Britten Water Filtration System Team 0G

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1. Executive Summary

The purpose of this senior design project was to create a water filtration system within a recycled 10’ shipping container powered by a renewable energy source and shore power. Research was conducted on various topics including water standards, energy sources for potable use, and types of water filtration. Since the shipping container is designed to be transported anywhere in the world, in-depth analysis of countries and their water standards were conducted. To cover all regions, the team decided to abide by United Nations’ water standards. The team also deliberated on the type of energy source; solar energy was chosen due to its efficiency and energy capture accuracy. Along with the solar panels, a backup generator was included for supplemental supply. Next, the team designed and mapped the water filtration layout. The shipping container intakes water from a natural source by an inlet pump and pumps it into the system for sanitation. First, the water flows through a depth filter to remove sediment and then a water softener to reduce the hardness, both of which extend the lifespan of the system. The water is filtered through a Reverse Osmosis (RO) system which eliminates harmful minerals, ions, bacteria, and chemicals. Once the water undergoes filtration, the clean water flows to a holding tank. From here, the water passes through a UV water filter to either be recirculated back into the tank or pumped out of the system as potable drinking water. Another important layout design was the electrical schematic; it was key in observing how the inner electrical connections work. Connected to the solar panels, a combiner box outputs solar power to a 48V inverter. Additional shore power from a generator and a battery bank also input to the inverter. To design the solar panels mounts, several CAD models of the container underwent a DFMEA analysis. Ultimately, the design that utilizes a hinge mount with shocks performed the best. To meet the design goals, the team created several documents with parts needed, assembly designs, pricing, and product requirements. Due to time constraints, the team will not fabricate and assemble a prototype. Instead, the design will be submitted to the sponsor, BoxPop powered by Britten, for their own fabrication. To assist in future fabrication, two bench tests were conducted. One test confirmed all electrical and power standards are met; the other tests the water output loop. Facing several obstacles involving parameter changes and patent concerns the team worked with the sponsor to finalize the project. Additionally, feedback from sponsors, faculty, and field experts led to constant improvements throughout the two semesters. The final design of the water filtration system is enclosed in this document along with all documentation.

2. Acknowledgements

The team would like to acknowledge and express our gratitude towards all the faculty who helped us throughout this project. The team's advisor, Tony Pinar, guided the team throughout the project by providing insight on technical components as well as customer relations. His enthusiasm and attention to detail has kept the project on track throughout the year. The team would also like to thank Dr. Gross for giving a tour of the Michigan Tech Microfabrication Facility and providing advice on the systems used. The team also received advice and insight on several faculty in various specialities. Thank yous are extended to all of them for taking the time to make this project successful. Furthermore, the team is grateful to Dr. Hassell for extending his knowledge on self contained solar power systems, as well as supplementing power. Additional gratitude is extended to professors Bergstrom, Hassell, Morgan, Lukowski, and Pinar for their feedback on in class presentations. Lastly, the team is grateful to the Britten sponsors, Nathan Bildueax and Matt Egan, for supporting this project and allowing the team to take creative lead. The bi-weekly meetings to discuss updates helped propel this project towards its successful completion.

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3. Introduction and Background

3.1 Project Sponsor

The team's sponsor, Britten, is a creative production house that custom prints various innovative displays. A subsector of Britten includes their brand BoxPop® in which they design custom shipping containers that can be transported anywhere in the world. Various designs of the shipping containers include bars, stages for artists, food venues, etc.

3.2 Project Scope

BoxPop® was looking to launch a new line of shipping containers that would be used as a water filtration system. The system would address a constant demand for fresh water across the globe, whether it be due to a disaster, a community not retrieving quality water, or in events that would benefit from a water filtration system to eliminate plastic waste. BoxPop® asked the team to design and create a water filtration system to be added into their line of products. The goal of this project was to create an entirely self contained water filtration system within a 10 foot ISO shipping container. The system should be able to run without outside power or interference for an extended period of time with minimal maintenance. The shipping container should be able to be placed anywhere in the world; targeted areas include disaster relief zones and isolated communities to provide clean water. The shipping container should be able to pull from any water source, and the output should be cleaned to the NSF-53 standard [5]. With the shipping container, the team also provides documentation for assembly, operation, and maintenance.

3.3 Preliminary Research

3.3.1 Water Filtration Products

In the first week the team researched information about various water filters. More specifically, research focused on acquiring background knowledge on emergency relief water and existing portable water filtration systems. This included industrial and personal water filters found in disaster relief locations. From this research, the team learned about the possibility of condensing a system into a small transportable body. The research provided methods of filtration used and the type of water encountered while using water filtration devices. The most valuable information learned was that most industrial systems utilize Reverse Osmosis (RO) filtration.

Based on that information, further research focused on reverse osmosis and what it would need to sustain its lifetime. Several RO suppliers manufacture advanced filtration systems and had information on their websites in regards to the requirements. This information was used to determine pre-treatment filters and plumbing system methods.

3.3.2 Patent Review

After identifying several potential competing products, the team performed a patent review with Google Patents and the USPTO website. Key terms like “reverse osmosis”, “portable”, “shipping container”, and “water filtration” were used to narrow down a list to under fifty patents. The patents were compiled into a spreadsheet, which can be found in Appendix E Table 16.2, with their respective patent numbers, titles, and brief descriptions. Each patent was carefully read to be marked as a concern. It was determined US20210061693, US7775374, and US8808537 could be infringed on by our design. Therefore, a presentation was created to present to the sponsor to inform them of the issue. The patents were determined to target a different market that this project, and this project continued.

3.3.3 Water Rights

A crucial component to the product being provided is that everything is environmentally and legally conscious. Drawing too much water depletes the source, and the customer, Britten, would inevitably endure the consequences. In order to prevent this, the team researched the process for obtaining permits needed to operate the system. They reached out to various professors and compared various US State regulations. Based on the research for obtaining a permit with the team’s criteria, the location of the container was a key factor in obtaining permit records. State requirements showed that the system would be tested manually after dispensing to ensure potable water is outputted. The tests require the water to not exceed the Maximum Contaminant Level (MCL), a standard set by the Environmental Protection Agency in the Safe Drinking Water Act. The team plans to have tests readily available on site that will indicate by color if the water is safe. These test strips will be located on the exterior of the container by the outlets. The strips will indicate if the water is undrinkable, based on the EPA’s maximum contaminant level, by measuring bacteria, lead, and pH. Another safety indicator will be a handheld meter that reads the amount of total dissolved solids to verify our water is less than the EPA MCL requirement of 500 mg/L.

If the need for water spans several states, post hurricane for example, the target customer is FEMA; FEMA does not require any permitting. For developing nations, the process is less demanding, but each country has its own regulations. The biggest concern for developing countries is whether or not the water is privately owned. Overall, the process for receiving permission to pull water from various sources is not an issue as long as the water is tested for safety.

Design Problem Solution

4. System Overview

4.1 Water System Overview

After researching each part of the water filtration system, the team created a water flowchart to demonstrate the flow of water through the system. Found in Figure 1, the system starts with the inlet hose powered by an inlet pump. From here, the water is shown to flow through two pretreatment systems, a depth filter and a water softener, which is to be processed by the RO system. The RO system has both an outlet connection to the holding tank and a waste water outlet. The water flows through the UV filter to either be pumped out of the system for consumption or recirculated into the tank for storage. All piping will be Schedule 80 PVC besides the connection between pretreatment systems. The diagram labels all parts of the system including pipes, water pressure for the pumps, and water pressure for the RO system.

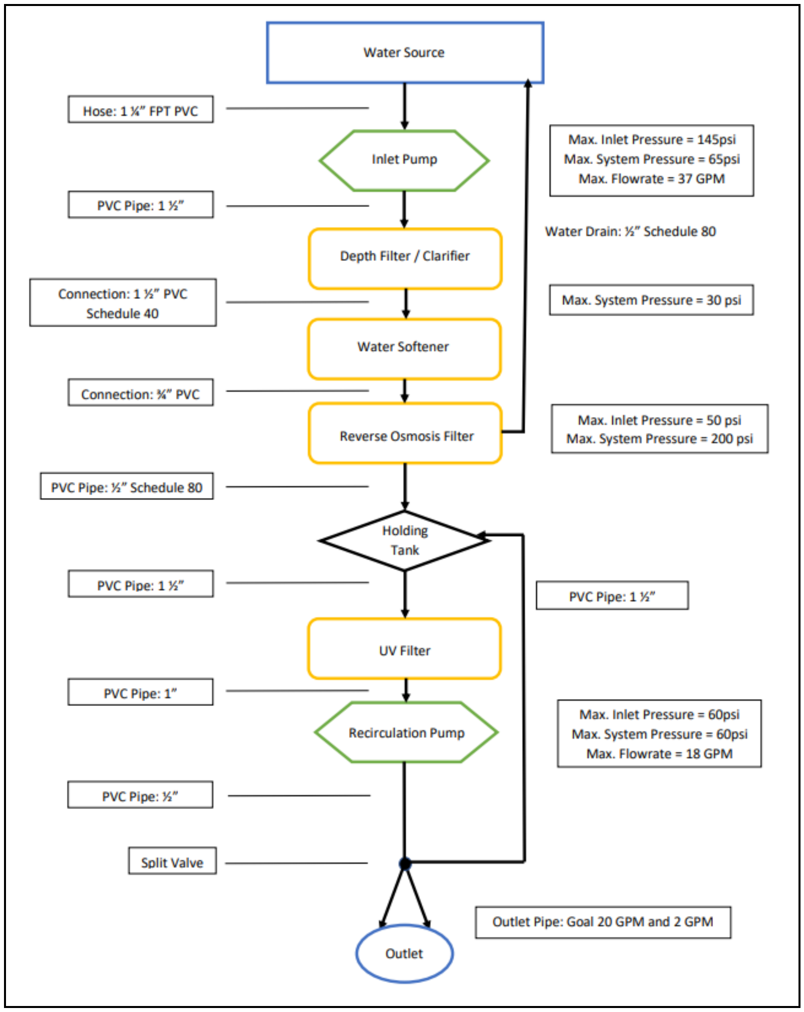

Figure 1: Water Flow Diagram

After designing the overall water system, the team collaborated with one another to determine specific parts to purchase. The team collected quotes from various suppliers and compared each through decision matrices. In Table 1, a complete list of parts the team recommended for fabrication was sent to the sponsor. The team also completed a container layout schematic to ensure all components could fit within the container. The CAD model is a rough layout with proportional components inside, as demonstrated in Figure 2.

