ENGS 21 Winter 2023

Introduction to Engineering

SnowBigDeal

Final Report

Team #1

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Executive Summary

This report details the development and design of the Sno2Go, a water bottle with the capacity to melt snow and provide drinking water to athletes in winter condition backcountry areas where water is scarce.

The problem that our design addresses is the threat of severe dehydration from insufficient water in the backcountry. Skiers and mountaineers on single to multi-day trips in the mountains are at increased risk of dehydration due to strenuous activity in a cold, dry environment. In these conditions, both increased metabolism to maintain normal body temperatures and faster loss of moisture from heavy breathing in dry air accelerate dehydration and cause effects ranging from dizziness to seizures, hypovolemic shock, or even death.

Current responses to this problem include using a camping stove to melt snow, which requires extra equipment and significant time, or eating snow itself, which is dangerous and wastes body heat. Considering products themselves, the only existing solution to this problem is the H2Snow bottle: a one-liter water bottle that melts snow with the heat created through friction generated by turning a crank to spin a blade inside the bottle. In contrast, our solution can be used passively rather than requiring 20 minutes of manual work from the user. When preheated, our design can provide up to 30% more drinkable water than the H2Snow, and it is portable and ready to use with the flick of a switch.

The most important decision we made was choosing a heat source to melt the snow. While fuel, chemical heating, and body heat were all considered, electrical heat powered by batteries rose above the rest of the alternatives as the preferred method of heating. Battery power would be easy and quick to use, reusable and safe. Our bottle holds four rechargeable Li-ion batteries at the base of the cylinder, wired with an on-off switch and connected to two electrical resistors which dissipate electric power and transfer heat to the snow packed in a copper tube. The batteries are removable and rechargeable, and are calculated to last 133 minutes on a full charge.This translates to around 4.5 uses under a full charge.

Our potential purchaser will likely be outdoor retail stores like REI and EMS whose popularity among our customer pool will provide shelf exposure for the Sno2Go. We envision our user as someone who frequents trips into the backcountry for skiing or mountaineering. They will spend continuous periods without access to water, and would prefer a lighter and smaller solution than 3-4 full water bottles. Primarily, our company's stakeholders will be backcountry ski and outdoor companies, as well as companies that lead outdoor expeditions, similar to NOLS. Reusable bottle companies may be negatively impacted by the new development in the market if the Sno2Go becomes the preferred option for outdoor athletes.

Our team is a dynamic and complementary group with experience in a diverse range of fields. Carson worked at a CAD modeling and design internship, and is comfortable with tools and hands-on jobs from time spent working in a hardware store. Pía also has experience with CAD, as well as with circuitry and thermodynamics. She is also familiar with the design process from previous projects. Julian has experience with circuitry and testing from previous courses. Additionally, he completed the TuckLABS program, which provided him with a unique understanding of the entrepreneurship process. Sam has a large background in hand tools, as well as a sound understanding of physics concepts important for this project. The whole team shares a passion for skiing and the great outdoors. Furthermore, we are all currently enrolled in Physics 14, which has allowed us to apply many of the E&M concepts and equations we've learned directly to our project!

Introduction

The problem that our team is aiming to solve is the lack of access to clean, drinkable water in the backcountry. This affects any individual who cannot carry the excess weight of the water necessary for a single or multi day trip.

Without enough water, individuals can become severely dehydrated. Dehydration, which is the result of an individual's body losing more fluid than they take in, disrupts the body's mineral balance and significantly affects function.[1] This can result in issues ranging from fatigue and dizziness to kidney problems, seizures, hypovolemic shock, or even death.[2] Both strenuous exercise and exposure to cold weather increase the risk of dehydration, particularly at higher altitudes. Considering this, individuals in mountainous, cold backcountry areas have an even greater need for accessible water.

Focusing on backcountry areas with snow, impacted individuals fall into two main groups. Our primary focus group is people participating in winter sports such as skiing — both downhill and cross-country — and mountaineering. These specifications limit our general age demographic to 18-30, since this bracket consists of mountaineers and cross-country skiers that consistently exert the most sustained effort.[3] Rather than by choice, the second group encompasses individuals who spend time in the backcountry because that is where they live or work. Individuals in rural, mountainous communities have limited access to clean drinking water, especially when traveling outdoors for work or other daily activities. We hope our product can aid these communities in addition to winter athletes. Unfortunately, this group is also less

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[1] NHS Inform
[2] Mayo Clinic
[3] Chápele

likely to be able to afford our more high-end product and, thus, will not be our primary target for sales.

Whether an individual is a college athlete or casually enjoying a recreational sport, the frequency of this problem may range from four days a week to once every two weeks — corresponding to how often they ski. When the individuals go skiing, their exposure to the backcountry lasts several hours in dry, high-altitude environments.

In essence, we hope to design a product that provides a portable way to melt and filter snow. The melting process will be passive so that the user can scoop up snow from where they are standing and then have water generated as they continue climbing or skiing. Without needing to expend extra energy into the melting process, the user will be able to continue to enjoy their activity while the snow is melting over a period of approximately 30 minutes.

We also hope that if our product is successful enough, we can match each sale with a donation of a bottle to the aforementioned workers in rural mountain communities.

Background and State of the Art

Currently, there are few existing products that address this problem. Instead, individuals have resorted to alternative methods such as melting snow in scenarios where there is snow but insufficient access to fresh water. In fact, both the Food and Drug Administration and the Center for Disease Control and Prevention have cited melting snow as an emergency measure for obtaining drinking water. The two current methods for melting snow use body heat and a stove, respectively. To utilize body heat, an individual can fill a bottle with snow and place it inside their jacket.[4] While it takes much longer periods of time, the snow will eventually melt.

[4] NCBI

However, all bacteria, salt, and other debris from the snow will remain in the water. Boiling snow, on the other hand, sterilizes the water but it is still a time consuming process. To boil snow, an athlete has to stop their activity, take out and set up their equipment, boil the snow, and then pack everything up again. We hope to eliminate the many extra steps and time needed to melt the snow with our product. A third method, eating snow, is common but dangerous and inefficient. When consuming snow, the human body allocates a significant amount of energy to maintain a level internal body temperature, resulting in energy depletion that advances dehydration. Furthermore, unheated snow contains pathogens and other contaminants that are dangerous to consume.

Beyond solutions such as boiling water, the only existing product is the H2 Snow bottle: a design that is not patented or available for purchase. As depicted in Reference 2, this product is described as "the world's first alpine survival tool that converts snow into drinking water through human power."[5] This product was designed and created by Tim Lutton in 2016, when he was a student at the Royal Melbourne Institute of Technology in Australia.

Lutton's product is a one-liter water bottle that melts snow with the heat created through friction from a spinning blade within a sealed copper tube. The blade spins from the user cranking the handle, taking advantage of human power to create friction and break down the snow. [6]

Given that the H2 Snow bottle melts the snow by converting friction to heat, a significant limitation is the amount of time and energy that it requires from the user. Per 20 minutes of operation, the bottle can convert 200g of snow into 100mL of water. Considering the

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[5] Dehydration, Mayo Clinic
[6] Paybarah

recommended range of water consumption for light physical activity being 0.5 to 2 liters per hour, the minimum water recommended after 20 minutes of operation would be 160mL.[7] In addition to requiring more water consumption than it provides, the user needs to actively rotate the bottle's handle in order for it to work, meaning that they must take a break from other activities or sports.

