations operate under very limited budgets and often require the workers to provide food and water for themselves.

Organization	Number of volunteers	Source
Peace Corp	7,810	[7]
Mercy corps	2,700	[8]
Red Cross	175,000	[9]
UN Peacekeeping	88,297	[10]
UNICEF	> 1,000,000	[11]

Figure 37: Aid Organizations at a Glance

ii. Disaster Victims

Recent national disasters like the 2004 tsunami disaster, Hurricane Katrina, and the earthquake in Pakistan have highlighted the importance of supplying people with immediate access to safe water. Displaced victims of natural disasters live in crowded camps marked by unsafe water and poor sanitation making it a breeding ground for Water-borne illnesses. Recurring tragedies result in millions of people placed in this situation every year.

Following a natural disaster, the three top priorities are the provision of sufficient quantities of safe water, establishment of basic sanitation arrangements, and the promotion of good hygiene practices.

Providing an adequate quantity of water is the most important priority, even if its safety cannot be guaranteed, and to protect the sources from contamination. According to SPHERE (Humanitarian Charter and Minimum Standards in Disaster Response), a minimum of 15 liters (4 Gallons) per person per day should be provided as soon as possible. During emergencies, people may use an untreated water source for laundry, bathing, etc to conserve treated water for drinking. [12]

iii. Bottled water consumer (primary water source)

Many people living in households that have tap water sources turn to bottled water because they believe their tap water is unsafe. Companies like Coca-Cola and Nestle have launched campaigns designed to sway consumer confidence away from tap water. The truth is that the bottled water industry is highly unregulated and may not be safer than tap water in some locations. Water tables are shrinking in areas that are mined for water that is shipped worldwide. Fossil fuels are used in both the distribution and production of plastic water bottles. The most commonly used plastic for making water bottles is polyethylene terephthalate (PET) is derived from crude oil. Making bottles to meet Americans' demand for bottled water requires more than 1.5 million barrels of oil annually, enough to fuel 100,000 U.S. cars for a year. Worldwide, some 2.7 million tons of plastic are used to bottle water each year. 86 percent of plastic water bottles used in the United States become garbage or litter that take 1000 years to degrade in landfills. Global dependence on bottled water is depleting our natural resources and polluting our world.

Bottled water costs more than gasoline and 10,000 times more than tap water. In Mexico, for example, all but the poorest buy bottled water, while Mexican tap water has gotten dramatically cleaner in recent decades, especially in the cities. Mexico City has a population of 17 million people. [13]

http://www.irc.nl/page/26315

2.3 Market Size and Forecast

Market Analysis

		2006	2007	2008	2009	2010	
Potential Customers	Growth						CAGR
Military	0.50%	271,381	272,738	274,102	275,473	276,850	0.50%
Outdoor Recreation	5.00%	31,500,000	33,075,000	34,728,750	36,465,188	38,288,447	5.00%
Travelers to a developing country	5.00%	50,000,000	52,500,000	55,125,000	57,881,250	60,775,313	5.00%
Government Agency	2.00%	100,000	102,000	104,040	106,121	108,243	2.00%
NGOs	1.00%	1,000,000	1,010,000	1,020,100	1,030,301	1,040,604	1.00%
Disaster Victim	0.00%	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	0.00%
Bottled water consumer (primary water source)	10.00%	50,000,000	55,000,000	60,500,000	66,550,000	73,205,000	10.00%
Total	6.48%	142,871,381	151,959,738	161,751,992	172,308,333	183,694,457	6.48%

Figure 38: Market Size Analysis

2.4 Industry Analysis

Portable water purification is a vastly decentralized industry composed of relatively small companies offering substitutable products. Dated technologies, such as chemical tablets and mechanical filtration, are the dominant industry solutions, with only three small companies offering innovative portable water purification systems. Those dominant solutions represent over 95% of the total sales in this market and with the current alternative solutions, it is no wonder.

3. MARKET SOLUTION

3.1 Product Offering

Our company offers a full range of water sterilization products to a broad set of customers. Utilizing proven ultraviolet technology, each TurnPure product is designed to purify contaminated water faster, and with more safety loops, than any current portable sterilization device on the market.