Table 1: Water System Parts List

Item Name	Manufacturer	Product Name
Intake Filter	Northern Metal Products	Kleen Flo Filter
Inlet Pump	RainFlo	MHP-150a
Water Softener	Culligan	HET-090
Sediment Depth Filter	Culligan	HE DF-14
R.O. System	Culligan	G2 6HE
Storage Tank	Tank Market	Custom
Drain Valve	SharkBite	1" Ball Valve
UV Filter	Viqua	VP600
Outlet Pump	Finish Thompson	DB4P
3-Way Valve	Belimo	3-Way Valve

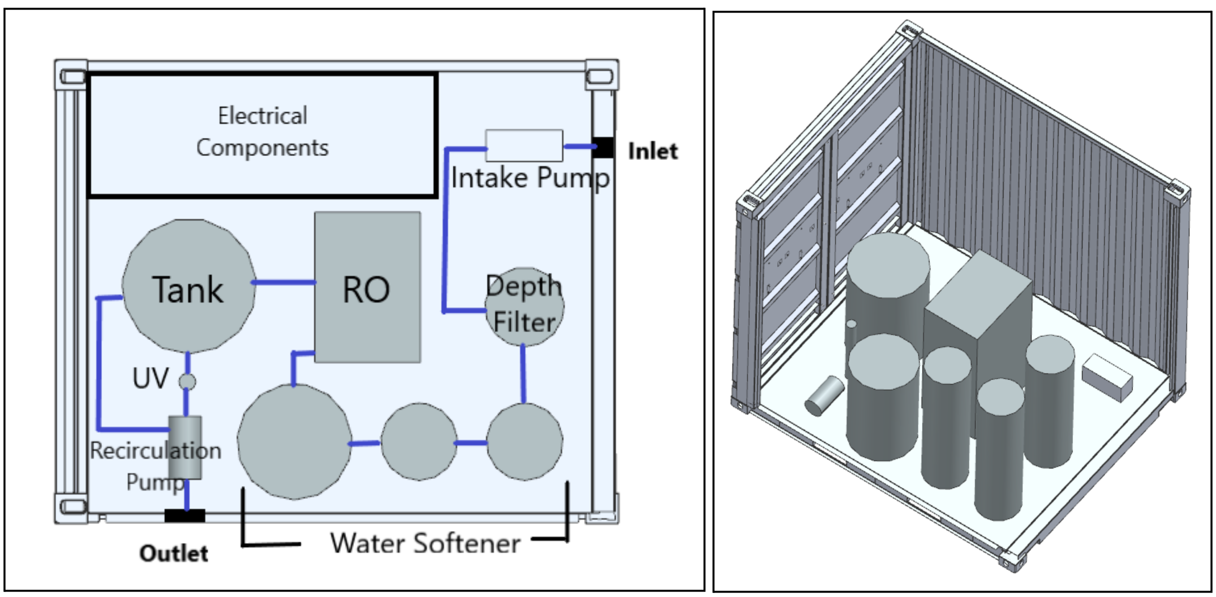

Figure 2: Container Layout Schematic

4.2 Electrical Systems Overview

With the research into components for the electrical system completed, a comprehensive schematic was created to illustrate the individual components and how they will be connected to one another. Seen in Figure 3, the two power sources both flow into our inverter/charger, directly in the case of grid power and through a combiner box that joins all of the solar power input lines into one live line. From our inverter, we can send power straight to our output at 120VAC, or we can route power to our 48V battery bank to charge them. These batteries can also act as a supplemental power source, allowing us to pull power from them in addition to the other two sources. We will also fork 24V off of our inverter output to power our PLC. Table 2 is a components list for fabrication that was sent to the sponsor.

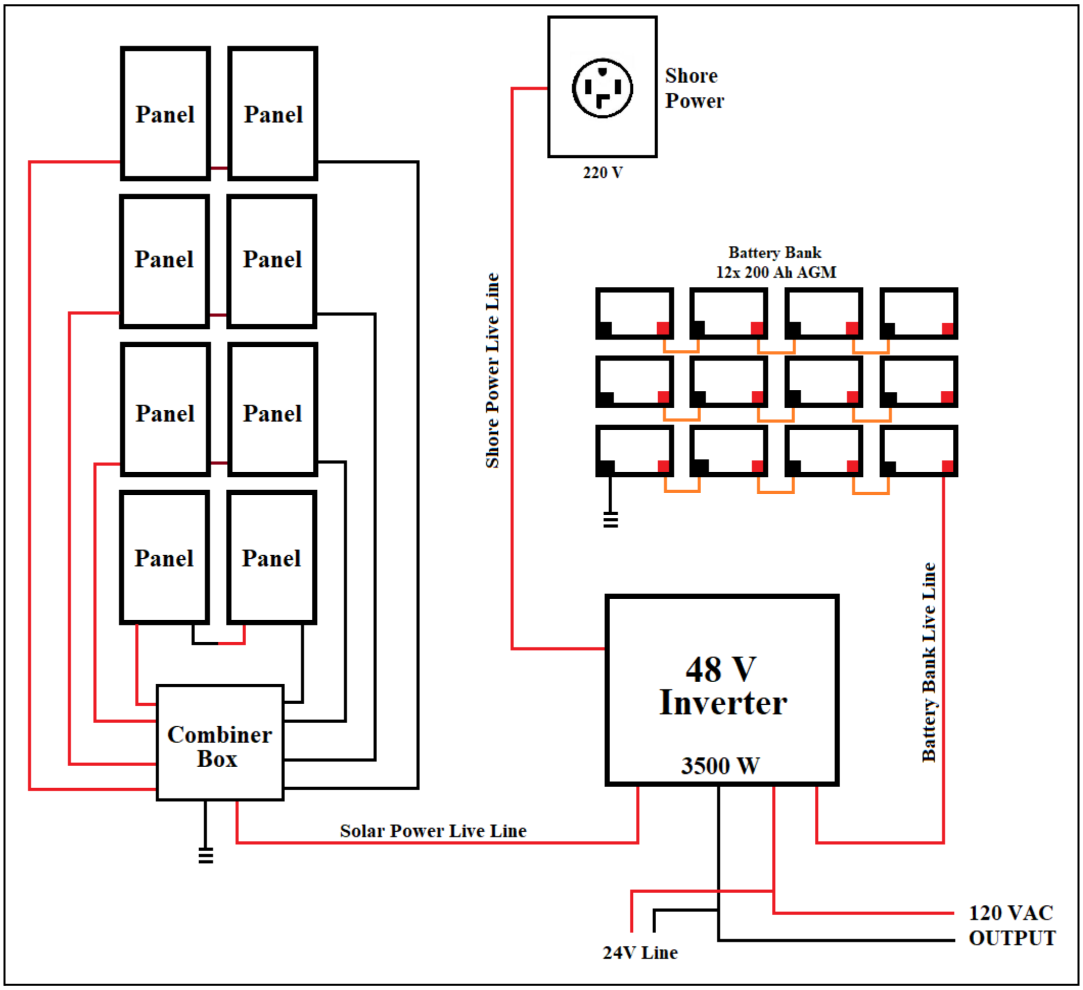

Figure 3: Electrical System Diagram

An essential feature of our electrical system is the ability to run entirely on renewable energy. As seen in Figure 4, the container includes 8 solar panels deployed in pairs on the left, right, top, and back of the container. Power from the panels is centralized in the combiner box before being routed into the battery energy storage system. To facilitate easy transportation as well as efficient power production, the panels are hinged-mounted on the side of the container. They are also surrounded by a tube frame to protect the panels and provide improved structural stability.

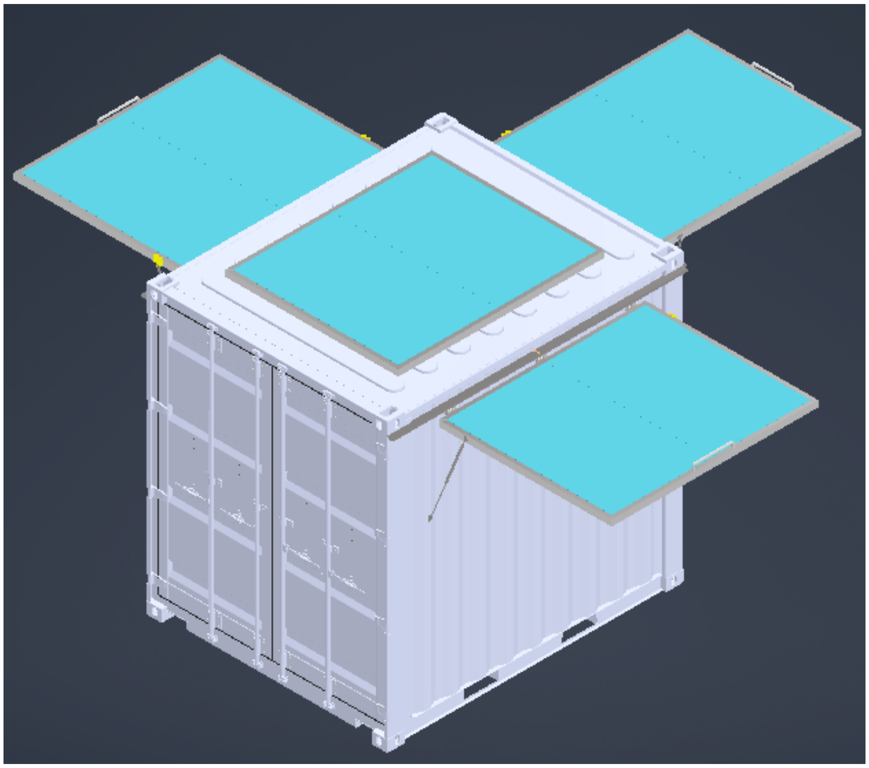

Figure 4: Deployed Design

Table 2: Electrical System Parts List

Item Name	Manufacturer	Product Name
Solar Panels	Renogy	300W Solar Package
Inverter/Charger	Renogy	3500W Full Sine Wave Inverter/Charger

4.3 Control System Overview

The PLC and the sensors had to be physically connected to each other in order to program the sensors to turn on and off at certain specifications. Both the load cell sensor and the pressure transducer had digital outputs which made connecting to the Micro820 PLC straightforward. The team created a drawing in order to represent the controls' connections to each other, which can be seen in Figure 5. Once the physical connections were made the PLC code had to be produced to allow the sensors to work. Specifically, the team programmed the load cell sensor to indicate when the load was at 80% full, which would output a light within the shipping container to indicate that the system needs to briefly stop or to have customers utilize the stored water. The pressure sensor was placed after the water treatments and before the output pump to measure the pressure going out of the system. The connection from the pressure sensor to the PLC allowed for the pressure measurements to be seen on the monitor connected to the PLC. This would indicate whether the pressure measurement from the sensor validated what the actual output pressure was. Table 3 is a components list for fabrication that was sent to the sponsor.