In contrast to the H2 Snow bottle, we centered our design process around creating a product that would not require any of the user's energy or focus and would be able to produce a greater volume of snow. For the latter specification, we incorporated a spring compression system to densely pack snow and decrease the average 10:1 snow-to-water volume ratio.

Description of the Potential Purchaser and User

The average age for the typical user of our product is predicted to be 28 years old. Determining the average age of users of our product required consideration of various conflicting data sets. Our target population consists of individuals between ages 18 and 30, as the research demonstrates that this age group participates in the most consistent and strenuous skiing and mountaineering and thus requires a reliable rehydration system.[8] However, we also needed to account for the availability of disposable income. According to the Bureau of Labor, disposable income has its greatest increase after the age of 25, with the population of individuals 25-30 nearly doubling the available spending money of those under 25. This increase in disposable income in conjunction with the average age of skiers and mountaineers being 33 demonstrates that the average user age would be on the upper end of our target demographic range.

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[7] US News
[8] Pubmed

Considering disposable income, the average age of participants, and age at which strenuous activity was maximized, it was determined that our average age for users is 28.

Within this age range, we will target all genders equally. While men require more water on average than women — needed an average of 3.7 liters per day rather than 2.7 liters[9] — this does not consider the added energy expenditure of men or any individuals with greater body weight.

In general, our users will also be our purchasers. Other purchasers may include outdoor guide outfits who want to provide their customers with state of the art gear. Furthermore, outdoor equipment outfitters such as REI and EMS or online retailers such as backcountry.com may purchase our product in bulk, and resell to their loyal retail base on a larger platform.

To gauge interest in a product like ours, we contacted 19 nordic skiers in person and all of these potential users demonstrated interest in the product. Many expressed how avoiding dehydration is something they would like to prioritize and noted that it is difficult to manage because they have to carry multiple bottles into the backcountry in order to have sufficient volumes of water.

Specifications

In developing our new and improved solution we prioritized safety, size, weight, cost, and function. For function, we considered durability, energy usage, and efficiency. Additional specifications that we prioritized were cost, temperature, and materials. We weighed each specification by how it affects the potential user group. Accordingly, we placed safety as our most important specification, as it is of the utmost importance that our product does not cause

[9] Mayo Foundation

injury or sickness. Safety was followed by energy usage: a critical factor in the feasibility and function of our product. The bottle must be able to be used multiple times before needing to be recharged or refueled, otherwise it would have little benefit over a standard bottle.

Energy usage and efficiency also impacted other design aspects. Namely, the energy source was the biggest question in creating our design, as it would significantly affect the cost of the product, its weight, the speed of the melting process, and the volume of water that can be produced. Cost was also an important consideration because, while the bottle is more expensive than a standard water bottle, it still had to have a reasonable price so that the scope of potential purchasers was not limited. Finally, both the weight and the size of the water bottle were heavily considered. If the water bottle is either too heavy or large in volume it will be difficult for the user to carry. While being small enough to comfortably hold, the volume also had to be large enough to provide a sufficient amount of water to the user.

Specification	Justification	Quantification	Weight: 1 (lowest) - 5 (highest)
Safety	The user should not experience any sort of harm from our product	We would like the user to not get sick from drinking the water produced as well as not sustain injury from use of the product (including burns, cuts, electric shocks, etc)	5
Energy Usage	Enough power for multiple uses must be provided within one charge of the batteries	Battery voltage under 9 V must be able to provide ~20 W of power into heating	4
Cost	The cost must be affordable for potential consumers	The material cost will ideally be under $150.	4
Volume	The size must be as easy to carry as a standard water bottle while providing similar amounts of	The volume will ideally be under 1L	4

	water		
Weight	The weight cannot be too heavy or else it will be hard to carry and no different than carrying a large volume of water	The weight will ideally be under 1kg	4
Time	The bottle must provide water at frequent enough intervals	We would like the bottle to provide 500mL of water within an hour	3
Durability	The bottle must be able to survive cold temperatures and moderate drops in order to justify the cost and to be of use to users in the backcountry	The bottle should be able to survive a 2 m fall and -10º C	3
Materials	The water bottle should be made from primarily recyclable materials .	We would like for our bottle to be made of 50% recycled material	1

See equation 1 for energy calculations

Problem Solving Methodology and Alternatives

With the aforementioned specifications in mind, we began to brainstorm and develop our solution. To do so, we considered various approaches for the power source, type of filter, and the design itself. All considered variations of the design consisted of a water bottle containing a heat source used to melt snow and a filtering straw for the resulting water. The key consideration for these initial designs was the efficiency of heat transfer to the snow, so we explored how to maximize the surface area of heat transfer and contact with the snow.

The seven design alternatives were ranked and weighted as seen in *Table 1* in the appendices. From the design matrix, we decided to pursue a design that incorporated aspects of both the spring compression system and the coil-lined walls.

Sketches of the seven design alternatives can also be seen in the appendices as References 2-8. The first design featured spring compression, which was included for two reasons. The first was to maximize the amount of snow that our product could hold, and thus the amount of water produced. The second was to aid melting, as compression increases the melting point of snow by decreasing the distance between the water molecules within.[10] The second alternative featured a buoyant heat source that would remain in between the snow and the water, directing heat into the snow rather than wasting energy towards heating the water further.[11] Next, our third design was centered around a fuel compartment in the middle of the bottle. The compartment door would require venting, and similar to the alternative with the floating heat source, the heat would rise from the compartment into the snow sitting above.[12] Our fourth design incorporated heating into the walls of the bottle. Originating from a battery at the bottom of the bottle, coils lead through the walls of the bottle in order to maximize the surface area for heat transfer and increase efficiency.[13] Our fifth alternative centered around heating prongs, leading wires from a battery through prongs incorporated vertically inside the bottle to maximize the surface area for heat transfer.[14] Our sixth solution featured a heat source attached to the lid, with a rechargeable battery that can be charged through a port in the lid. This included insulation at the top and sides of the lid to protect the battery and keep the heat near the snow that floats to the top of the bottle.[15] Finally, our seventh design incorporated a heat source at the bottom of the bottle, with heat radiating up to the snow.[16]

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[10] Meinecke
[11] Rehydration Project, Water Facts
[12] Mulder
[13] Physics Essay, Melting Ice
[14] Aerenhouts
[15] Summit Post, Melting Ice
[16] US News, How much do you sweat

Once we decided on a design framework, we had to analyze different energy sources to incorporate into the design. The four energy sources were weighted and ranked as seen in matrix 2 in the appendices.

First, we considered camping fuel, also known as white gas, a distilled liquid petroleum, as it can generate large amounts of energy from a small quantity and weight. However, we decided against it as this heat source uses a fuel canister that has to be lit, requiring the fumes to be vented and introducing a safety hazard. Heating with fuel would also require the user to stop their activity, light the fuel canister, and wait for the snow to melt before resuming activity.

Next, we considered a rechargeable battery — whose resulting current would be sent through resistors to convert the energy to heat. Specifically, we considered a lithium titanate battery as it can produce large amounts of energy despite weighing as little as 1.3 kilograms. This is the energy source that we decided to pursue, as it is relatively safe and easy to implement.