3.2 UV Technology

At a molecular level, ultraviolet light breaks down, or denatures, the DNA of the waterborne contaminants. In water, the three main categories of contaminants, protozoa, bacteria, and viruses, require very different doses of ultraviolet light for DNA breakdown. Therefore, our baseline UV application is set at the waterborne contaminant requiring one of the highest UV doses (presently nematode eggs at ~100,000 mw*s/cm^2). With this set UV dose, our safety loop actively measures the instantaneous dosage and gives the user complete confidence that the water is completely sterilized. All of our devices will exceed the limits imposed by NSF/ANSI standard 55 for UV purification equipment.

3.3 Product Lines

i. PhotoPure™

Essentially the next-generation water bottle - rugged, lightweight and highly portable with an added benefit: it has an integrated germicidal bulb that is powered via a hand crank generator/power supply built into the bottle. Simply pour contaminated water into the bottle, close the top, flip a switch or turn the generator crank until an indicator light tells you the water is safe to drink. Our current prototype is biologically tested and can make 1L of water safe to drink in less than 1 minute. On top of this, the hand crank generator can be outfitted with numerous accessories to charge, or power, any device. This line will be sold to the whole consumer market; however, will be the workhorse of our charitable device distribution and the international travel market.

ii. SpiralPure™

This line will rapidly fill any reservoir, such as CamelBaks™, buckets, or water buffalos with sterilized water for near instantaneous consumption. The product line is divided among portable and stationary units, scaled for individual market needs. The portable units will be heavily marketed to the military and recreational hikers, ideally replacing iodine tablets or MIOX™ systems presently employed by the armed services. Currently, as explained later, service men and women wait 30 minutes for their current water sterilization methods to work; our system will fill their canteen in less than a minute. The stationary unit will serve purposes in both developing countries and military missions, rapidly outputting large amounts of water for a village or military base. This version will be able to run either from a vehicle, battery, generator power, or be easily retrofitted for human generated power.

iii. HomePure™

TurnPure's inexpensive wall unit is ideal for countries where consumer confidence in the public water supply is low. In Mexico City for example, 95% of the city's public water is safe to drink, however confidence is so low, that people purchase bottle water instead as their primary potable water source. A simple wall mounted unit, similar to water dispensers on refrigerators, supplies sterilized water at a flow rate similar to faucet taps. A user needs only to place the HomePure™ unit close to a water source and power outlet.

3.4 Competitive Analysis

- **Boiling**: The oldest method of water purification. Requires a large energy input and is very inefficient, though a ten minute boil will kill 99.9% of waterborne contaminants. The boil culminates in a long cool down time during which there is a high risk of recontamination. The water also acquires a stale flavor.
- **Chemical tablets:** The industry standard, these tablets are manufactured by numerous companies. Once added to the water, the chemicals activate over time and kill the microorganisms which cause disease. However, the unpleasant taste, long treatment time, risk of re-infection, and health concerns with prolonged use, pave the way for a new sterilization method.
- **Mechanical filtration:** An extremely popular purification method, mechanical pumps push water through micron filters, capturing harmful contaminants. However, the filters are severely prone to clogging, contain numerous parts that require maintenance/replacement, and cannot remove viruses. Several companies fabricate and sell these filtrations devices, with annual revenues in the hundreds of millions.
- **MIOX™**: This Company offers a unique sterilization technology that uses activated sodium chloride to sterilize water. Major pitfalls of the MIOX™ system include supply-chain dependence (batteries and salt) and long lead time for sterilization (30+ min). Additionally, the cost of the MIOX™ system ($150) detracts from widespread market penetration. In FY2004 MIOX™ reported revenues of $7 million.
- **UV water purification**: Our most direct competitors, these companies sell portable UV water purification devices with expensive non-standard replacement batteries.
  - **Steripen™**: The non-enclosed design methodology for this device produces a high risk of re-contamination and without a dosage feedback, offers little to no assurance of purification. Last year Steripen reported revenues of $1 million, equating to about 7000 units.
  - **Aquastar™:** This design of this device is not nearly robust enough for most outdoor activities, or the market they are attempting to penetrate. Requiring a user to remove the bulb twice with every use creates a high potential for breaking the bulb. Unfortunately, breaking the bulb requires a user to buy a whole new Aquastar unit.
- **Biosand**: This sand filtration method offers a low tech and relatively inexpensive way of cultivating good bacteria to destroy harmful diarrheal bacteria. This filter requires heavy maintenance, but may be able to remove arsenic from the water source. It is not portable but scales to home use. It takes hours to filter through the sand and only rids 90% of the bacteria from the water, not suitable for infants or the elderly. This has extremely low to non existent market penetration thus far.