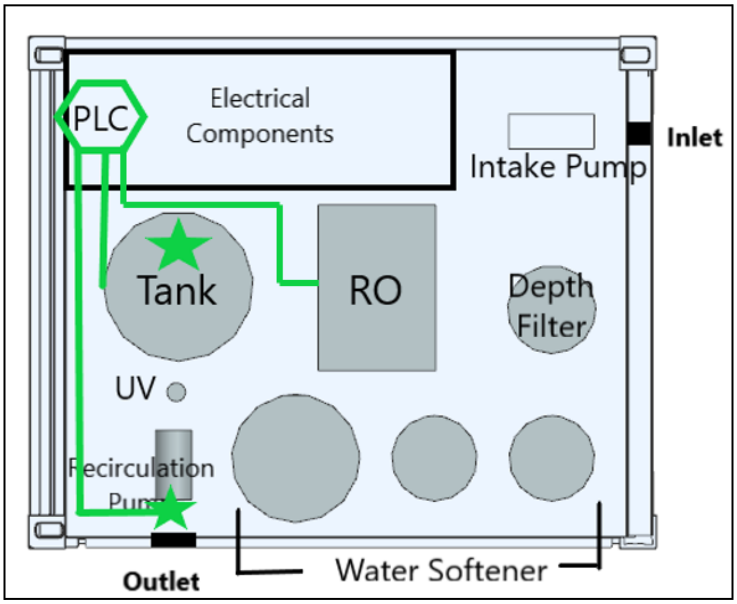

Figure 5: Control System Diagram

Table 3: Control System Parts List

Item Name	Manufacturer	Product Name
PLC	Allen Bradley	Micro 820
Pressure Sensor	TE-Connectivity	M32JM-000105-100PG
Load Cell	TE-Connectivity	FC2311-0000-1000-L

Design Problem Analysis

5. Water Purification System

5.1 Preliminary Research

The first aspect of research was to determine the main purification system. Research started with this because the type of pre- and post-filter depended on characteristics of the main purification system. The team researched the high-level pros and cons of the potential purification methods, which can be found in Appendix D Table 15.0 within Appendix D. Based on the general information of the various methods, a decision matrix was constructed. The purification method data and development were found and formatted into Appendix D Table 15.0; the table shows the contaminants that could be found, removed, and treated within each purification method. Each contaminant was weighted the same since it was unknown where water would be drawn from. Because water can be drawn from a variety of sources and locations, the levels of contaminants, such as metals and bacteria, will vary. Thus, we decided to treat each contaminant as equally likely to occur. Additionally, the decision matrix shows a RO system is optimal over a distillation system in the slightest margin. To further validate the choice in utilizing a RO system, another pro and con chart was created for a deeper comparison of a RO system and a distillation system. Table 15.2 within Appendix D proves that a RO system is optimal, and the two determining factors for an RO system over the distillation system was the slow start-up time and the heat production of distillation systems. [1] [5]

Figure 6: Block diagram of the generic water purification system

5.2 Main Purification System

Once the RO system was selected, the team reached out to various companies for quotes on the system. In total, five quotes were received but the uniqueness of every system called for another organized table comparing every product quoted. Tables 15.3 and 15.4 in Appendix D shows the comparison of the RO systems quoted and the different specifications of each of the efficiencies, energy usage, water production, control panels, and price points.

Based on the data of each system, a decision matrix shown in Table 15.5 in Appendix D was constructed to evaluate the five systems quoted to the team. The two highest weighted categories were energy usage and the max total dissolved solids (TDS) the system could handle. Energy usage is a significant constraint for the system since it is primarily powered by solar energy, which would not produce as much energy as other sources. Furthermore, the higher the TDS range of the system then the more water sources the system would intake. The maximum clean water output, price, and extra features were also weighed heavily since these were critical aspects to the design of the system. Extra features include sensors, flowmeters, displays, and various other items that enhance the RO system. In addition, the team decided that another necessity was that the system should be compatible with an external programmable logic controller (PLC). This was a critical component, as an external PLC would be used to control various aspects of the project. The ability for an RO system to be compatible with a PLC was the determining factor between the highest ranked products which ultimately led to obtaining the Culligan G2 6-HE RO system.

5.3 Pre-Treatment System

Once the decision regarding our main purification system was made, a pre-treatment system was needed. After completing research into the efficacy of RO systems it was determined that the RO system was capable of treating all of the identified contaminants that would need to be eliminated and treated. However, another problem arose in which the higher the concentration of those contaminants, the lower the efficiency of the RO system. Therefore it was determined that a pre-treatment system would be beneficial to improve the performance of the filtration system.

Based on a discussion of the RO system performance with a variety of engineers at various water purification companies, it was discovered that the suspended solids, total dissolved solids, and the water temperature are the three greatest factors relating to RO system efficiency. The first potential problem began with the system obtaining suspended solids while drawing from the various surface water sources. Suspended solids are problematic because they will greatly reduce the efficiency of the RO system, as they are relatively large particles such as sand and sediment that will clog the RO filter. To solve this potential problem, the team reached out to water purification companies for quotes on depth sediment filters and clarifiers, both of which could eliminate suspended solids. Culligan, our RO system provider, sent a quote for a sediment depth filter for $1,958. Inputting this system and comparing it to other systems in a decision matrix found in Table 15.6 Appendix D, the team chose the Culligan sediment depth filter with the main factors being the cost and the maximum water flow rate. Secondary factors considered were the maximum pressure and temperature and the filter media volume. In addition, this system is compatible with the RO system chosen which provides ease in creating technical drawings, any compatibility complications, purchasing, and organization.

Once the suspended solids are reduced, the amount of TDS needs to be decreased in the water. TDS are broken down into four categories: salts, minerals, organic matter, and metals. Each category does not affect the system the same; thus, the correct purification system is needed to meet the needs of the project. To begin, most organic matter is removed by the sediment depth filter and because the system is designed to draw from mainly freshwater sources, the team did not foresee salts or metals playing a significant role. However, it is expected that large amounts of minerals would be present within our water source. Based on this information, the team's primary focus was on the elimination of minerals and having the RO system effectively remove all TDS present in the water that is fed into the system.

A water softener is ideal for removing minerals from the surface water. Water softeners remove the "hardness" from water, which comes from minerals such as calcium and magnesium. Therefore, the team reached out to water purification companies for quotes. The water softener from Culligan was quoted at $4,118 which led to the ultimate decision of utilizing that water softener. The finalized decision matrix of this decision is shown in Table 15.7 Appendix D. In conclusion, the team decided to buy the two main components of our pre-treatment system, the sediment depth filter and the water softener, from Culligan. Not only are these relatively inexpensive products, but both were also quoted to be perfectly compatible with the RO system. Additionally, buying from one supplier would make it easier for the team's sponsor to purchase and potentially work through any troubleshooting.

5.4 Post-Treatment System

Once the main filtration system and the pre-treatment system were determined, the final objective was to narrow down and choose the post-treatment system. Although the sediment depth filter, water softener, and reverse osmosis system remove almost all contaminants from the water, there had to be consideration of the holding tank in which all of the newly purified water would settle into until use. Since water would settle in the holding tank for unknown periods of time, it is susceptible to the build up of bacteria or viruses. Therefore, a treatment system was needed to successfully counter that threat. An ultraviolet (UV) system was the perfect choice based on these stipulations and concerns. As seen in the purification method analysis in Table 15.8 Appendix D, UV systems are excellent at combating bacteria, viruses, and protozoa.

Once the UV system was identified as the ideal post-filtration method, the team reached out to companies for quotes of this type of system. After all potential quotes were received, the team concluded to not use the UV system from Culligan, but rather a system from Fresh Water Systems. Due to high flow capability and ideal pressure conditions of the Viqua VP600 UV filter, the team decided to move forward with that product. Periods of high demand during meal times require a robust system, and a more effective UV system, overbuilt for the system, will decrease the maintenance cycle of the project. The decision matrix used to make this decision can be seen in Table 15.9 Appendix D.

The UV system is implemented within a recirculation tube that will continuously run to purify the water within the holding tank. Once water is demanded, a valve in the recirculation tube will open to allow water from the holding tank to flow through the UV system prior to being outputted.

6. Electrical Systems

6.1 Preliminary Research

The power system for this design was one of the major pieces that required careful planning to ensure that the team met their goals. Initially, it was expected that the system be powered primarily by alternative energy, with a shore power/grid hook up being a secondary possibility. However, as the design evolved, it came to light that the container should be powered by the grid if it was available, and only utilize alternative energy for the worst case scenario. Due to the primary purpose of the container being utilized as disaster relief or humanitarian product, whatever power system was designed would need to be both robust and simplistic to operate, to allow for continued long term use as well as easy maintenance with minimal training. As a result of these parameters, a couple of alternative energy sources were discussed, however for the scale of the project and the limitations of the use case, solar power is the only feasible option. There was also consideration of electrical codes for both the United States and abroad in which the team followed the UL-1741 standards and the Canadian Electrical Code [6] [7].

6.2 Solar Power

After deciding on solar energy as the alternative source, the team needed to determine the exact parts that would constitute the design. Early on, Renogy jumped out as a company that could provide most of the components at market price and, most importantly, would deliver on the expected output. The system design consists of 8 320W solar panels, arranged in 4 groups of 2, capable of generating up to 2500W (realized) at ideal conditions. These panels were chosen primarily for their efficiency as well as durability, as demonstrated in Appendix D, Table 15.10. At 40 pounds, this makes these groups of panels capable of being deployed from their storage solution (see Section 9) by one person. From the panels, the power is consolidated into one live line at the panel combiner box, which is connected to the main inverter/charger that controls the flow of electricity within the container depending on the operation mode. A battery bank consisting of 12 12V, 200Ah AGM batteries is connected to this inverter, which can be charged by the solar array and is capable of powering the entire water filtration system for up to 8 hours continously. A diagram of this power path can be seen in Figure 2 above.

6.3 Shore/Grid Power

When balancing the power the system would consume, the primary option was to utilize the grid of the area that the team found themselves in, if it is operational and reliable. If the system can run without draining the resources of the in-need area, then the shore power option helps extend the lifespan of our battery bank and/or lighten the load. With this stipulation in mind, the 48V inverter/charger mentioned previously also has the ability to route power directly from a grid source to its output, and let power from the solar array go directly to the batteries if needed. The container will come equipped with a standard NEMA generator inlet plug, as well as a 110V rated cable to connect to a grid power output plug and various adapters for any country electrical standard that the container may encounter.

6.4 Generator Options

Initially, the option for connecting a generator to the container was a backup plan if the team could not find a way to utilize grid power. However, it was ultimately decided to provide an input socket capable of connecting to a standard generator. The expectation for the generator is that it is capable of generating and distributing the same amount of power (2500W) to the container as the solar system would be, in case of an unexpected failure within the power subsystem. Ultimately, the decision on whether or not to purchase a generator to go along with the system, as well as what specific model was left up to our sponsor and the engineers who will put together the final product.

7. Plumbing

7.1 Pumps

7.1.1 Preliminary Research

Initially, various types of pumps were researched including centrifugal, jet, and positive displacement. Centrifugals are the most common and best for pumping water. They transport fluids by converting rotational kinetic energy to hydrodynamic energy. By creating a decision matrix shown in Appendix D, the team was able to figure out which pump would work best with the power constraint and desired properties. It was found that centrifugal pumps are most efficient at moving water vertically, require the least amount of energy, and are the most durable.