We also investigated two types of chemical hand warmers: reusable and non-reusable. The reusable warmers utilize supersaturated sodium acetate that releases heat as it recrystallizes. Afterward, the packet is boiled to return it to the supersaturated state so that it can be used again. The non-reusable hand warmers are oxidation-based packs that contain iron powder, water, salt, activated carbon and vermiculite. When exposed to oxygen, the iron is oxidized and forms rust, generating heat through the equation[17] $4Fe_{(s)} + 3O_{2(g)} \rightarrow 2FeO_2$.[18] Further research revealed standard oxidation hand warmers produce 1.7 kilocalories of energy from 1g of iron. Converting kcal to kJ, we get 7.1128 kJ of energy from 1 gram. To melt 0.5L of snow would take 152 kJ, so about 21 grams of iron based hand warmer would be required to melt this amount of snow. This

[17] "The Chemical Magic of Hand Warmers." *Science Focus*
[18] "The Chemical Magic of Hand Warmers." *Science Focus*

is a lot for only 0.5L of snow, and since it is not reusable, even more would be needed to be carried with the bottle for multiple uses. The reusable hand warmers function the same way and, while they would not need replacements, they would need to be removed from the bottle and heated in a microwave before being able to be used again.

Finally, we considered body heat, for when placed in close proximity to one's body, the emitted heat can be applied to an external object such as a bottle.

For the filtering component of our design, we considered several options including ultrafiltration, physical mesh, ultraviolet light, and charcoal. The filter options were weighted and ranked as seen in matrix 3 of the appendices.

Despite being prohibitively expensive and bulky for our project, ultrafiltration forces water through a semipermeable membrane, removing bacteria in addition to most particles and dissolved contaminants, making it the safest option out of our filter alternatives. Physical mesh, on the other hand, only removes larger, undissolved particles. Doing the opposite, ultraviolet light only kills microorganisms. Working through adsorption, activated charcoal removes chemicals, gas, physical contaminants, and most bacteria.

The primary considerations in the analysis of these options were ease of implementation — namely, can it be included inside of a straw within the bottle — cost, and the extent to which the water will be sufficiently filtered. The dangers within snow that must be filtered out are pathogens, chemicals, and physical particles such as rocks and dirt.

Combining these three elements, we decided to pursue a design that features a spring compression system and uses a rechargeable battery to power nichrome wires wrapped around an inner shell of the bottle in order to heat the snow. We chose for the accompanying straw to have activated charcoal filtration.

Design and Performance of Prototypes

After deciding on an initial design, we created some initial prototypes to gauge the feasibility of design aspects. Focusing on the chosen design itself, Julian prototyped a visual representation of the wire-wrapped inner shell idea and Pía prototyped the spring compression system. Both of these prototypes, along with the prototypes that Sam and Carson made of alternative heating designs, can be seen in the appendices as References 13-16.

For the spring compression system, the prototypes leveraged the restoring force of springs to upwardly compress the snow. We saw that the springs could provide sufficient force but their contact with the snow negatively impacted the springs' compressive ability.

For the wire-wrapped inner shell, the prototype displayed how the batteries would fit under the inner shell and how the wires would wrap around that shell. Looking at how to combine the two prototypes, we decided that we would try incorporating a spring into the lid to provide downward compression on the snow — pushing it towards the bottom and sides of the inner shell in order to maximize contact for heating.

We then moved on to prototype our updated design, focusing on the nichrome wires first. In order to do so, we began by researching the ideal arrangement of the wires in order to limit magnetic induction. Then, to implement this arrangement, we used TAPEGO tape (thermally-insulative, heat-conductive) between the wires and the inner copper shell — which we chose because of copper's antimicrobial properties and heat conduction quality.

After some unsatisfactory test results with this first prototype (see Testing), we transitioned to electric resistors as our means of converting the battery power to heat. In this prototype, we started with a new copper pipe, and capped its bottom with a watertight aluminum plug. We added the two 3 Ω resistors and applied heat transfer grease at the contact point between them and the aluminum. We also secured the resistors using aluminum tape and foam insulation.

After further electrical testing, we determined the ideal circuit configuration and thus switched to 5 Ω resistors. The foam insulation component was also overhauled, as we molded it with higher precision for a tighter fit. Below the insulation, we arranged the four 3.7 li-ion batteries using a custom 3d-printed holder. With this final configuration, we soldered the wire connections for a secure and stable fit, adding a hardware switch for on/off functionality.

With the heating component optimized, we moved onto the spring compression system. Starting with a CAD model for the disc (see Reference 9), we cut and milled an acrylic disc. We then attached the disc to the bottle cap via the spring. In a second iteration of the lid design, we removed the threads on the cap and bottle because the tight seal within the cylinder made it difficult to insert and remove the component through twisting. The updated design, as can be seen in Reference 17, allowed for the lid to be pushed straight on instead.

The external shell of the water bottle was formed by sawing two Nalgene water bottles and sealing the mouth of the upper bottle to the copper tube. The bottom half of the shell was filled with foam insulation for the battery pack, and we cut a hole in the bottle to give users access to the on/off switch.

Since the safety of our design was such a priority, we decided not to design our own filtering straw at this stage. Instead, we opted for a tried and true solution and fastened an OxGord filter straw to the outside of the bottle with hook and clasp strips for easy on/off functionality.

Testing

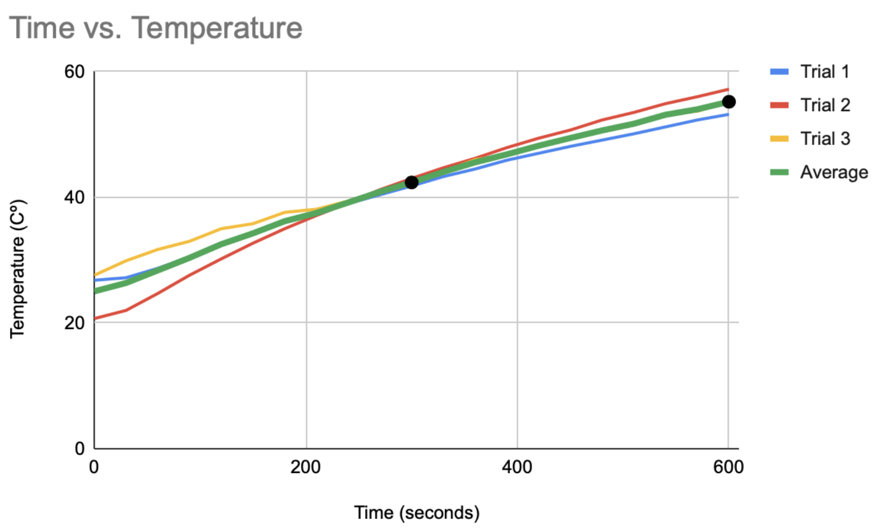
Throughout the engineering process, we developed several benchmark tests for quantifying the performance of certain components of our prototypes. Beginning with our initial design of using nichrome wiring as a heating source, we ran initial tests on how fast the copper pipe heated up, the maximum temperatures it could reach, and how quickly it could melt snow. We varied wire length and wire configuration, and researched a wire configuration which would optimally reduce magnetic induction and ensure minimal energy loss. We quickly discovered that despite all of our variations of wiring, our heat transfer was not working well enough to melt the snow in a timeframe that would satisfy our goals. Our hypothesis for why this wasn't working was that too much heat was lost to the surrounding environment, and the surface area of the wires contacting the copper was too small to transfer the magnitudes of heat needed.

We consulted both Raina White and an upper level engineering student, Noah Canel, about our problem. Both sources suggested using a different type of resistor called cement resistors which could get much hotter than the wires. Noah also lent us some heat sink grease which we applied to the tops of the resistors that would be in contact with the plate at the bottom of the tube. This would allow for easier transfer of thermal energy to the tube and then to the snow. More testing of the temperature changes with the Vernier heat sensor followed, yielding better results than the Nichrome wires but still lagging behind the temperatures and time we needed.