3.5 Competitive Advantage

A Comparision Among Water Purification Systems

Competitors	Supply Chain Independence	Viral Inacti-vation	Portable	Rapid (<1min)	No Toxic By-products	Low Rein-fection risk	Water safety indicator	Durable
Chemical tablets			•					•
Mechanical filtration			•	•	•			•
Boiling		•			•		•	
MIOX		•	•				•	•
Steripen		•	•	•	•			
Aquastar		•	•	•		•		
Biosand	•				•			
TurnPure	•	•	•	•	•	•	•	•

4. OUR STRATEGY

4.1 Market Penetration

In the early phases of our company, we will seek out key individuals who can champion our products. Most likely, they will be representatives of major markets that will evaluate and provide feedback on our prototypes. Their input will be extremely valuable both in product development and quantification of demand for our technology.

We expect to make our social mission well known through our website, brochures, and labels on the product itself. Socially minded consumers can track our distribution efforts (via our website) and will likely motivate others to purchase our product. Based on the serial number of the device, a consumer can view where we have deployed products funded by his purchase.

4.2 Barriers to Entry

We are on our way to securing patents for our devices. Intellectual Property protection will give us the right to exclude other from making, selling, importing, or offering for sale similar products.

5. PRODUCT DESIGN AND DEVELOPMENT PLANS

5.1 Development Status and Tasks

The beta prototype for PhotoPure™ World is currently under development. This prototype is being built for testing the modularity of our product, so we can serve both military and volunteer customers simultaneously in our first rollout. The two accessories in this rev are a motor assembly enclosure and a battery powered enclosure. The PhotoPure™ product line consists of four main functional components, a UV bulb, a UV photosensor unit, a Flourpolymer sleeve, and support/power supply electronics. Additionally, the power supply accessories consist of four AA batteries and an inline DC motor. Currently, the main work is focused on developing better circuitry for the photodiode sensor, completing DFM criteria on the parts, and finding overseas ISO9001 suppliers for motors and UV bulbs.

5.2 Current Design Goals

- Decrease losses in the photodiode support circuitry
- Evaluate beta prototype's modularity

- Design a more ergonomic and low profile hand crank
- Refine production model with beta prototype feedback
- Test robustness of design with drop tests
- Optimize motor wattage and rpm to better match the needs of the UV bulb to increase life
- Begin alpha prototype of SpiralPure™
- Meet with a design specialist to increase sex appeal
- Increase functionality of motor circuitry to allow in situ charging and powering of a DC device
- Accessorize charging functionality with DC output connectors

5.3 Difficulties and Risks

- Ensure water tightness at the modular connector seam and the sleeve contact
- Designing, with DFM in mind, the fixture for holding and connecting the UV bulb inside the bottle
- Meeting all the needs of the military, they ask the world
- Keeping in mind that the developing countries offer very extreme conditions

5.4 New Products

a) SpiralPure™

A flowthrough device that will use FEP tubing coiled around a UV bulb. Primarily targeted to the profit market, the device will be the size of similar outdoor filter devices and will likely use a rechargeable power supply for the UV bulb. For the water flow, a hand powered vacuum pump or gear pump will be used. Most importantly, this flow must stay under a maximum threshold to allow the water sufficient UV exposure, most likely fulfilled by flow restrictors. The output side will be sold with connector accessories for common threaded containers such as CamelBaks™ or Nalgene™ bottles. We expect this line to follow our first product rollout by six months.

b) HomePure™

Similarly, HomePure™ will also be a flowthrough device and use similar technology to SpiralPure™. This device will be wall-mounted and requires a power source and a nearby water supply. Higher rated UV bulbs will be required, along with switching the FEP tubing to a quartz crystal for increasing transmittance and easy periodic maintenance. This product line will be designed concurrently with SpiralPure™, however, will require more R&D and added functionality, lagging behind by three extra months.