There are also several other types of pumps that use centrifugal technology to compare. A decision matrix shown in Appendix D Table 15.11 to compare the various types, including submersible, trash, and variable speed. Submersible and trash pumps have to be placed in the source, and this highly affects the durability and maintenance. The variable speed pumps are either used for low flow application or very large flow application. Neither work for the parameters of the outlet pump. By conducting research on over twenty-five different centrifugal pump models, the team was confident in the decision to select the best centrifugal pump for the inlet and outlet. Each inlet and outlet pump had different requirements that are listed in the following sections.

7.1.2 Inlet Pump

The chosen pump for getting water out of the source is a RainFlo centrifugal pump. The decision matrix is in Appendix D Table 15.12 The chosen centrifugal pump, Rain Flo 150A, is capable of operating at a head lift of 164’ and a flow rate of 36 GPM. The operating requirements is to pull water from 50’ of a source and a max flow rate of 10 GPM. This means that the pump will require less maintenance, and if needed, can operate at a higher demand. This scenario may occur if the source is further than 50’ and if the team needs the RO system to require more than 10 GPM. This pump also has a feature other pumps do not have that simplifies the product. Once the RO system begins to filter water, the pump will automatically begin drawing water from the source. This negates the need for external control from the PLC. The maximum power requirement is 1.2 kW which is well within the power constraint.

7.1.3 Outlet/Recirculation Pump

The team decided to consolidate the recirculation pump and outlet pump by using a single pump and a controllable T-valve. The pump chosen was a Finish Thompson DB4P Centrifugal pump that required minimal amounts of energy. Since there was no head lift required to travel within the container, the main constraints for this pump included power and flow. This pump has a max output of 18 GPM which will be able to fill large containers fairly fast out the highflow output. The maximum power drawn from the pump is 0.18 kW.

7.2 Tanks

7.2.1 Preliminary Research

The team researched several different water tanks that would suit the system in both size, cost, and efficiency. The research initially brought seven different water tanks: carbon welded steel, pillow, folding, polyethylene, fiberglass, and stainless steel. Automatically the folding, pillow and fiberglass were out of the scope the design needed, but the carbon steel, stainless steel, and polyethylene tanks were great options. Looking more into the specifications of the remaining three water tank options, a decision matrix was created. The decision matrix, shown in Table 15.13 Appendix D, observes that a polyethylene tank is the most effective and efficient for the design based on its various resistances, cost, and sizing. [4]

The next step found the correct water tank by identifying a product that had two inputs and one output. One for the recirculation pump to pump water back into the water tank, and the other for the RO system to pump water into the tank. The output connects to the UV filter for secondary filtration. The 100-gallon vertical water tank was fabricated to meet the system’s needs with specifications of one input and the output being 1 ½“ and the other input remaining 1

¼”. The reason for the specific sizing of these inputs and output was due to the piping that would connect to the water tank. There was only one company that would fabricate a polyethylene water tank, Tank-Mart, and the only dimensions they had for a 100-gallon vertical water tank contained a height of 43” and a diameter of 28”. The placement of the fabrications are based on the feedback of the company producing the water tank along with the sizing of the specified holes needed.

7.3 Pipes

7.3.1 Preliminary Research

Initial pipe research included copper, PEX, PVC/CPVC, and galvanized steel. All types were put into a decision matrix to determine the best one for our application. Several manufacturing websites were used to compile this information and put in a decision matrix. The decision matrix is located in Appendix D Table 15.14 with key categories being corrosion resistance, safe for potable water, leak resistance, and cost. The corrosion resistance for potable water, leak resistance, and UV resistance columns are based on standards it met as well as recommendation by plumbers and experts. The remaining columns are based on actual values collected during preliminary searches; this data is included in Table 15.14 Appendix D. The decision matrix determined PVC to be the best option, however, our customers preferred PEX piping based on their own experience and products. The team started to create another decision matrix solely for PEX-A and PEX-B. However, once fabrication began the team learned PEX does not handle high pressures from the RO System. Based on these results, the team decided to follow the water treatment recommendation of PVC. A comparison of PEX and PVC was created to justify the change to the customer. Schedule 40 PVC would be used to connect the pretreatment systems based on the manufacturer's recommendations. Schedule 80 would be used throughout the rest of the systems based on its ability to withstand water pressure of 400-850 psi depending on the diameter size used. This fulfills our max pressure of 200 psi produced at the RO Systems outlet. [3]

The team also looked into what type of piping to draw water from a source. By conducting research and speaking with professionals, the team found that the piping from the source needed to be flexible and UV resistant. The team decided on using Schedule 40 flexible PVC piping since flexible piping can accommodate various terrains and is UV and microbial resistant, which will prevent the build up of algae. The end of the piping that is placed in the source will have a 28” x 9” Kleen Flo Filter with a fine mesh to strain out large solids. This was based upon a decision matrix shown in Appendix D Table 15.15. The filter requires minimal maintenance and is large enough that it won’t get clogged by only a few leaves.

7.3.2 Sizing and Connections

Based on the sizes of the piping throughout the system, there were a few different connectors that were purchased to ensure the piping was all connected properly. There is a ¾” PVC connector in between the water softener and the RO filter in order to connect the two systems together. The RO system will also have a drain valve of ½” that will be sent back to the water source through a ½” hose. The main size of the piping after the holding tank was 1½”, which needed a T-connector to input a pressure gauge to manually validate the pressure going to the output. A drain valve was also placed on the holding tank with dimensions of ½” to release possibly old water or for maintenance purposes.

7.3.3 Brands

Based on our preliminary research, the team performed searches on various manufacturing websites. Using Lowe’s and Home Depot’s websites allowed the team to compare pipes based on size and pressure requirements. The team collected data for both Schedule 40 and Schedule 80 PVC to compare the companies. It can be found in Table 15.16 Appendix D. Grainger and JM Eagle are the two companies that manufacture PVC for potable water. Both have pressure ranges of 400-850 psi and temperature ranges of 33-140 F for Schedule 80 PVC. Grainger has a larger range of sizes which fit the system’s specifications and needs since the inlet piping for the RO is ¼”. All this information was placed in a decision matrix, and the team decided to go with the Grainger PVC brand.

8. Control Systems

8.1 Programmable Logic Controller

A Programmable Logic Controller (PLC) was decided as the best option for controlling the system since it could handle the input and output capability, be easy to program, and be easy to troubleshoot since a PLC is a standard in manufacturing. All of the sensors used within the system are able to interface with the PLC. Another advantage to a PLC is that they are cheap for its type of application, low power, and expandable. Appendix D Table 15.17 gives a breakdown of how the PLC in the system was considered, compared, and chosen.

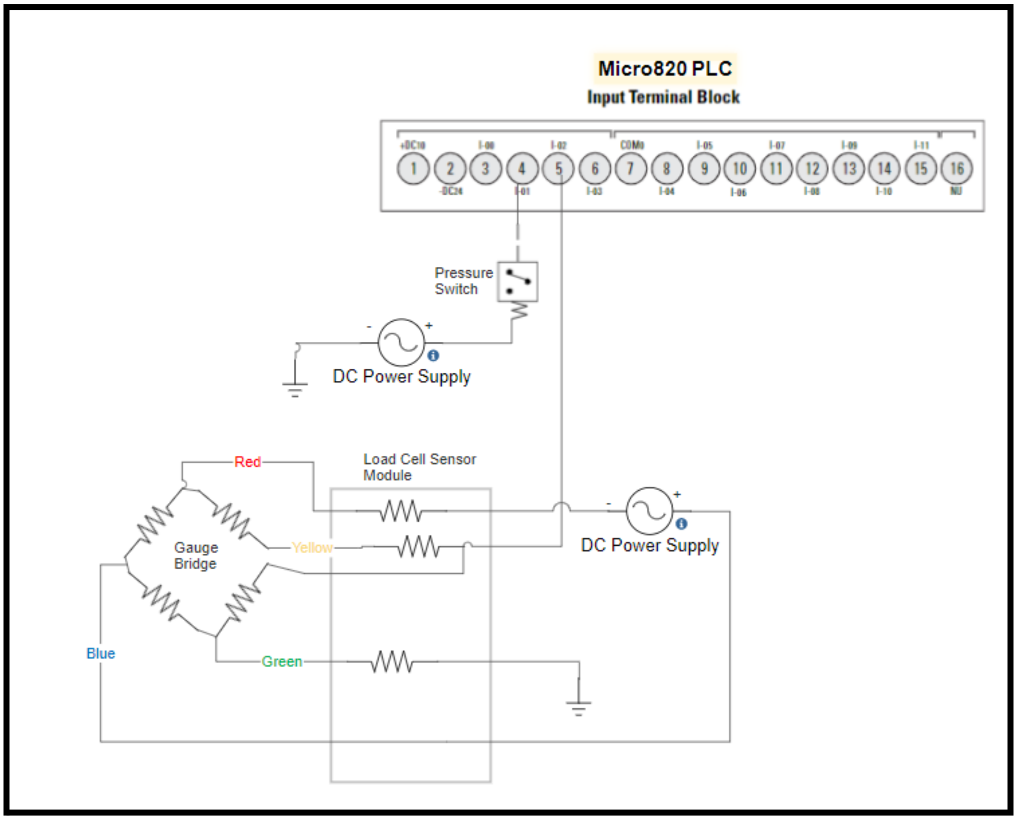

Figure 7: PLC and Sensors Wiring Schematic

8.2 Sensors

8.2.1 Water Tank Sensor

Initially, the team determined what measurements were needed within the tank to assess which type of sensor would be placed. The team considered two different types of sensors, continuous and point level. Between continuous and point level, several styles of sensors were considered and compared in a decision matrix shown in Appendix D Table 15.18. Although continuous sensors have more accurate and multiple measurement readings, they contain more information than needed while point level sensors are simple and are more relevant to the application. To mitigate all the concerns and feedback given, a load cell sensor became the primary choice. It has the ability to handle the weight of the tank, little calibration when installed, accurate measurements, and no possibility of leakage or overflow directly influenced by the sensor; all of which can be found in Appendix D Table 15.19. The amount of load cells utilized depended on the weight of the tank when empty, the diameter of the tank, and the height of the tank. Additionally, a mounting setup was crucial to accurately setup and measure the force of the tank on the load cell sensors [2]. Based on the decision matrix, TE Connectivity's load cells were cheap and only required one load cell while also giving accurate and reliable measurements with little calibration. The load cell sensor contained a digital output which would allow the cells to be connected to the PLC in order to observe and manage the progress of the capacity of the water tank. The load cell, however, had to include a mounting setup in order to exert force only on the center of the load cell. In the bench testing trials the team made their own mounting setup to allow the force of gravity of the container to remain centered on the singular load cell. The actual water filtration system will have three load cells dispersing their force equally in a triangular shape under the water tank. This eliminates any risks of the water tank tipping over or not being able to obtain accurate readings.

8.2.2 Pressure Sensors

The goal for the pressure sensor was that once the outside spouts are turned on, the water against the spout would pour out and drop in pressure. The pressure drop would communicate with the PLC to tell the pump to turn on, as well as the 3-way valve to be open for the outlets. The pressure sensor had to be able to handle 60 psi since that was the max pressure of the recirculation pumps. The static pressure of household faucets range from 20-80 psi which gives insight on how much pressure the pressure sensor should be able to indicate. Appendix D Table 15.20 shows the decision matrix on which pressure sensor was utilized. The main reason for the sensor chosen was because it was cost effective and had a pressure range more relevant to the pressure range the system utilized.