Next, we looked at configurations of resistors. In our Physics 14 textbook, a class that our whole team is taking this term, we found equations for systems of resistors in series and parallel as depicted in Reference 10. We decided to wire the resistors in parallel so that they would not overheat and break, since $P = IV$, and $V = IR$, so therefore, $P = I^2R$, which means greater resistance would increase power output and overload the resistors. Since our batteries had not arrived yet, we tested this setup with a DC voltage source which yielded qualitatively successful results.

The final stage in testing involved integrating the batteries into our circuit. Like resistors, the configuration of batteries in series or parallel would have a significant effect on the voltage produced. To integrate the batteries into the system, we had to plan out a circuit configuration and fabricate battery holders which would connect the batteries together. In the appendix, Reference 9 displays our final circuit design, which included (from top to bottom) a switch, two cement resistors in parallel, and two battery packs in parallel each made of two individual battery cells in series. Once we had determined our arrangement of batteries, we began fabricating the custom battery holders. Because we bought special Li-ion rechargeable batteries that were bigger than standard AA batteries, we had to custom make holders and terminals for our battery packs as depicted in Reference 11. This involved CAD modeling, 3D printing, and soldering copper terminals to wires.

With our battery packs assembled, it was time to test our inner chamber's heating capacity and our final prototype's melting capabilities. To test the temperature, we used a vernier surface temperature probe to record the temperature of the bottom of the copper pipe over time. We discovered a relatively linear increase in temperature over time, with the chamber reaching an average temperature of 42.4 C^o in 5 minutes and 55.2 C^o in 10 minutes. All our trials were within a reasonable range of one another, highlighting the consistency of our final product. Finally, we tested the melting time of our product by packing in a consistent amount of snow (105g) and recording the time it took to melt to completion. We determined that with 5 minutes of preheating before packing in the snow, the average melt time is 34.9 minutes.



Analysis

After compiling a final prototype, we were able to test its actual performance against theoretical predictions. Based on our tested current across the resistors, we found that the power generated by the resistors was 19.83 W, slightly less than their theoretical 20 W power output. This output which is 0.85% than our expected value is probably due to the small internal resistance within the batteries, and the small resistance within the copper wiring to the resistors.

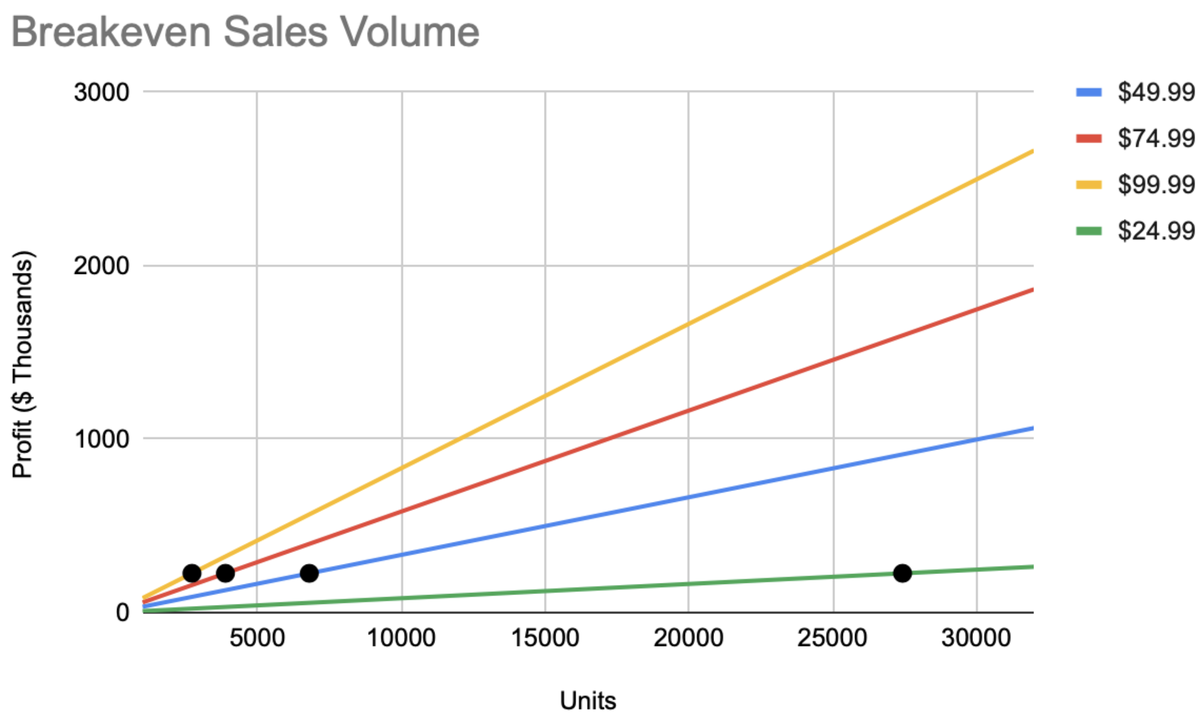
Based on this power output, the theoretical time to melt 105 g of snow is 29 Minutes and 49 Seconds (see Equation 4 in Appendix). However, we found through our testing that the average time to melt this amount of snow was 34 Minutes and 56 Seconds. This tested time is 14.6% longer than our calculated theoretical time to melt snow. This discrepancy between the theoretical and actual time to melt snow can be explained by various factors. First, the heat transfer between the resistors and the aluminum plate at the bottom of the cylinder may be far from optimal. Although we applied heat grease at the contact point between the aluminum and the resistors, significant power loss can occur at this contact point, and more could be lost externally. This brings us to our second possible explanation for our longer heating time: the power generated from the resistors may not all be directed towards the aluminum plate, and thus towards melting the snow. Although the resistors were sufficiently insulated using aluminum tape and foam insulation, our insulation system is far from perfect. To improve this, we would like to make our bottle airtight around the copper tube to keep even more heat in. A completely closed system can be used to mitigate losses in a future iteration of the prototype.

Another key specification of our prototype is the battery capacity. This determines how long a potential user can run the heating element on a single charge. Using the tested current and the reported battery capacity specified by the manufacturer, the battery life was found to be 2 Hours and 13 Minutes (see Equation 5). With the ambiguity of determining when the batteries were actually fully charged, we were unable to accurately test this theoretical runtime, but assuming thorough testing from the battery manufacturer, and the actual current which we tested in the electronics lab, we assume that this runtime is accurate. Therefore, the theoretical number of uses on a single charge was found to be 4.5 times, according to the theoretical time to melt one quantity of snow (see Equations 4 and 6). With our tested melting time, this number of uses drops to 3.8 times, which produces 400 mL of water (see Equation 7). This quantity on a full charge is 14.4% less than the theoretical capacity, and can be explained due to factors mentioned above.

Furthermore, we determined the impact score of our initial prototype. *[Table 8]* Impact scores indicate the environmental and ethical repercussions of utilizing different materials (higher impact scores signify a negative effect). We determined that our product has an impact score of 15.72 with the batteries (36.4%) and the 3D printed cap and battery containers (51.2%) contributing the most. We plan on using injection molding for the 3D printed parts in future iterations which will decrease the impact score substantially (51.3%).