5.5 Manufacturing Strategy

Initially we will use North American manufacturing facilities either in the US or Mexico for fast delivery time to speed up our time to market. Fast injection molding prototype facilities with soft Aluminum tooling offer very competitive prices in the US and will likely be used to produce our very first product line. However, considering cost and demand, we will likely contract out the injection mold tooling abroad to Asia for the next rollout. Depending on demand for each product, we will then plan to shift certain product lines completely abroad, with assembly plants still in the US.

5.6 Facilities Required

We will require simply a building for assembly. In the beginning we plan on using our office space, but eventually we will move the assembly work to a small warehouse. We plan on looking into commercial real estate for our office in Cambridge and eventually renting warehouse space off I-95 or possibly I-495.

5.7 Quality Assurance

Before production we will ensure that each product line is given an EPA certification for microbiological organism purification. On the contract side, we will deal solely with ISO equivalent manufactures abroad. In the assembly plant, we will test each product before it leaves our facility in component sets for quality control. The nature of our safety loop allows us to easily check if our product is in working order before it goes out the door. After traction is gained, we plan to receive ISO 900x compliancy in our own assembly plant to bolster our chances at receiving government and international contracts.

5.8 Organizational Issues

Our Chief Operating Officer is responsible for the implementation of our manufacturing plan. Our CEO will be responsible for securing manufacturing contracts with fabrication plants and securing an overseas partner for DC motors, UV bulbs, flouropolymer tubing, and any future needs. The COO will ensure that those companies comply with their contracts and that our assembly team is given all the necessary parts without having to wait for lagging deliverables. While being responsible for identifying problems in the supply chain, the COO will also constantly look for more cost effective solutions for the next rollouts. Furthermore, working with the VP of Engineering, he will oversee the transition of R&D efforts to full scale manufacturing.

5.9 Resources

We are currently looking for an Enterprises Resource Planning (ERP) inventory management system and hope to have a full business ERP system by August. With regards to money, we have a relative idea of how much up front cash we need for initial product rollout. Referencing Exhibit 5-1, PhotoPure™ World will require approximately $29,000 to have the necessary tooling fabricated. This initial investment includes 25 runs for each part, and will be used to insure that all the pieces fit together in the desired fashion and as preliminary product testing before investing in a full scale run. We will require approximately another $13,000 for a run of 1000. Including the front end design and cost, we expect to budget $125,000 for this product line for the first 12 months of being on the market. With the budget we plan to produce up to 6000 bottles in two large runs, an initial run at 1000 units, following up with a run number depending on market traction.

	Initial Investment			
Runs	25	1000	5000	10000
Injection Molding				
Tooling	18200	0	0	0
Assembly Cost		136	678	1356
Processing Costs		502	2510	5020
Motors	113	4500	22500	45000
Uv bulbs	56	2250	11250	22500
Pre filters	38	1500	7500	15000
Electronics	200	1150	5750	11500
Overhead		1048	5242	10484
subtotal	18606	11086	55430	110860
Accessories				
Enclosure M	5000	258	1292	2584
Enclosure B	2600	118	590	590
Subtotal	7600	376	1882	3175
Total w/ 10% addition	28827	12609	63044	125438

Our initial investment produces the tooling needed for secondary runs. For further explanation of these number see Appendix B

5.10 Assembly steps overview for PhotoPure™ World:

13) Receive parts via freight to our assembly location, add to ERP software
14) Test the UV bulb, photodiodes, support circuitry and accessory power supplies in sets for QC
15) Snap fit electronic circuit board to bottle fixture
16) Run photodiode through the bottle and snap fit in place
17) Place UV bulb inside bottle fixture
18) Slip sleeve over bulb
19) Seal sleeve with intrinsic Bottle features
20) Assemble motor to Enclosure M
21) Screw on either accessory enclosure
22) Connect power leads from the batteries or motor to circuit board
23) Add filter bag and instructions to box, package, ship

6. MANAGEMENT TEAM

6.1 Founders

Gary M. Long *–CEO –*

Gary has led many interdisciplinary teams in engineering design competitions, winning an Advanced E-Team grant from the National Collegiate Inventors and Innovators Alliance for $11,000. Holding a B.S. in Biomedical Engineering from Johns Hopkins University, Gary has been working as an associate staff scientist at MIT Lincoln Laboratory for over 3 years. His creativity and diligence, as well as his unsurpassed engineering abilities make Gary an irreplaceable part of the team.