9. Structural

9.1 Solar Panel Mounting

Although the system is designed to be capable of running off of solar power, the array of panels required far exceeds the available surface space of the top of the container. Thus, the panels required some form of physical deployment from a contained storage position into a power position oriented parallel to the earth.

9.1.1 First Option Considered: Sliding Rail

The first version of the solar panel deployment was a staged sliding rail. The panels would be stored on rails inside of the container behind a locked door. Deployment would be accomplished by unlocking the door and pulling the panels out on a stepped sliding rail that provided the travel path and structural support of the panels.

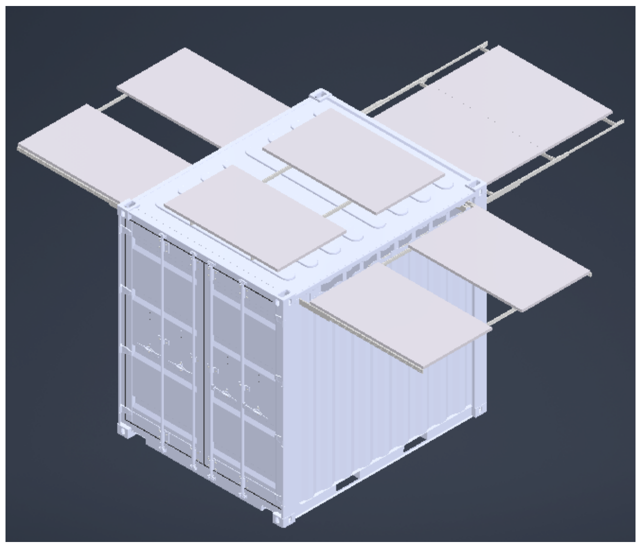

Figure 8: Sliding Rail Deployed Design.

In total, three panels are deployed to the right, left, and back. The top panels are fixed. This design allowed for easy deployment, as well as protecting all panels except the top from damage during travel. The sliding rails, however, had a major drawback. They were vulnerable to dust inclusions that are challenging to clean and could quickly make the design inoperable.

9.1.2 Second Option Considered: Hinged Mount

The second, more matured design changed to an angular side deployment pattern. The stored panels were moved to sit external to the container, on the three available sides, as well as the top and rear. Deployment involved pulling the panel assembly up and out, supported by a set of gas springs and hinged to the container. This was all achievable with commercially available parts, chosen carefully to minimize cost. The only part modifications necessary were miter cuts and tapped holes in the structural frame. The design is detailed in Figure 4.

The first development of this pattern involved a robust steel frame protecting the panels along lateral dimensions and providing structural support independent of the thin steel plating of the storage container. With further analysis of the material capability of the storage container, and in the aim of reducing project and material costs, these steel frames were minimized down a singular line of tube stock to support the hinges. The side columns and undersupport were removed. The gas shock supports, designed to be similar to existing projects of the client, were mounted directly onto the storage container.

These panels are vulnerable to shipping damage, but with the benefit of easier maintenance and longer predicted lifespan. This is also a similar design to existing design solutions by our project client.

An FMEA was created to quantify the differences between these competing designs, visible in Appendix E, Table 16.1. Based on the conclusions of that analysis, the team proceeded with the hinge design and continued with further modifications.

9.2 Container Modifications

9.2.1 Power Connections

In order to facilitate electric connections to shore power or to an external generator, the team needed to construct a connection panel. The guiding principle of this design was to build it for standard electrical connections, and include a kit of various adaptors for different international power standards.

9.2.2 Plumbing Connections

The container required two sets of plumbing connections: inlet and outlet. The inlet panel consists of a single input line to draw from the water source and two outlet connections. The first outlet connection is a high speed connection designed for filling up a large mass of water. The second outlet connection is designed for individual use.

9.2.3 Electrical Conduit

Electrical conduit had to be implemented in order to prevent any water leakage to the wires throughout the system. In Appendix D Table 15.21 a decision matrix on which materials to use for the electrical conduit. The ultimate reason that PVC was utilized was because the rest of the system utilized PVC and so connections, assembly, and acquisition of the product would be made simpler. Additionally, Britten had recommended that PVC be used for the electrical conduit.

10. Results

10.1 Solar Bench Testing

The power system will be tested to ensure that the team is able to produce enough power from both the solar and shore power systems to meet our needs, as well as verifying that switching between modes of power provision creates no additional stress on the system. Finally, the power system will be tested for short term performance to ensure that there will be no drop offs in power during regular use. The values that the team wanted to verify in particular were the solar panel efficiency and power production rate, as well as just verify that all components worked together. During testing, all components functioned as expected and worked with one another, and our solar panel performed in line with expectations, as it produced 149.5W of power at 17.54% efficiency. The advertised values for this panel were 380W at 21% efficiency, and these lowered values are a result of Houghton not receiving a large amount of solar radiation on any given day, especially not in the evening when this test was performed. As such, these results are in line with what the team expected from these tests.

10.2 Tank Forward Bench Testing

The water filtration system from the holding tank forward will be assembled and tested to verify that our recirculation works as well as our multiple outputs and all the sensors. The control system will also be integrated into this testing set up. This allowed us to ensure that there is no damage caused to the pump by having a flow restrictor downstream from it. The team also tested various faucet options to determine which is the best choice for each output. Due to time constraints, the sudoe water filtration system was assembled and built but was not able to do any thorough testing.

10.3 Sensor Bench Testing

The load cell sensors and pressure sensors will be tested to assess how the wiring will be assembled and to get familiar with the setup of the sensors. The load cell sensor will be tested to figure out the mounting setup and to make sure that the sensor is working properly within a 0.5%

margin error. The pressure sensor will be tested to determine the wiring schematic most fit for the application at hand, and to figure out the placement of the sensor within the piping of the system. Unfortunately, since the license to RsLogix was unavailable the team was not able to continue actual testing.

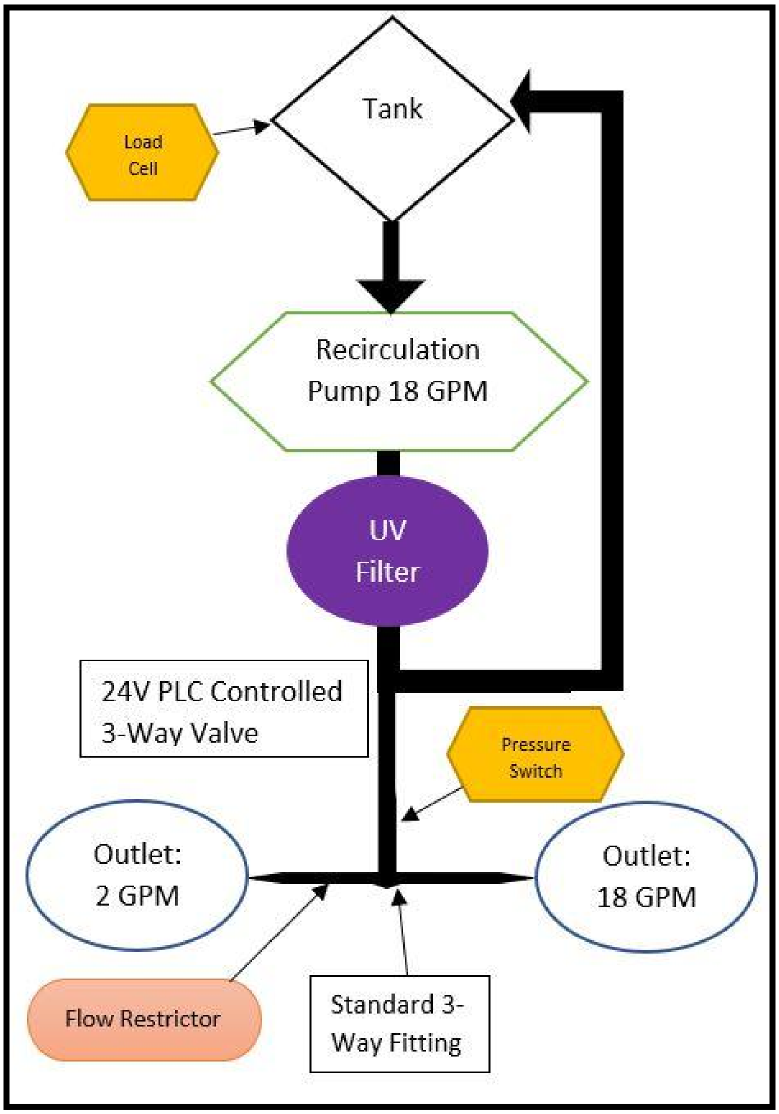

Figure. 9: Water Flow and Sensor Testing Flow Plan

10.4 References

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11. Recommendation for Future Work

11.1 Prototype Future Work

The next stage of the project will be a full prototype construction by our project sponsor. Britten will be responsible for the construction of a complete prototype and any further developments in the scope of the project.

Although the design portion of the shipping container has primarily been finished, there are other features that will need to be addressed. The team only had one load cell sensor for purposes of bench testing, but the load of the water tank would be more evenly distributed and accurately measured with two additional load cells. Additionally, there will need to be a mounting setup, likely in a triangular form, for the load cell sensors, in order to ensure reliable results. Full prototype fabrication will also necessitate routing the electrical conduit and the piping system. This system should be designed to maximize efficiency of space use and minimize hazards such as electric shock and container flooding.

11.2 Additional Component Suggestions

There are additional features that would further allow the system. One feature would be the ability to remote control the shipping container's controls system. This could be done by implementing a network that would allow Britten to communicate with the deployed shipping container. This would reduce maintenance time and additional labor costs. Future engineers should also investigate the effect of the automated solar panel direction control to maximize solar panel efficiency. These features were omitted from this design iteration with the aim of reducing system complexity.

A fully featured prototype should include temperature and ventilation control. Research will need to be conducted on how to ventilate the inside of the shipping container to eliminate any interference or hazards in the system such as overheating or corrosion. Additionally, the temperature of the container should be monitored and regulated by the addition of a system that would indicate when the temperature is over or under a certain temperature. This would include complying with OSHA standards and other electrical standards. Furthermore, active temperature control through the implementation of temperature gauges that connect to the PLC could help to improve the system efficiency.