Economic analysis

After we improve upon a few aspects of our current prototype (snow capacity, battery placement, and the number of resistors), we plan to sell our product. To start, we analyzed the breakeven volume at several price points. *[Table 5]*



Our key partners will be individuals, outdoor equipment retail stores, and ski shops. They will be integral in promoting our product to our target market. Our target market consists of winter sports athletes and outdoor guides. More specifically, an estimated 4.5 million nordic skiers, 20 million downhill skiers and snowboarders, and 2.4 million mountaineers.[19] We plan on striving to maintain a strong customer relationship. To do this, we will constantly conduct surveys to learn more about the customer experience with our product. Additionally, we plan on providing free repairs if the product is damaged and a free initial set of batteries.

[19] Statista

The per unit cost of production is $16.75. *[Table 6]* We plan on sourcing all of the materials required via wholesalers. It will be challenging to bring the price far below $16.75, as lithium-ion batteries account for most of our cost (62.1%). However, we can minimize the cost of the outer shell, which accounts for the second highest percentage of the cost (16.75%), by using injection molding rather than purchasing water bottles. While the injection molding will be a considerable expense ($10,000), it will lower the cost of the shell from $2.76 to $0.50. Beyond this, there are seemingly no ways to decrease the production cost.

We estimated our fixed costs to be $226,000 per year ($18,833.33 monthly). *[Table 4]* The majority of the fixed costs are due to the salaries of our team ($40,000 yearly per member). We feel that this is a modest salary that we can feasibly live off of. Additional fixed costs of note are research and development ($15,000 yearly) to consistently improve our product, along with a small legal retainer fee ($2,000 yearly) in case any trouble arises.

With the per unit cost of production and fixed cost in mind, we plan on selling our bottles for $74.99, which would net us a profit of $58.24 per bottle and correlate to a yearly breakeven volume of 3,881 bottles (.014% of our total market). We settled upon this price point as the breakeven volume appears more than attainable, and the price is low enough to allow people to take a risk on our product. We plan on selling primarily direct to consumers through a website, as this will maximize our profits. However, we are open to seeking retail partnerships with ski resorts and retail stores such as REI down the line. Our projections indicate that we will sell 100 bottles during the first month, a fraction of our target market. As we begin marketing and the market becomes more familiar with our product, we will see a 10% increase in monthly bottles sold for the first year and a half, which will see us break even shortly before our third year of business. *[Table 9]* However, after an initial surge in purchases, we will not see the same growth and have only a 5% increase in bottles sold for the next year, then decreasing again to a 2.5% increase for the next six months. The projections indicate that we will sell 18,967 bottles over our first three years, leaving us with 7,324 bottles over our theoretical breakeven point, netting us $426,549.79 in total profit. *[Table 9]*

As our fixed costs are very high, we anticipate an initial loss. However, as our sales rise monthly, we anticipate exponential profit growth with a net zero profit after around 23 months. While we plan on financing the following stages of product development ourselves, we will eventually launch a Kickstarter campaign with a goal of $90,000. This will allow us to cover initial fixed costs such as rent, electricity, and initial loss more without taking out a loan. This is the most effective way to obtain capital without jeopardizing our business.

Due to the feasibility of production, low cost of production, large target market, and lack of competition, this product is economically viable. The Snow2Go provides a unique solution to a problem that has yet to be addressed. Coupled with the low price point, it will allow us to attract enough consumers to generate profit. While some may point to the startup costs and the lack of a loan as the downfall of our product, the initial costs are low enough to be funded entirely via Kickstarter. This unique solution to acquiring funds will allow us to maintain flexibility in our finances and grow our business securely.

In the future, we will be seeking an exit opportunity. Ideally, this would take the form of a buyout. For reference, conglomerate Helen of Troy purchased HydroFlask for over 200 million dollars. While we do not anticipate an acquisition of this magnitude, our company has the potential to be valued at eight figures. We would also accept a royalty on the lower end of the standard figure (2-5%).

Conclusions and Recommendations

We would certainly recommend that the DCEF proceed with development of the Sno2Go. Our testing was quite successful, and we have a working prototype that has a clear path for future development.

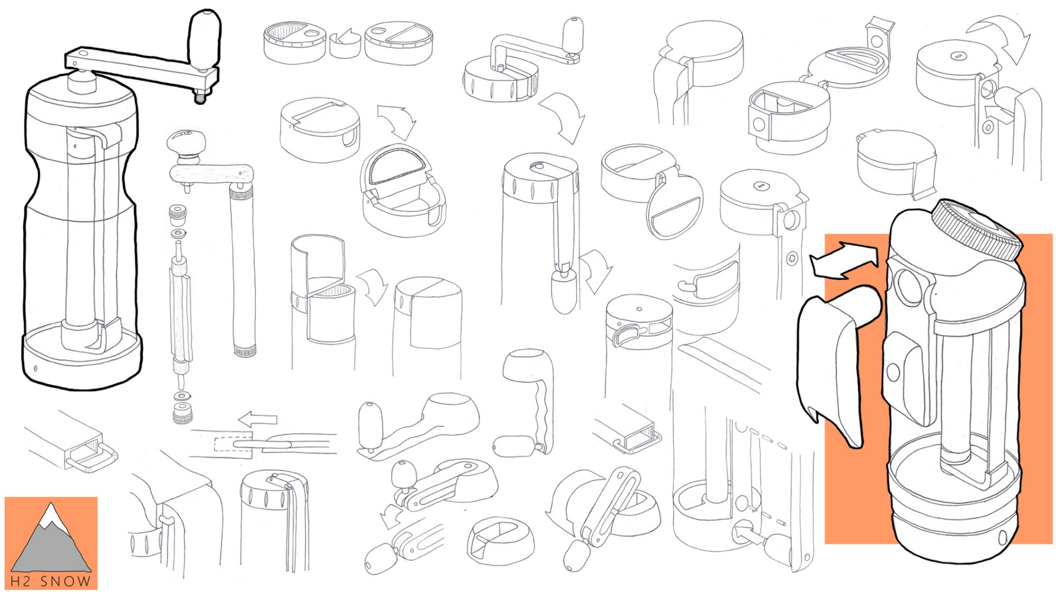
Future research will be largely focused on thermodynamics and electric circuits. We were by no means experts in these fields, and were able to consult professors and other engineering students about problems we ran into. However, there is a lot of room for improvement in the heat transfer, insulation, and efficiency of our resistors and batteries. To make our product feasible to sell, we will realistically need to heat much more water in a smaller amount of time. We believe this can be done, but we will likely need to hire an expert to help with this. We have already allocated funds for research and development in our financial plan, so expenses for this should not be a problem.

While our product functions as envisioned, it is still in its prototype phase and thus has its limitations. Our current prototype has only a few areas that require immediate attention. We would like to immediately make two minor improvements: our cap fastening system, which can be made more durable, and the switch hole, which we will seal to keep our electronics dry and clean. User feedback indicated that our inner chamber could hold a larger volume of snow. In future iterations, we plan on utilizing an inner chamber 3 inches in diameter rather than 2. Users also indicated they would like future iterations to melt the snow faster. We plan to address this by adding a third resistor and another set of batteries for the new resistor. Additionally, as discussed in our analysis section, we plan on utilizing injection molding to lower our impact score and make our product more environmentally friendly.

