H_2ydratiOn®: a Sulfur-Adsorbent Water Filter

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DIAMOND CHALLENGE FOR HIGH SCHOOL ENTREPRENEURS

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Executive Summary

From April, 2014, to October, 2015, residents of Flint, Michigan, gradually noticed growing problems in their drinking water; many recall apparent discoloration and an odd taste. In 2015, tests by the EPA found dangerous levels of lead in the city's supply of drinking water. A class-action lawsuit against the state followed, along with allegations that the state did not treat the water with an anti-corrosive agent. Meanwhile, Flint's citizens were left with dirty water and the certainty of future health problems. Amidst the crisis, only one thing was certain: the people of Flint could not remove the lead from their water in a fast, affordable way.

H_2ydratiOn® is a revolutionary filter that effectively removes heavy metals from water. It utilizes modified plant material that is carefully crafted using a novel synthesis procedure to bring the consumer pure, clean water. It overcomes traditional methods by being biodegradable, lightweight, and inexpensive to produce. Through its unique functionality, it can appeal to a market which prioritizes healthy living.

1. Customer Profile

According to the Environmental Protection Agency, roughly 18 million Americans (5.51% of the total U.S. Population) live in areas where water systems are contaminated with a dangerously high level of lead. Furthermore, CNN reported that agencies involved with detecting this contamination have failed to do so reliably, suggesting that millions more could be at risk[1]. Flint, Michigan, a city with a population of nearly 100,000, was infamously ravaged by water with lead levels 300 times above the threshold limit for what is generally considered safe[2]. However, it was not even listed as having violated the EPA's lead rule. Thus evidence suggests that lead contamination could be a problem that is ubiquitous across the United States.

These data only account for the United States; of the 9,087 billion gallons of water consumed per year, the US uses about 1/9 of it[3]. Considering that the rate of lead contamination in water is much worse worldwide than in the US, using the US' contamination rate would provide a conservative estimate of the potential market size. With 5.51% of Americans known to be at risk, the most conservative estimate for the global market would total 410 million (calculated using a world population of 7.5 billion)[4]. It is likely, however, that the true global market is several times this size, due to a combination of poor conditions in underdeveloped countries and a lack of proper detection of failing water systems.

2. The Problem

Currently, over 5,300 US water systems are known to be in violation of EPA standards regarding metals like mercury, arsenic, and lead. This places millions of Americans at risk for heavy metal poisoning. Specifically, lead, a naturally occurring metal, is toxic to humans when blood levels are over 5 micrograms per deciliter (μg/dL). Too much consumption damages all major body systems, leading to nervous system, heart, and kidney failure. It is especially devastating in children, causing behavioral problems, lower IQ, slowed growth, and hearing problems. More recent studies have connected lead exposure to long-term degenerative neurological disorders, including Alzheimer's, Parkinson's disease, and muscular dystrophy[5].

Lead contamination in water poses a serious threat to communities worldwide. Lead enters drinking water through the corrosion of plumbing materials (especially water pipes). Homes built before 1986 are at a high risk for contamination, as older houses were built with lead pipes and fixtures. However, the EPA found that even the legally "lead-free" pipes of newer houses may contain 8% lead. Additions to the Safe Drinking Water Act reduced the maximum allowable concentration of lead in pipes, however, as noted in the crisis in Flint, Michigan, many dangerous pipes remain undetected[5].

Most consumer water filters, including Brita and Pur, employ activated carbon filtering. While activated carbon effectively removes organic compounds from water, it does not remove lead or other heavy metals. In order for activated carbon to remove heavy metals, it must be further treated with acids, ultimately increasing cost. New methods must be developed that can effectively filtrate water without incurring additional costs to the consumer.