12. Appendix A: Project Management

12.1 Meetings and Communication

When the team was created there had to be conversations on when to meet and how to communicate with one another. With seven members in the team, along with the advisor and client it was important to create a consistent schedule to meet and update everyone on the progress of the project. Tuesday and Thursdays at 11:30am-1:00pm became the time slot to come together and discuss project matters. A conference room on the 5th floor of the EERC was reserved for regular meetings. The main method of communication amongst each other was through a text group chat while more technical information was dealt with through email. Since there were many aspects of the project researched a Google Drive was created which contained all the project's information. Within the Google Drive each team member created folders for specific aspects of the project. Additionally, meeting minutes were developed for every meeting for organizational purposes, to help keep track of important deadlines and deliverables. Tuesdays were for the team to meet with each other, update any information, and deliberate on the tasks that everyone had taken upon. Tuesdays were also meant to figure out discussion points for Thursday's meeting with the advisor, Tony Pinar, and the clients, Nathan and Matt of Britten. Every other Thursday Britten, Inc and the design team would meet over Zoom and Tony would attend these meetings as well. After every client meeting the advisor meeting would proceed. On the Thursdays that the team did not meet with Britten the team would just meet with Tony for the purpose of feedback, comments, and concerns.

12.2 Finance

Part of our research and development has been to track expected costs to see if the project is marketable and profitable. The team tracked the cost of each component in our prototype, as well as looking at cost savings from a mass production standpoint. The total estimated cost is just over $60,000 for the prototype. See Table 12.1 - Table 12.2 for a breakdown of the cost.

Table 12.1: Prototype Cost

Item	Cost	Tax + Shipping?	Power Cost (kW)			
10' Shipping Container	$7,500.00	Y	0		Total:	$63,665.62
Shipping Container Mods	$1,740.00	-	0		Total Pwr (kW):	3.272
R.O. System	$13,596.00	N	1.5			
Pre-treatment	$6,076.00	N	0.122			
Intake Pump	$688.95	Y	1.2			
Outlet Pump	$310.44	Y	0.18			
UV System	$1,125.00	Y	0.07			
Water tank	$758.00	Y	0	Updated - Shipping increased		
Solar Components	$10,155.80	No Tax, Free Shipping	0			
Solar Mounting	$6,308.43	N	0			
PLC	$207.00	N	0.2			
Generator (gasoline)	$700.00	N	0			
Labor (Bill @ $95)	$11,400.00	-	0	120 Man Hours		
Miscellaneous	$2,000.00	N	0			
Sensors/Valves	$1,000.00	N	0			
Electrical	$100.00	N	0			

Table 12.2: Solar Power Cost Breakdown

Item	Total Quantity	MTU Quantity	Unit Cost [Total]	Unit Cost [MTU]
380 W Solar Panel	8	2	$ 388.00	$ 388.00
48V 3500W Solar Inverter	1	1	$ 899.99	$ 899.99
12V 200 Ah AGM Battery	12	4	$ 439.99	$ 439.99
Quad Enclosure Fuse Box	1	1	$ 59.99	$ 59.99
Solar Combiner Box	1	1	$ 109.99	$ 109.99
Battery Balancer	3	0	$ 65.45	$ -
4AWG Battery Interconnect Cables	9	3	$ 12.99	$ 12.99
10AWG Solar Panel Connectors	8	4	$ 24.64	$ 24.64
Solar Circuit Breakers	4	4	$ 15.75	$ 15.75
Panel Mount Breaker	1	1	$ 28.58	$ 25.58
500A Battery Monitor w/ Shunt	1	0	$ 99.99	$ -
			Total Cost	**Total Cost**
			$ 10,155.80	**$ 3,832.04**

13. Appendix B: Individual Contributions

Each member of the team was responsible for parts of the project under their realm of study. Nick Hoffbeck and Nika Orman, both electrical engineers, worked with Evan McKenzie, a computer engineer, on power systems and electrical components. There are four mechanical engineers on the team: Kyle Clow, Luke Schloemp, Gabriela Sgambati and Matt Zambon. The four of them created subteams for the water filtration components, plumbing, and container design. The following section outlines what each team member worked on throughout the project.

13.1 Kyle Clow

Kyle is a mechanical engineer with additional majors in finance and economics. For this project, he mainly focused on the purification method. He first conducted preliminary research on purification methods to determine that a reverse osmosis system would be the best system to handle the bulk of our purification. Kyle then reached out to companies and ultimately decided upon a specific system. Knowing the specifications of the RO system, he then researched pre- and post-treatment methods to determine the ideal systems for each. He decided upon a sediment depth filter and water softener for the pre-treatment and a UV system for the post-treatment. He then contacted companies to determine the specific systems the team would purchase for the pre-treatment. Kyle made decision matrices for each of the four purification steps: depth filter, water softener, RO, and UV. In addition to the water purification method, Kyle completed a competing products search to gauge similar products on the market that are similar to what the team wanted to build, and he worked on a patent review with Gabriela.

13.2 Nick Hoffbeck

Nick is an electrical engineer with a focus on control systems and process automation. For this project he researched MIL-STD-810, a standard used by the military to test for system hardiness from dust intrusion as well as impacts to the container. This standard was selected as dust intrusion needs to be kept to a minimum to protect the electronics and systems inside the container. He also kept track of the project cost throughout the semester, including power and monetary costs of parts. This budget was used as a baseline to see what the final product would cost compared to similar products on the market. This budget is an estimate of the prototype cost, not the cost once production begins, so the cost is higher here. See Table 12.1 for the final budget. Additionally, Nick worked on finding a way to supplement the solar power with shore power from a generator or the electrical grid. This ended up being shared with Evan McKenzie as they were able to find a solar inverter/charger that could handle multiple inputs. He also worked with Nika Orman to design the control system for the container. While Nika chose the sensors and valves, Nick found how they would interface with the PLC and what information is needed to run the whole system.

13.3 Evan McKenzie

Evan is a computer engineer with a specific focus on software development and process automation. For this project, he conducted research on electrical energy systems, specifically alternative energy sources and how these systems can be combined with other sources of power to create a cohesive power delivery system. Initially, this research was focused on identifying a target value for daily power production in relation to daily power usage by each subsystem. This research was then used to determine solar system providers and components, as well as the necessary components for grid power integration. Additionally, Evan assisted with smaller manufacturing details for the solar panel deployment system designed by Luke Schloemp, and co-designed the electrical schematic with Nick Hoffbeck, the visual graphic for which he also created. Finally, Evan aided in several smaller projects such as wiring decisions and designs, logo designs, and bench testing planning.

13.4 Nika Orman

Nika Orman is an electrical engineer with an interest in management. She served as the team manager and assembled all the organizational tasks and communication with the advisor. The google drive and meetings were arranged by her and she arranged and completed all team tasks such as presentations, meeting minutes, the gantt chart, reservations, team availability, and itineraries. Initially she researched types of pumps and renewable energy sources, which was then taken over by Matt Zambon and Evan McKenzie. She worked with Gabriela to research which piping would work best for the system, and then went ahead and created a list of what valves and gauges would be needed. Additionally, she assessed the sizing of pipes needed coming into and out of the water tank. Once the list was created she assessed where the valves and gauges should be placed and then went on to research sensors. She researched, contacted distributors, and developed decision matrices for all the sensors that are included in the system. Additionally, she worked on researching various water tanks and created a decision matrix for the type of material to be utilized for the water tank. When working on the sensors, she consulted and worked alongside Nick Hoffbeck, who was in charge of the PLC, and determined how to make the sensor connections and code with the PLC. Additionally, she created bench testing manuals for the sensors and assisted in smaller tasks such as creating lists of wire gauges and their locations, editing presentations and papers, and assisting any member who needed an extra hand.

13.5 Luke Schloemp

Luke is a mechanical engineer with a focus in electrical controls and mechanical design. During the initial research phase of the project, he identified and analyzed relevant NSF standards for water quality and purification system verification. He used this knowledge to look through commercially available ultraviolet (UV) system purification systems and identify ideal candidates. Later in the project timeline, Luke designed the solar panel deployment mechanism. This was first a sliding rail deployment system, for which Luke developed a 3D CAD model using commercially available units. Addressing client concerns around maintenance challenges, Luke redesigned the system such that the panels hinged to the side of the container and were supported by a pair of gas shocks. He worked with Evan McKenzie to understand the electrical organization and was assisted by Matt Zambon in developing mechanical methods. Over the course of the project, Luke assisted with project management details and preparation of technical documents.

13.6 Gabriela Sgambati

Gabriela is a mechanical engineer with concentrations in manufacturing and law. For research, she analyzed water rights and the needed water intake. She worked with the team to determine a goal for water output. Also, she researched known water filtration systems to base their project off of. A list was compiled to discuss and allow other members to use in determining which water filter was best for the project. Following general research, Gabriela compiled a document of types of pumps to use. From here, Matt Zambon used this research paired with his own to determine the two pumps needed for the system. For system design, Gabriela was assigned to determine the pipes for the system. She created decision matrices based on types and brands. With the plumbing, she generated a list of outlets to use. She designed the water flow chart to help the team and customer visualize the filtration plan. Additionally, Gabriela performed a patent review for the team when concerns of patent infringement arose. She also helped perform research on water softeners and the minimum grain capacity needed for the filter. Kyle Clow and her generated a list of brands to purchase from, and a decision matrix was made. Gabriela also created the CAD model of the project. She made rough shapes of each component and placed them within a proportioned container. Screenshots were taken, so she could label the plumbing system and control system layouts. Like her fellow teammates, she took on smaller tasks including: note taking, template design, logo brainstorming, created presentation slides, and edited the final report.

13.7 Matt Zambon

Matt's role with the team was the Communication Lead. This included setting up meetings with Britten, reaching out to various professors, and various suppliers as well. Matt also performed in depth research on pumps, which led to sourcing the intake and recirculation pumps that best our systems requirements and constraints. Additional research was conducted by Matt to find the best piping from the source, and what initial large debris filter would work best with our system. Matt also assisted Luke Schloemp with container design, and how the panels will be placed. Another large component of the project was to perform research into the legality of our system. This involved researching permits, state laws and regulations, and meeting with faculty to ensure our system can be used around the world. The main requirement is that our water can be tested for cleanliness after being outputted. Water testing methods were then researched and we will use testing strips.

During the second semester, Matt continued as the Communication Lead. However, this semester transitioned from research to purchasing and testing. Matt wrote the test plan for our water outlet testing, and did the purchasing for the components. This involved sourcing the components, having Britten purchase the components only available online, and purchasing parts available locally. Matt and Kyle Clow performed the assembly of the water outlet testing.

14. Appendix C: Gantt Chart

14.1 Project Timeline

In order to track progress, the team created a Gantt Chart to demonstrate planned and actual dates of each activity. Initially, the team researched water filtration systems and figured out background information on what components were needed as well as the specifications of the shipping container. The preliminary research took about two weeks to complete. Next, the team started to look into specific parts of the water filtration system. The research topics were divided amongst the team, and in total the research lasted about four weeks. Once research was completed, decision matrices were completed for specific products as an engineering solution for the decision on products. This process took longer than anticipated because of the slow communication on the distributors' end. Once the team was given specifications and quotes for all the parts, the budget was created and individual parts' CAD drawings were assembled. Each part was meticulously selected and had to be verified by not only the team but with the client and the compatibility with other parts in the system. Majority of the research and background was done in the fall semester. The spring semester focused on assembling the container, bill of materials, testing, and the creation of maintenance manuals for the parts that were tested. Spring semester showed the team working on validating the container layout for both the inside and the outside of the container. Luke focused on the container itself while the rest of the team focused on the inside layout and dynamics. This was anticipated to start fall semester; however, the plan undermined the uncertainty of events and was not feasible to begin until spring semester.