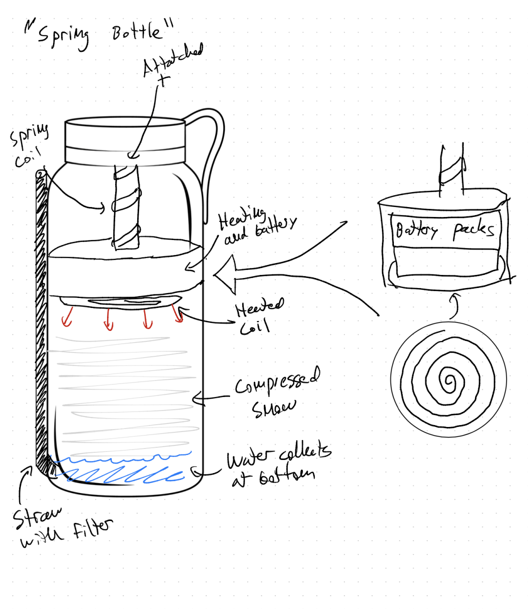
Appendices

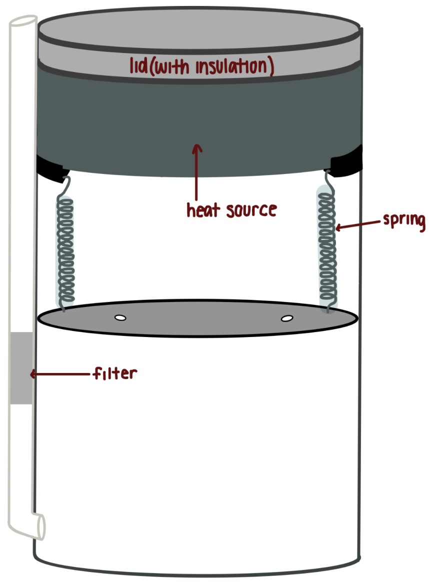
References

Reference 1: H2Snow Parts Diagram

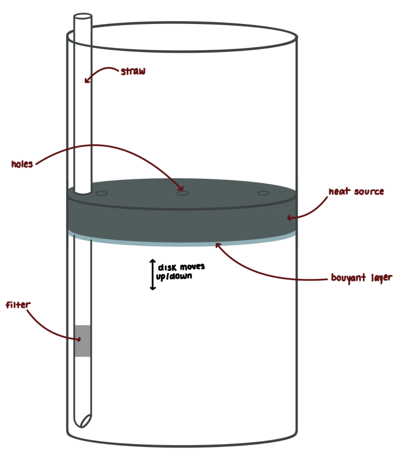


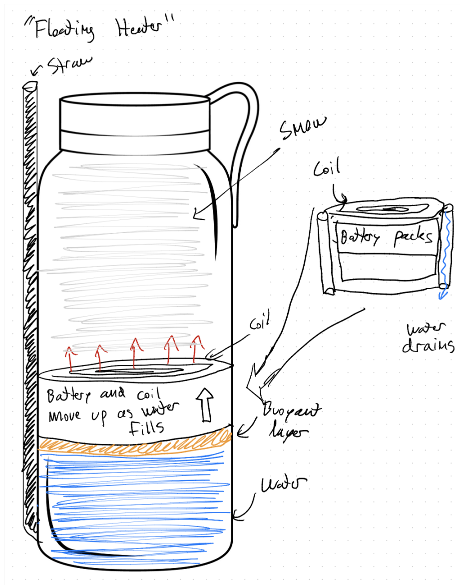
Reference 2: Spring Compression System



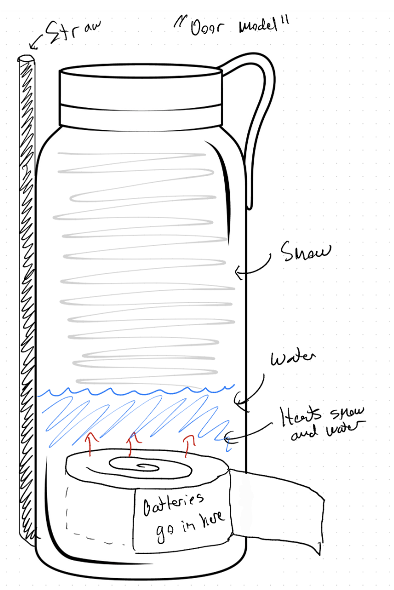


Reference 3: Buoyant Heating Device

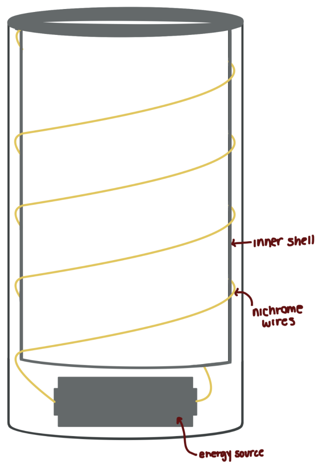




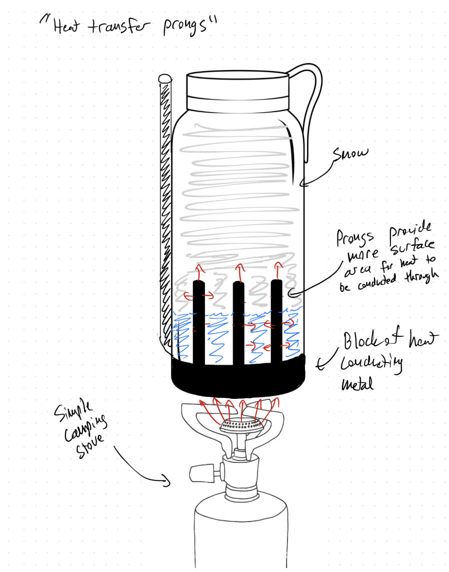
Reference 4: Door Compartment Heating Component



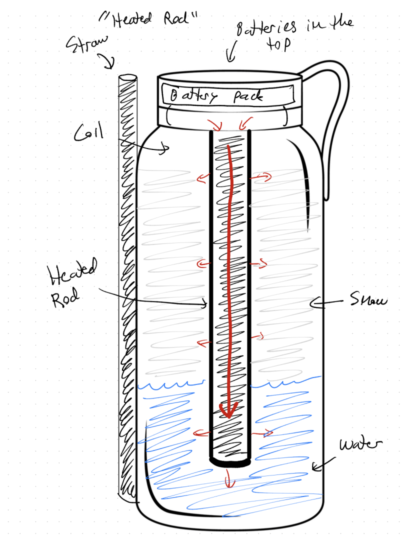
Reference 5: Coil-Heated Walls



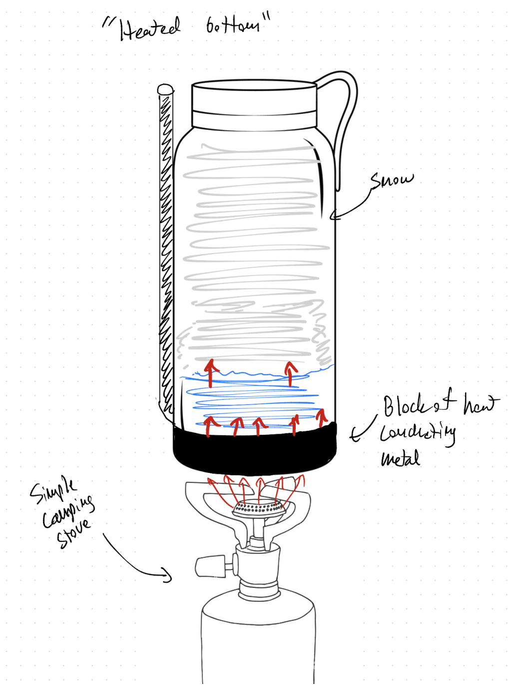
Reference 6: Heating Prongs (powered by camping stove)