Chandan Das *–COO –*

As much a entrepreneurial businessman as an MIT engineer. Chandan will bring his experience in running operations for two past startups to TurnPure Inc. Currently a B.Sc. candidate in the Mechanical Engineering Department, his ability to grasp new ideas and his creativity in solving problems are great assets.

Justin Holland *–CTO –*

Justin is a B.Sc. candidate in Mechanical Engineering and Management at MIT. He has worked in the past for a national laboratory and a private defense R&D contractor, focusing on product design. His unique ability to engineer without losing focus of the business potential makes Justin an integral part of the team.

6.2 Board of Advisors

Gen. Charles Holland, Ret. – Chairman of the Board –
Currently a retired four star general in the U.S. Armed Forces, Gen. Holland directed SOCOM for three years through many campaigns. He currently serves on the board of advisors for many defense contractors. His extensive contacts in the U.S. Armed Forces and knowledge of the system will help us tremendously when obtaining military contracts.

Pramod Das – Board Member –

Holding an MBA from the Indian Institute of Management, Mr. Das currently serves as the Commissioner of Commercial Taxes for the Government of Madhya Pradesh, India. Mr. Das has held many positions in the local and national governments of India. His extensive knowledge of the Indian business environment and his ability to cut through the red tape in India, added to his entrepreneurial mindset makes Mr. Das an invaluable board member.

Maude Barlow – Board Member –

Maude Barlow is the National Chairperson of The Council of Canadians, Canada's largest citizen's advocacy organization with members and chapters across Canada as well as the co-founder of the Blue Planet Project, which works to stop commodification of the world's water. Her political and NGO connections will assist us in setting up distribution channels and find an adequate CEO.

7. FINANCIAL ANALYSIS

7.1 Startup Costs

Start-up Funding	
Start-up Expenses to Fund	$44,500
Start-up Assets to Fund	$34,500
Total Funding Required	$79,000
Assets	
Non-cash Assets from Start-up	$14,500
Cash Requirements from Start-up	$20,000
Additional Cash Raised	$31,000
Cash Balance on Starting Date	$51,000
Total Assets	$65,500
Liabilities and Capital	
Liabilities	
Current Borrowing	$0
Long-term Liabilities	$0
Accounts Payable (Outstanding Bills)	$0
Other Current Liabilities	$10,000
Total Liabilities	$10,000
Capital	
Planned Investment	
SBIR phase 1	$100,000
SBIR phase 2	$0
Additional Investment Requirement	$0
Total Planned Investment	$100,000
Loss at Start-up (Start-up Expenses)	($44,500)
Total Capital	$55,500
Total Capital and Liabilities	$65,500
Total Funding	$110,000