14.2 Gantt Chart

Table 14.1: Semester 1 Gantt Chart

Select a period to highlight at right. A legend describing the charting follows.

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Preliminary Research	2	1	2	1	100%
Parts Research	3	5	3	4	100%
Budgets	6	4	6	5	100%
Verify Parts	7	2	6	10	100%
Individual Parts' CAD Drawings	7	2	7	17	100%
Container Layout (Pre-Fabrication)	8	5	9	15	100%
Purchasing	11	4	20	9	100%
Subsystems	16	15	20	11	100%
Benchtesting	26	10	23	12	90%
System CAD	29	8	26	12	100%
Maintanence Manual	30	5	26	12	100%

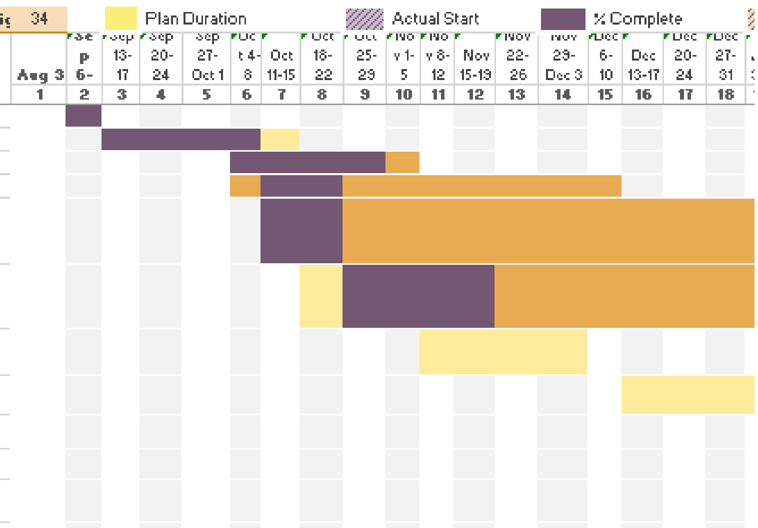
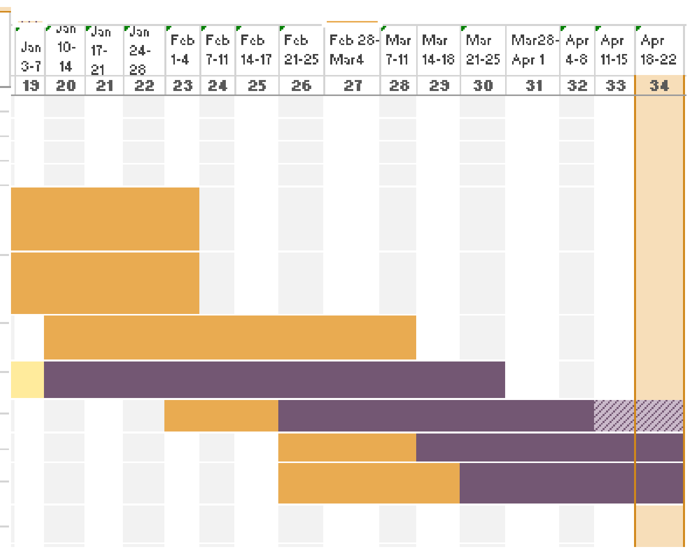


Table 14.2: Semester 2 Gantt Chart

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Preliminary Research	2	1	2	1	100%
Parts Research	3	5	3	4	100%
Budgets	6	4	6	5	100%
Verify Parts	7	2	6	10	100%
Individual Parts' CAD Drawings	7	2	7	17	100%
Container Layout (Pre-Fabrication)	8	5	9	15	100%
Purchasing	11	4	20	9	100%
Subsystems	16	15	20	11	100%
Benchtesting	26	10	23	12	90%
System CAD	29	8	26	12	100%
Maintanence Manual	30	5	26	12	100%



15. Appendix D: Engineering Decision Matrices

Table 15.1: Purification Method Decision Matrix

	Sediment	Bacteria	Viruses	Protozoa	Arsenic/ Chemicals	Fluoride	Salt	Metals	Totals
Microfiltration (0.1 micron)	High	Moderate	Zero	Very High	Zero	Zero	Zero	Zero	**9**
Ultrafiltration (0.01 micron)	Very High	Very High	Moderate	Very High	Low	Low	Zero	Zero	**16**
Nanofiltration (0.001 micron)	Very High	Very High	Very High	Very High	Moderate	Moderate	Zero	Zero	**20**
Chemical Treatments	Zero	Very High	Very High	Very High	Zero	Zero	Zero	Zero	**12**
UV Treatment	Zero	Very High	High	Very High	Zero	Zero	Zero	Zero	**11**
Reverse Osmosis (0.0001 micron)	Very High	Very High	Very High	Very High	Moderate	Moderate	High	High	**26**
Ion Exchange	Zero	Zero	Zero	Zero	Zero	Zero	High	Very High	**7**
Distillation	Very High	Very High	High	Very High	Moderate	Moderate	Very High	Moderate	**25**

Very High	4
High	3
Moderate	2
Low	1
Zero	0

Table 15.2: Additional RO vs Distillation Comparison

	Pros	Cons
Reverse Osmosis	- Quick purification - Short start-up time - Negligible heat production	- High maintenance - Expensive - Waste Water
Distillation	- Low maintenance - Cheap	- Slow purification - Long start-up times - Heat production

Table 15.3: RO System Quotes and System Information

Company	Model	Max GPD	Input Flowrate (GPM)	Clean Flowrate (GPM)	Efficiency (%)	Energy (kW)	Price ($)	Length (ft)	Depth (ft)	Height (ft)	Weight (lb)	Max TDS (mg/L)
Applied Membranes	J-64A	10,000	10	6.9	69	0.75	13,150.29	6'8"	2'11"	6'3"	1,190	2,000
Culligan	G2 6HE	10,000	9.25	6.9	75	1.49	13,596.00	1'10"	2'7"	4'8"		2,500
RO Superstore	Promax 11500	11,500	15	7.63	51	1.12	9,944.00	2'2"	2'4"	5'4"	150	2,000
Crystal Quest	High-Flow RO 10k	10,000	9.25	6.9	75	1.12	13,395.00	4'1"	2'8"	4'6"	385	2,000
American Aqua	N1-12000	12,000	14.33	8.33	58	1.49	13,978.51	2'	1'9"	4'7"	240	2,000

Table 15.4: Additional RO System Features

Company	Model	Additional Info
Applied Membranes	J-64A	5 micron sediment prefilter, pressure gauges (filter in/out, pump, concentrate), flowmeters (product, reject, and recycle), product TDS display, tank floats, temperature monitoring, feed water flush at system shutdown, LED display, multi-function keypad
Culligan	G2 6HE	Pretreatment sediment filter, pressure gauges, electronic turbine style flow meter, pressure transducer, control panel, comprehensive system monitoring, lighted display, TDS monitoring of water quality and rejection, elapsed run time monitor, system flow rate monitoring, visual alarms
RO Superstore	Promax 11500	TDS monitor for product and feed, product and drain flowmeters, operating pressure gauge, control panel, auto flush
Crystal Quest	High-Flow RO 10k	Feed and system pressure gauges, permeate and concentrate flowmeter, permeate and feed TDS display, automatic shut down at tank full
American Aqua	N1-12000	LCD display, TDS monitoring, temperature monitoring, flow meters (permeate and concentrate), prefilter, postfilter, manual flush, feed flush, tank level input

Table 15.5: RO System Decision Matrix

Company	Max GPD	Efficiency	Energy	Price	Length	Depth	Max TDS	Extras*	Total
Weight	**8**	**6**	**10**	**7**	**5**	**5**	**10**	**7**	
Applied Membranes	5	6.9	2	4.8	1	5.3	8	9	**31**
Culligan	5	7.5	8	4.5	10	6.7	10	9	**44.3**
RO Superstore	6.5	5.1	9	6.8	8.9	7.7	8	7	**43.2**
Crystal Quest	5	7.5	9	4.6	2.6	6.3	8	8	**38.8**
American Aqua	7	5.8	8	4.3	9.5	10	8	10	**44.8**

Table 15.6: Sediment Depth Filter Decision Matrix

Category	Flow Rate	Media Volume	Max Temp	Max Pressure	Cost	Standardization	Total
Weight	**4**	**2**	**2**	**2**	**4**	**0.5**	
CW 5900-BT 1.5 CF	10	6.3	6	5	10	0	**114.5**
APEX WH-3010	10	8.3	8	1	10	0	**114.7**
Fleck 2510F-SED-200	6	8.3	8	10	9.5	0	**114.7**
US Water Matrixx	6	8.3	6	5	5.9	0	**86.2**
Culligan HE DF-14	8	10	10	10	7.3	10	**126.1**

Table 15.7: Water Softener Decision Matrix

Category	Flow Rate	Max Temp	Max Pressure	Grain Capacity	Cost	Standardization	Total
Weight	**4**	**2**	**2**	**4**	**4**	**0.5**	
Fleck 2900	10	7.5	10	10	3.2	0	**127.8**
Fleck 9100	6.6	7.5	7.5	7.5	10	0	**126.5**
Softpro HE Excel Duplex	8.1	5	5	8.1	7.0	0	**113.0**
Culligan HET-090	8.3	10	7.5	9	5.9	10	**133.0**
Culligan HET-150	8.4	10	7.5	10	3.9	10	**129.1**

Table 15.8: UV System Decision Matrix Data

	Flow Rate (GPM)	Price ($)	Power (W)	Min psi	Max psi
Sanitron S50C	20	1,201	54	5	100
Viqua VP600	30	900	70	0	125
Mighty PureMP49C	20	944	54	5	100
Polaris UV-24B	24	875	78	0	125
Viqua E4	22	1,073	83	0	125
Viqua UVMax G	19	2,237	120	10	100

Table 15.9: UV System Decision Matrix

Category	Flow	Price	Power	Min psi	Max psi	Total
Weight	**1**	**2**	**5**	**0.5**	**0.5**	
Sanitron S50C	5	5.1	9.7	5	5	**68.8**
Viqua VP600	10	6.3	8.6	10	10	**75.4**
Mighty PureMP49C	5	6.2	9.7	5	5	**70.9**
Polaris UV-24B	7	6.4	8.0	10	10	**69.9**
Viqua E4	6	5.6	7.6	10	10	**65.5**
Viqua UVMax G	4	0.9	5.0	1	5	**33.8**

Table 15.10: Solar Panel Provider Decision Matrix

	Wattage (W)	Size (in²)	Weight (lbs)	Kit or Single Panels	Cost	Software Provided	12 Hour runtime capable	Total
Weight	**2**	**1.5**	**1**	**1**	**2**	**1**	**2**	
Renogy 320 W Package	9	3	3	9	1	8	9	**62.5**
Inverter Store 480 W Panels	1	7	6	9	4	1	1	**38.5**
ECO-WORTHY 300 W Panel Kits	8	5	6	9	2	1	9	**61.5**
Solar Kits 100 W Package	2	6	9	9	5	1	5	**52**
Solar Kits 300 W Panels	6	6	8	9	4	1	7	**61**