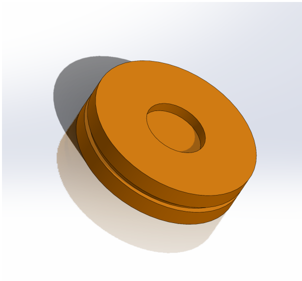
Reference 7: Heating Component in the Lid



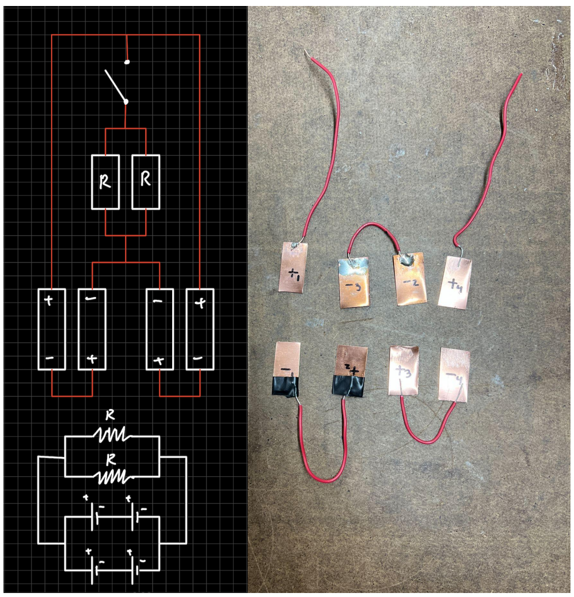
Reference 8: Heating Component in the Bottom (powered by camping stove)



Reference 9: CAD Model of Spring Disc



Reference 10: Full Circuit Design and Battery Terminal Layout

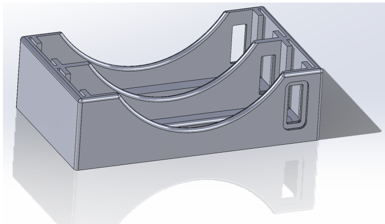


Reference 11: Physics 14 Textbook Equations

$$R_P = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_{N-1}} + \frac{1}{R_N}\right)^{-1} = \left(\sum_{i=1}^{N} \frac{1}{R_i}\right)^{-1}.$$

$$R_S = R_1 + R_2 + R_3 + \cdots + R_{N-1} + R_N = \sum_{i=1}^{N} R_i.$$

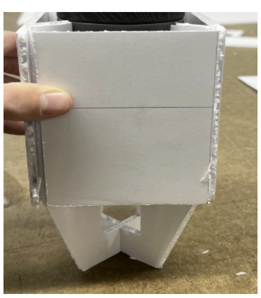
Reference 12: CAD model of battery container



Reference 13: Spring Compression Prototype

Reference 14: Wire-wrapped Inner Shell Prototype

Reference 15: Bottom-heating Stove Attachment Prototype



Reference 16: Fuel Chamber Prototype

Reference 17: Spring and Lid Iterations

Calculations

Equation 1: Energy needed to melt snow: for 105 mL of water at -3 ºC

- 334 J/g required for snow at 0℃ -> water at 0℃
- 2.108 J/gºC for ice

$$1\ g/mL\ x\ 105\ mL\ (334\ J/g\ x\ +\ 2.108\ J/g\ ℃\ x\ 3\ ℃) = 35.5\ kJ$$

Equation 2: Force on the snow by the springs: restoring force back to equilibrium

$F = -kx$

with $k = 1.86\ lbs/in$ (for a beryllium-copper spring with a free length of 1.0 in, an outer diameter of 0.5 in, and 10 coils)

If stretched 3 inches from equilibrium, the force on the snow will be 5.6 lbs of force. This total force will be proportional to the distance stretched, which will be achieved by how much snow is initially packed in, with the work being done by the weight of the lid and the user closing it.

Equation 3: Grams of Iron needed to produce 152 kJ:

0.5L H_2O →152 kJ

152 kJ = 36.33 kcal x (1g Iron / 1,7 kcal) = 21.37 g

Equation 4: Time to Melt 105 g of Snow

- $t = \frac{E}{P}$

With the energy requirement (*E*) being 35.5 kJ, and a power output (*P*) of 19.83 W, the time (*t*) to melt 105 g of snow is 1789 s or 29 Minutes and 49 Seconds.

Equation 5: Battery Life with Continuous Power Usage

- $t = \frac{S}{I}$

The battery runtime (*t*), with a battery capacity (*S*) of 6000 mA•h and a current (*I*) of 2.71 A is 7970 s or 2 Hours and 13 Minutes.

Equation 6: Number of Uses on a Single Battery Charge

- $N = \frac{T}{t}$

The number of full melting periods (*N*) with a full battery runtime (*T*) of 7970 s and a single melting period (*t*) of 1789 s is 4.5 times.

Equation 7: Quantity of Water on a Single Battery Charge

- $V = N \cdot V'$

The volume of water on a single charge (*V*) is with a number of melting periods (*N*) of 4.5 times on a single charge and a volume of water on a single melting period (*V'*) of 105 mL is 466 mL on a single charge.

Tables and Matrices

Table 1

Design Alternatives	Safety (3x)	Energy Usage (2x)	Cost (2x)	Volume (2x)	Weight (2x)	Time (1x)	Durability (1x)	Materials (1x)	Scale (1-5) #x indicates multiplier	Total
Spring Compressing System	15	10	8	10	7	5	4	3	na	62
Floating Heater	12	7	6	8	7	4	3	3	na	50
Door Compartment	10	8	5	7	5	5	2	3	na	45
Coil Lined Walls	14	8	8	7	8	4	4	3	na	56
Prongs though Bottom	12	7	6	7	7	4	4	3	na	50
Heating in Lid	15	5	5	8	7	2	3	3	na	48
Heating in Base	15	5	5	8	7	2	3	3	na	48

Table 2

Energy Alternatives	Safety (3x)	Energy Usage (2x)	Cost (2x)	Size (2x)	Weigh t(2x)	Temperatur e(1x)	Durability (1x)	Materials (1x)	Scale (1-5) #x indicates multiplier	Total
Battery	15	8	6	7	6	8	8	8	na	64
Camping Fuel	6	10	8	7	8	3	6	1	na	58
Hand Warmers	10	2	9	10	10	6	10	6	na	63
Body Heat	15	0	10	10	10	10	10	0	na	65

Table 3

Alternatives	Safety (3x)	Energy Usage (2x)	Cost (2x)	Size (2x)	Weight (2x)	Temperature (1x)	Durability (1x)	Materials (1x)	Scale (1-5) #x indicates multiplier	Total
Ultrafiltration (thin membrane)	9	10	2	2	2	na	5	2	na	32
Charcoal Filter	8	10	7	7	5	na	7	1	na	45
UV Light	6	7	3	3	2	na	4	4	na	29
Physical Mesh	2	10	9	9	5	na	8	1	na	44

Table 4

Rent (Factory)	$15,000
Leasing Equipment	$5,000
Heat	$2,000
Research and Development	$15,000
Electricity	$1,500
Advertising	$3,000
Manufacturing	$20,000
Insurance	$2,500
Legal	$2,000
Salary	$40,000 (x4)
Total (yearly)	$251,000

Table 5

Price per Board	Profit per Board	Breakeven Volume	Percent of Market
$24.99	8.24	27,428	0.102%
$49.99	33.25	6,797	0.025%
$74.99	58.24	3,881	0.014%
$99.99	83.24	2,716	0.010%