3. The Solution

In order to prevent more crises like that of Flint, we created an adsorbent filter which effectively removes heavy metals from water. This filter, named H_2ydratiOn®, is a breakthrough in filtration technology, and it overcomes the disadvantages of current filtering methods by employing several key concepts. To begin, this filter operates on the basis of sulfur chemistry; sulfur readily binds to the metals that humans consider dangerous, such as lead (II), cadmium (I), mercury (II), arsenic (III, V), chromium (III to VI), zinc (II), nickel (II, III), and cobalt (I, III). In addition, the synthesis reaction, or the reaction to produce our filter, is quite simple to carry out, aiding in scalability. We have limited the number of reactants (chemicals) used during synthesis to decrease the synthesis cost and increase commercial viability. The resulting product is lightweight and does not require the use of heavy equipment that might impede accessibility. Anybody can use the filter without prior knowledge of how sulfur-adsorbent filters operate. The filter must be environmentally friendly by being both biodegradable and sourced from relatively innocuous chemicals.

a. Ingredients

i. The ingredients of a H_2ydratiOn® filter demonstrate how accessible and inexpensive production is. The filter consists of the following compounds: Cellulose, which is found in plants and is essentially free; Cysteine, which is a ubiquitous chemical because it is an amino acid; 1,1' Carbonyldiimidazole, which is an organic chemical commonly used in linking amino acids together; and Dimethyl Sulfoxide, which is a solvent commonly used in medicine synthesis.

b. Synthesis Process

i. As previously mentioned, the synthesis procedure is simple and inexpensive, leaving high potential for scalability.
ii. Cellulose and 1,1' carbonyldiimidazole is added in 5 mL Dimethyl Sulfoxide. The solution is stirred for 2 hours in the absence of light at 60°C under inert (nonreactive) gas.
iii. Cysteine is added and mixed for 24 hours.

c. Proof of Concept

i. To test this product, copper was utilized as the heavy metal for prototyping because of legal concerns involving minors working with toxic metals like lead. Copper, however, reacts identically as lead does, so these test results apply to lead.
ii. In a controlled experiment, the filter was shown to be effective in removing copper from water (**Supporting Document for results)**
   1. According to the EPA, the toxic effects of copper can be felt at 1300 micrograms per liter. Our filtering method has been experimentally shown to remove up to 1800 micrograms of copper per gram of filtering material. In short time, as the synthesis reaction becomes more efficient, this figure will increase by a large factor

4. Unique Value Proposition

H_2ydratiOn® possesses an advantage over every other major consumer water filter on the market: its ability to filter out lead and other heavy metals. Because our filter removes a wide variety of heavy metals from water, and because the price to produce the filter can decrease tremendously, it can compete with any major filter. When tested on its effectiveness at filtering out heavy elements/metals, common filters fail in spectacular fashion. For instance, Brita, a common store brand filter, did not meet expectations regarding heavy metal removal; in an experiment it removed only 14.1% of lead[6]. Another popular filter, Pur Water Filter, only removed a quarter of the lead compared to our filter[7]. Finally, our product consistently removed more heavy metals than another competitor: WaterMan Mini[7].

a. Efficiency

i. Every filter has a "charge," or how much substance it can remove before it is depleted. Most filters, such as ZeroWater, waste their "charge" by binding to innocuous chemicals such as magnesium and calcium. However, our product only filters harmful chemicals and does not waste its "charge" on harmless substances. It *only* binds to heavy metals, such as lead, mercury, cadmium, chromium, arsenic, and cobalt.
ii. Because filters like ZeroWater waste their filtrate, consumers need to buy more. For poverty-stricken areas, or places in crisis (like Flint), most filters strain consumers' budgets. For example, the comment on ZeroWater's website that the company itself labeled as the "Most Helpful Critical Review" stated, "I

bought my first Pitcher not even a week ago. The Water tastes great. Today 5 days after we started using Zero Water the Water started to taste funny after filtration. I live in an area with a TDS [total dissolved solids: having a value of 700+ is near toxic levels] of 700+. If one filter does not even lasts me for one week this will get extremely expensive soon, even with coupons"[8].