Table 15.11: Pump Type Decision Matrix

Pump Type	Durability	Maintenance	High Head Lift	Flow Rate	Power Consumption	Sound/ Vibration	Cost	Total
Weight	**1.5**	**1**	**2**	**2**	**2**	**1**	**1**	
Submersible	7	7	8	9	8	6	8	**81.5**
Centrifugal	9	6	9	8	9	5	7	**83.5**
Positive Disp	5	9	6	3	2	1	5	**44.5**
Utility	8	9	8	8	8.5	7	6	**83**
Jet	8	7	6	6	7	7	1	**65**

Table 15.12: Inlet Pump Decision Matrix

Pump Model	Type	High Head Lift	Flow rate	Power Consumption	Price	Total
Weight	**2.5**	**2**	**2**	**2**	**1**	
Tsurumi Submersible	9	4.5	8	8	8	**71.5**
Goulds Centrifugal	10	10	8	6	2	**75**
RainFLo Diaphragm	4	3	1	10	10	**48**
Goulds Jet pump	6	4	6	7	1	**50**
Liberty Utility	9.5	8	5	8	7	**72.75**
RainFLo Centrifugal	10	10	8	7.5	6	**82**

Table 15.13: Water Tank Material Decision Matrix

	Corrosion Resistant	Safe for Drinking Water	Temp Resistant	Lifespan	Weight	Leak Resistant	Cost	Size	UV Light Resistant	Input Pressure	Total
Weight	**2**	**2**	**1**	**1**	**1**	**2**	**1**	**1**	**1**	**2**	
Polyethylene	9	8	7	8	9	9	8	8	8	4	**108**
Stainless Steel	8	7	7	8	4	9	4	6	8	8	**101**
Fiberglass	9	5	4	4	8	3	3	7	2	5	**72**
Carbon Steel	6	7	8	8	3	8	3	6	8	8	**94**

Table 15.14: Pipe Type Decision Matrix

	Corrosion Resistant	Safe for Drinking Water	Temp Resistant	Lifespan	Weight	Leak Resistant	Cost	UV Light Resistant	Total
Weight	**2**	**2**	**1**	**1**	**1**	**2**	**1.75**	**1**	
Copper Pipes	9	9	9	8	5	9	6	7	**98.12**
Galvanized Steel	6	7	8	7	1	6	4	9	**74.03**
PVC	9	9	7	9	8	9	8	5	**102.42**
CPVC	9	8	7	9	8	9	6	9	**100.54**
PEX	9	7	8	9	9	6	10	3	**94.49**
Stainless Steel	8	9	9	9	1	9	3	8	**87.74**

Table 15.15: Intake Filter Decision Matrix

	Filter Size	Maintenance	Ease of Use	Required Depth	Price	Total
Weight	**2**	**2**	**1**	**2**	**1**	
Floating Pond	10	2	2	1	1	**29**
Centrifugal	4	4	4	4	5	**33**
Kleen Flo	9	8	9	7	9	**66**
Grainger Strainer	3	10	8	8	10	**60**
Mcmaster Carr Strainer	9	9	8	8	4	**64**

Table 15.16: PVC Brands Decision Matrix

	Corrosion Resistant	Safe for Drinking Water	Temp Resistant	Lifespan	Weight	Leak Resistant	Cost	Total
Weight	**2**	**1.5**	**1**	**1**	**2**	**2**	**1.75**	
Grainger	9	8	6	6	9	9	7	**90.25**
JM Eagle	9	6	6	6	9	9	8	**89.00**

Table 15.17: PLC Decision Matrix

	Size	I/O Capability	Price	Expansion Potential	Supportability	Power Consumption	Total
Weight	**1**	**2**	**1**	**1.5**	**2**	**2.5**	
Micro 820	10	7	10	7	8	10	**85.5**
MicroLogix 1100	9	8	9	10	10	8	**89**
MicroLogix 1400	7	9	6	10	10	4	**76**
Simatic S7-1500	8	10	5	9	6	4	**68.5**

Table 15.18: Water Tank Sensor Decision Matrix

	Process Pressure	Process Temperature	Corrosive Resistant	Accuracy	Cost	Lifespan	Size	Total
Weight	**2**	**1**	**1**	**2**	**1**	**1**	**1**	
Capacitance Level Sensor (C)	7	7	3	5	8	4	7	**261**
Guided Wave Radar (C)	9	8	8	8	2	8	6	**273**
Vibrating Fork (P)	8	8	9	8	4	9	6	**289**
Float Switch (P)	8	8	7	6	6	7	5	**274**
Optical Level Switches (P/C)	8	8	6	8	9	5	9	**325**
Load Cell	8	8	9	8	7	8	9	**330**

Table 15.19: Load Cell Decision Matrix

	Operating Temp	Load Capacity	Corrosive Resistant	Accuracy	Cost	Lifespan	Size	Total
Weight	**2**	**1**	**1**	**2**	**1**	**1**	**1**	
TE Connectivity FC2311-0000-1000-L	8	10	7	7	8	8	8	**454**
Honeywell Low Profile Load Cell Model 3132 Series	9	10	8	9	2	9	8	**443**
SMD2094-1000 S400 Button Load Cell	6	10	7	8	4	8	8	**413**

Table 15.20: Pressure Sensor Product Decision Matrix

	Pipe Size	Accuracy	Pressure Range	Cost	Lifespan	Process Temp	Total
Weight	**2**	**2**	**1**	**2**	**1**	**1**	
TE Connectivity M32JM-000105-100PG	9	8	9	8	7	7	**388**
ProSense Mechanical Pressure Switch MPS25-1C-D100D	9	6	7	7	7	8	**353**
OEM Style, Compact Pressure Transmitters with Mini DIN	9	7	8	6	7	8	**362**
Honeywell MIP Series MIPAN1XX100PSAAX.	9	9	9	9	7	8	**411**

Table 15.21: Electrical Conduit Decision Matrix

	Corrosion Resistant	Size	Temp Resistant	Watertight	Cost	Flexibility	Final Weight
Weight	**2**	**2**	**2**	**2**	**2**	**1**	
RMC	7	2	8	6	3	5	**57**
PVC	8	9	7	8	7	5	**83**
EMT	4	4	6	7	8	8	**66**
LFMC	8	6	8	9	7	7	**83**

16 Appendix E: Failure Mode and Effects Analysis

Table 16.1: Solar Panel Mounting Structure DFMEA

Item/ Function	Potential Failure Mode	Effects of Failure	Severity	Causes/ Mechanisms of Failure	Prevention Controls	Ocurrence	Detection Controls	Detection	RPN
Solar Rail Deployment									
Solar Panels	Panel Fracture	Panels not operable	8	Environmental Damage	Require deployment away from natural hazards	4	Allow for easy contact with technicians in case of system failure	3	**96**
Sealing Door	Dry and stiff rubber	Dust and moisture inclusions allowed	5	Hazardous Environment	Study rubber preservation	2	Regular maintenance schedule	5	**50**
Sliding Rails	Grit accumulation	Panel Deployment more challenging	4	Grit accumulation	Require rails to be cleaned before putting panels away	7	Regular maintenance schedule	5	**140**
Mounting Beam	Shear Failure	Panel Detatchment	9	Improper weight distribution	Material load analysis	1	Allow for easy contact with technicians in case of system failure	5	**45**
Structural Support	Shear Failure	Panels collapse into container	10	Improper weight distribution	Material load analysis	1	Allow for easy contact with technicians in case of system failure	5	**50**
Hinged Solar Deployment									
Solar Panels	Panel Fracture	Panels not operable	8	Collision during shipping	Require isolated shipping	5	Visual inspection of container upon delivery	2	**80**
			8	Environmental Damage	Require deployment away from natural hazards	4	Allow for easy contact with technicians in case of system failure	3	**96**
Door Seal	Dry and stiff rubber	Dust and moisture inclusions allowed	5	Hazardous Environment	Study rubber preservation	2	Regular maintenance schedule	5	**50**
Gas Shocks	Stiff piston	Panel Deployment more challenging	4	Collection of Grit	Ensure piston rod cleaning before folding away	7	Regular maintenance schedule	3	**84**
Door Hinges	Stff Hinges	Panel Deployment more challenging	4	Rust or grit in hinges	Hinge Lubrication	3	Regular maintenance schedule	5	**60**

Table 16.2: Patent Review Competing Products

Patent No.	Title	Description	Notes
US20120312755A1	Mobile clarifier and sludge dewatering system for onsite wastewater treatment	mobile waste water treatment on trailer not cargo	
US20140014188A1	METHODS AND SYSTEMS FOR PRODUCING, TRADING, AND TRANSPORTING WATER	transports water via shipping container and fluid membrane on inside filter not claimed	
US20070199875	PORTABLE WATER PURIFICATION SYSTEM	portable container with water filter inside; does not claim RO but claims microfilter, intake pump and storage tank inside '	abandoned
US20210061693	EMERGENCY WATER FILTRATION KIOSK AND METHOD OF USE	transportable container with inlet and outlet and four part filtering system	pending
US20210061674	INTEGRATED SYSTEMS OF A MODULAR SUPPORT SYSTEM	container with layered filtration systems; layered downwards	
US20200039611	METHOD AND SYSTEM FOR A TOWED VESSEL SUITABLE FOR TRANSPORTING LIQUIDS	a vessel for transporting and purifying water	
US20200002209	MOBILE PROCESSING SYSTEM FOR HAZARDOUS AND RADIOACTIVE ISOTOPE REMOVAL	portable nuclear waste treatment	
US20170081220	Water Treatment System Having Tubular Modules	tubular water treatment	
US20150166385	MOBILE WATER PURIFICATION SYSTEM AND METHOD	UV and RO used, airlift to locations; water pumped in and out;	abandoned
US20140094975	CONTROL SYSTEM FOR A MOBILE WATER FILTRATION UNIT, AND RELATED DEVICES, COMPONENTS, SYSTEMS AND METHODS	portable water filtration system with tanks inside rectangular container; ues shipping container	abandoned
US20140091041	MOBILE WATER FILTRATION UNIT AND CONTROL SYSTEM, AND RELATED DEVICES, COMPONENTS, SYSTEMS AND METHODS	portable container with tanks and filtration	abandoned
US 8808537	Self-contained transportable water treatment system		active
US20210187420	SYSTEMS AND PROCESSES EMPLOYING WET/DRY SUCTION FILTER	water filtration system; does not have to be portable	

US20130068698	MOBILE WATER FILTRATION UNIT		abandoned
US20120006738	Continuously Supplied Water Filtration Banks	filtration system for underdeveloped areas; uses ground, surface, and rain water; solar cells used; portable fabric	
US 7,775,374	Self powered water purification system		active