Table 6

Item	Cost
Water bottle shell	2 * $1.38 = $2.76
Copper piping	0.392 kg * $6.50/kg = $2.55
Batteries	4 * $2.60/battery = $10.4
Resistors	2 * $0.07/piece = $0.14
Switch	$0.30/piece
Wiring	0.3 m * $0.20/meter = $0.60
Total	$16.75 / bottle

Table 7

Month	Bottles Sold
1	100
2	110
3	121
4	134
5	147

6	162
7	178
8	195
9	215
10	236
11	260
12	286
13	314
14	346
15	380
16	418
17	460
18	506
19	531
20	558
21	586
22	615
23	646
24	678
25	712
26	747
27	785
28	824
29	865
30	908
31	931
32	954
33	978
34	1002
35	1027
36	1052

Table 8

Part	Impact Score	Impact Score (with injection molding)
Cap and Battery Containers	8.06	0.0936
Nalgene Shell	0.1924	0.1924
PVC Pipe	0.096291	0.096291
Copper Pipe	0.8526	0.8526
Batteries	5.72	5.72
Acrylic	0.2128	0.10944
Wires and Copper Plates	0.5	0.5
Electric resistors	0.08464	0.08464
Total	15.718731	7.648971

Table 9

Month	Revenue ($)	Expenses ($)	Monthly Net Profit ($)	Total Net Profit ($)
1	7499	20008.33	-12509.33	-12509.33
2	8248.9	20175.83	-11926.93	-24436.26
3	9073.79	20360.08	-11286.29	-35722.55
4	10048.66	20577.83	-10529.17	-46251.72
5	11023.53	20795.58	-9772.05	-56023.77
6	12148.38	21046.83	-8898.45	-64922.22
7	13348.22	21314.83	-7966.61	-72888.83
8	14623.05	21599.58	-6976.53	-79865.36
9	16122.85	21934.58	-5811.73	-85677.09
10	17697.64	22286.33	-4588.69	-90265.78
11	19497.4	22688.33	-3190.93	-93456.71
12	21447.14	23123.83	-1676.69	-95133.4
13	23546.86	23592.83	-45.97	-95179.37

14	25946.54	24128.83	1817.71	-93361.66
15	28496.2	24698.33	3797.87	-89563.79
16	31345.82	25334.83	6010.99	-83552.8
17	34495.4	26038.33	8457.07	-75095.73
18	37944.94	26808.83	11136.11	-63959.62
19	39819.69	27227.58	12592.11	-51367.51
20	41844.42	27679.63	14164.79	-37202.72
21	43944.14	28148.83	15795.31	-21407.41
22	46118.85	28634.58	17484.27	-3923.14
23	48443.54	29153.83	19289.71	15366.57
24	50843.22	29689.83	21153.39	36519.96
25	53392.88	30259.33	23133.55	59653.51
26	56017.53	30845.58	25171.95	84825.46
27	58867.15	31482.08	27385.07	112210.53
28	61791.76	32135.33	29656.43	141866.96
29	64866.35	32822.08	32044.27	173911.23
30	68090.92	33542.33	34548.59	208459.82
31	69815.69	33927.58	35888.11	244347.93
32	71540.46	34312.83	37227.63	281575.56
33	73340.22	34714.83	38625.39	320200.95
34	75139.98	35116.83	40023.15	360224.1
35	77014.73	35535.58	41479.15	401703.25
36	78889.48	35954.33	42935.15	444638.4

Works Cited

Aerenhouts D, Chapelle L, Clarys P, Zinzen E. Hydration Status in Adolescent Alpine Skiers During a Training Camp. J Hum Kinet. 2021 Jul 28;79:55-63. doi: 10.2478/hukin-2021-0062. PMID: 34400986;

PMCID: PMC8336538.

Dehydration (2021) Mayo Clinic. Mayo Foundation for Medical Education https://www.mayoclinic.org/diseases-conditions/dehydration/symptoms -causes/syc-20354086 (Accessed: January 20, 2023).

Dehydration symptoms and treatments (no date) Illnesses & conditions NHSinform.https://www.nhsinform.scot/illnesses-and-conditions/nutrit ional/dehydration#:~:text=Dehydration%20can%20also%20lead%20to ,the%20risk%20of%20kidney%20stones (Accessed: January 20, 2023).

"Energy Density: Why Gasoline Is Here to Stay." *Science 2.0*, 27 Aug. 2014, https://www.science20.com/science_20/energy_density_why_gasoline_here_stay-91403.

How much you really need to drink when exercising - US news &

at:https://health.usnews.com/wellness/articles/2018-07-09/how-much-y ou-really-need-to-drink-when-exercising (Accessed: January 20, 2023).

H2 snow (no date) James Dyson Award. Available at: https://www.jamesdysonaward.org/en-MY/2018/project/h2-snow/ (Accessed: January 20, 2023)

"How Much Water Do You Need to Stay Healthy?" *Mayo Clinic*, Mayo Foundation for Medical Education and Research, 12 Oct. 2022, https://www.mayoclinic.org/healthy-lifestyle/nutrition-and-healthy-eating/in-

depth/water/art-
20044256#:~:text=The%20U.S.%20National%20Academies%20of,fluids%20a%20day%20for%20women.

Meinecke, B. (2018) Column: Dehydration key factor in incidents in Backcountry, Cody Enterprise. Available at: https://www.codyenterprise.com/news/sports/article_64941f88-8abd-11e8-9e06-47cf73a5f93e.html (Accessed: January 20, 2023).

Melting snow for drinking water (no date) SummitPost.org. Available at: https://www.summitpost.org/melting-snow-for-drinking-water/774270 (Accessed: January 20, 2023).

Melting ice and boiling water in the mountains a history and physics essay https://www.wemjournal.org/article/S1080-6032(17)30238-7/pdf (Accessed: January 20, 2023).

Paybarah, A. (2021) Here's how to use snow when there's no water flowing from the faucet., The New York Times. The New York Times. Available at: https://www.nytimes.com/2021/02/17/us/how-to-use-snow-water-texas.html (Accessed: January 20, 2023**).**

Published by Statista Research Department and 6, J. (2023) U.S. mean disposable household income by age 2020, Statista. Available at: https://www.statista.com/statistics/980324/us-mean-disposable-househ old-income-age/ (Accessed: January 20, 2023).

"The Chemical Magic of Hand Warmers." *Science Focus*, https://sciencefocus.ust.hk/the-chemical-magic-of-hand-warmers#:~:text=Oxidaton%2Dbased%20hand%20warmer%20packs,%2Fhydroxide)%20and%20releasig%20heat.

Walther J, Mulder R, Noordhof DA, Haugen TA, Sandbakk Ø. Peak Age and Relative Performance Progression in International Cross-Country Skiers. Int J Sports Physiol Perform. 2022 Jan 1;17(1):31-36. doi: 10.1123/ijspp.2021-0065. Epub 2021 Jun 29. PMID: 34186511.).

Water facts - rehydration project - focus on dehydration and oral rehydration. Available at: https://rehydrate.org/water/ (Accessed: January 20, 2023).

Published by Statista Research Department, and Dec 9. "U.S. Americans Who Went Skiing 2021." *Statista*, 9 Dec. 2022, https://www.statista.com/statistics/191312/participants-in-skiing-in-the-us-since-2007/.

Published by Statista Research Department. "Traditional/Ice/Mountaineering Climbing Participants US 2021." *Statista*, 9 Dec. 2022, https://www.statista.com/statistics/763799/climbing-traditional-ice-mountaineering-participants-us/.

"Topic: Winter Sports." *Statista*, https://www.statista.com/topics/1770/winter-sports/.