Figure 39: Startup Costs

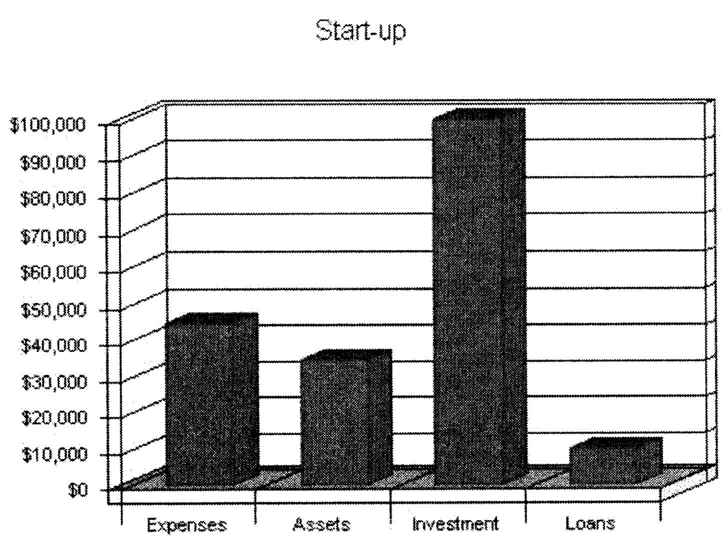


Figure 40: Allocation of Startup Costs

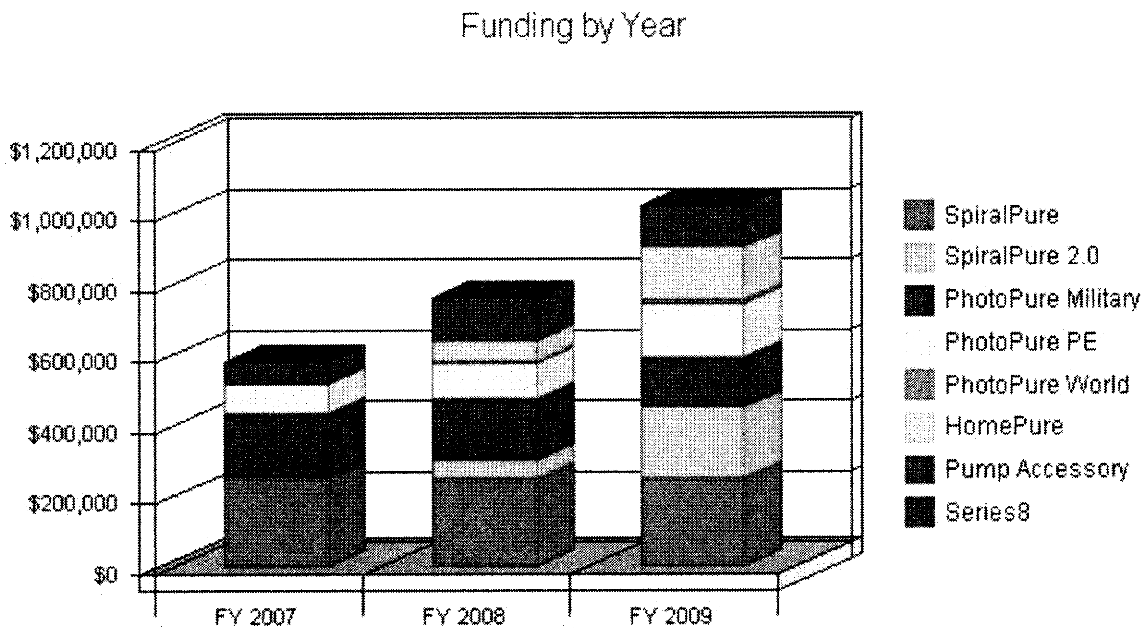


Figure 41: Funding By Year

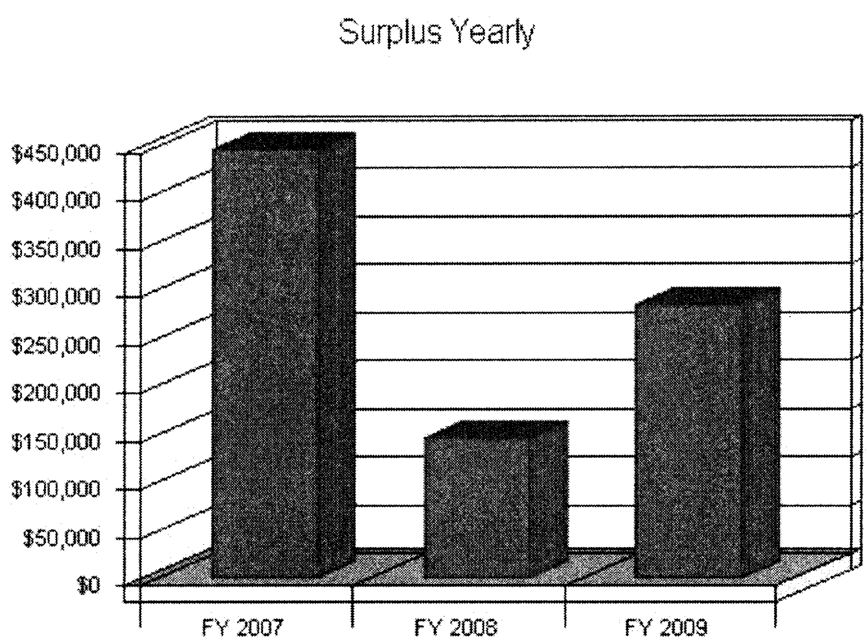


Figure 42: Yearly Surplus

Pro Forma Cash Flow			
	FY 2007	FY 2008	FY 2009
Cash Received			
Cash from Operations			
Cash Funding	$578,225	$758,075	$1,022,000
Subtotal Cash from Operations	$578,225	$758,075	$1,022,000
Additional Cash Received			
Sales Tax, VAT, HST/GST Received	$28,911	$37,904	$51,100
New Current Borrowing	$0	$0	$0
New Other Liabilities (interest-free)	$0	$0	$0
New Long-term Liabilities	$0	$0	$0
Sales of Other Current Assets	$0	$0	$0
Sales of Long-term Assets	$0	$0	$0
New Investment Received	$0	$0	$0
Subtotal Cash Received	$607,136	$795,979	$1,073,100
Expenditures	FY 2007	FY 2008	FY 2009
Expenditures from Operations			
Cash spending	$25,000	$414,000	$510,000
Bill Payments	$309,960	$232,507	$223,460