b. **Low Cost**

   i. Currently, the cost to produce 1 gram of filter is $4.99. However, this price can be drastically reduced (by at least 40 times) when production is scaled and percent yield increases (reduced to $.1248). Comparatively, Pentek sediment filters sell for $7.90. Scaling production is surprisingly a minimal challenge because of the facile nature of the synthesis procedure. Additionally, operation time and is minimal: 4 chemicals are mixed under mild conditions for 24 hours

5. **Revenue Model**

   a. **Primary Revenue Streams**

      i. The principal revenue is expected to come from the sale of our filter as a replacement for activated carbon in other filters. The product will be sold to customers through retail stores (e.g, Walmart, Target, Bed Bath & Beyond, Bath & Body Works, Lowe's, Home Depot) and on websites such as Amazon.com.

   b. **Unit Variable Costs**

      i. The cost to produce 1 gram of the filter (which removes 1800 micrograms of lead) is currently $4.99, consisting of the following components: $2.84 of 1,1'-Carbonyldiimidazole, $1.80 of Dimethyl Sulfoxide, $0.33 of Cysteine, and $0.02 of Cellulose. Currently, however, the filter is only at 2.0923% of its full potential **(Supporting Document 1)** . With more resources and time, we can optimize the reaction to potentially make our product *47* times more effective (**Supporting Document 1)**. At 90% yield, a feasible goal within the first year of sale, 1 gram of the filter would clean 77,426.76 grams of lead - 43 times our current yield. This means that we could sell 1/43 of a gram of the filter to clean the current 1800 micrograms of lead. Through economies of scale and improvements in the efficiency of production, the cost of producing our product will be significantly reduced. Thus, our product will become tremendously more affordable and more competitive toward our market competitors.

   c. **Product Selling Price and Unit Profit Margin**

      i. *H_2ydratiOn®* will retail at $8 per gram. We chose this price because we are selling in a monopolistic market in which the average price ranges from $7 to $10. Of this 60% markup, retailers like Amazon would take 15%, so the unit profit margin would be $1.81. As coupling yield increases and cost per gram decreases, however, profit margins will increase from 60% to 860% at 90% coupling efficiency. While this seems extreme, at 90% coupling efficiency, a 860% margin would mean that the filter is sold at $1.00 (with 1 gram of filter costing less than $0.12 to produce), *8 times* cheaper than before.

d. **Development Cost**
   i. The first year is intended for kickstarting the company. Specifically, we have filed for a provisional patent as a small entity ($130) to protect property rights**.** Prototyping involves refining the synthesis method -- this will allow the product to realize its full potential. The cost of prototyping can be minimized by using a university-funded laboratory. If this is not possible, renting out the necessary equipment can reach upwards of $2,000**.** As the business grows, a utility patent will be pursued. Regarding marketing, we will seek to occupy a heavy social media presence, especially on Instagram, to keep advertising costs at zero.

e. **Operating Cost**
   i. $5,000 for a 1,000L reactor, which makes 5,000g of filter per batch.
   ii. $80 for a 22 $ft.^3$ Nitrogen Air Tank High Pressure Aluminum Gas Cylinder.

f. **Breakeven**
   i. With fixed costs totalling $7,210, and current unit profit margin at $1.81, we would net a positive profit after selling 3,984 grams of the filter; such an amount is easily feasible, considering that a 1,000L reactor makes significantly more filter material than this in one batch.

6. Meet the Team

This team consists of four dedicated high school students: senior Max Medroso, and juniors Ishan Kasat, Joseph Sun, and Saman Verma. Max designed the filter during a research project, titled "An Eco-Friendly, Thiol-Modified Cellulose Adsorbent for the Chelation of Copper." Ishan Kasat and Joseph Sun both possess prior business experience, volunteering for SCORE, a non-profit business consulting organization. Saman Verma has participated in Business Professionals of America and has leadership experience from Technology Student Association.

7. Evidence (Sources)

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