Subtotal Spent on Operations	$334,960	$646,507	$733,460
Additional Cash Spent			
Sales Tax, VAT, HST/GST Paid Out	$0	$0	$0
Principal Repayment of Current Borrowing	$0	$0	$0
Other Liabilities Principal Repayment	$0	$0	$0
Long-term Liabilities Principal Repayment	$0	$0	$0
Purchase Other Current Assets	$0	$0	$0
Purchase Long-term Assets	$0	$0	$0
Dividends	$0	$0	$0
Subtotal Cash Spent	$334,960	$646,507	$733,460
Net Cash Flow	$272,176	$149,472	$339,640
Cash Balance	$323,176	$472,648	$812,288

Figure 43: Pro Forma Cash Flow

Highlights

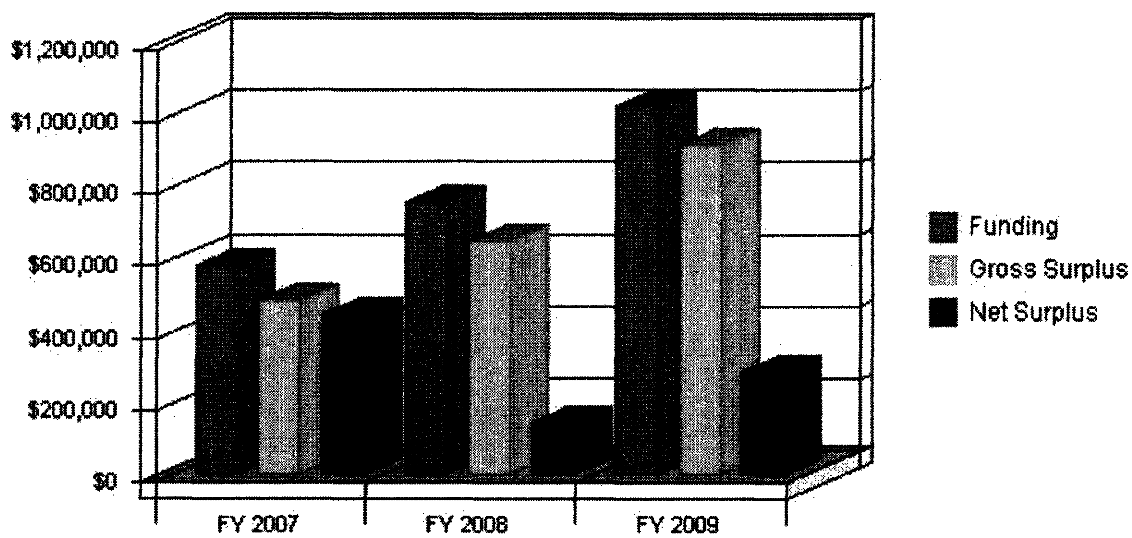


Figure 44: Financial Highlights

8. FUNDING REQUEST

We are seeking $110,000 in startup funding

BUSINESS PLAN ENDNOTES

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[3] http://www2.ncid.cdc.gov/travel/yb/utils/ybGet.asp?section=dis&obj=travelers_diarrhea.htm&cssNav=browseoyb

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