Solar Powered Water Purification through Membrane Distillation

Grant Proposal

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Executive Summary

Approximately 1000 million people worldwide do not have access to clean and safe drinking water (Ahmad & Azam, 2019). With this, the risk of morbidity and mortality from waterborne diseases is immensely high and causes serious health issues in various communities (Nwabor et al., 2016). But cleaning water requires money to generate energy for purification, which is not easily accessible to rural communities around the world. Current methods for water purification, such as reverse osmosis, ultraviolet disinfection, ozonation, and membrane technology, are functional, but they require excessive amounts of electricity, which is unaffordable and causes air pollution. Also, current methods are unable to remove all contaminants, which results in water that still remains dangerous for consumption. This proposal seeks to develop a membrane distillation-based water purification system powered by solar energy. Methodology includes prototyping and testing designs for the most effective removal of contaminants and clean water production, building the final design out of more permanent materials, installing an energy component that includes a solar panel and battery, and testing the device using a local source of contaminated water and conducting viral and bacterial tests. Expected results include the complete removal of all contaminants and the device's ability to function w. Overall, this proposal will improve the health and wellbeing of many communities around the world.

Keywords: Water purification, membrane distillation, solar power

Solar powered water purification device through membrane distillation

The earth is in an immense deficit of clean drinking water, a pressing global issue that demands solutions. Although most of the Earth's surface area is made up of ocean water, it is unsafe for humans to consume due to the high concentration of salt, which can lead to dehydration and health concerns. With this, freshwater derived from lakes, ponds, rivers, and reservoirs makes up only a small fraction of the earth's total water sources, which causes scarcity of a significant requirement for human life. Many of the limited freshwater sources that do exist are highly contaminated and are dangerous for human consumption due to the effects of pollution. Water pollution is a result of a variety of human-related and natural factors, such as chemical contamination, pesticides, physical debris, and biological contaminants. Approximately one billion people worldwide do not have access to clean and safe drinking water (Ahmad & Azam, 2019). With this, the risk of morbidity and mortality from waterborne diseases is immensely high and causes serious health issues in various communities (Nwabor et al., 2016). Consumption of unclean water results in diarrhea, typhoid fever, hepatitis, and various cancers; therefore, there is a major need to remove pathogens and contaminants from water sources (WHO, 2022). But cleaning water requires money to generate energy for purification, something not easily accessible to rural communities around the world. People in remote areas of the world are the most vulnerable to insufficient sources of clean drinking water since there is a lack of electricity and sufficient materials that are required for many water purification techniques (Rustico, 2023).

Currently, a variety of water purification methods exist, but they contain aspects that are not ideal. For example, ultraviolet disinfection is the deactivation of microorganisms such as protozoa, viruses, and bacteria using germicidal wavelengths by damaging the DNA of the organism (Ahmad et al., 2019). Although this method is quick and effective at removing organisms from water, it is unable to remove chemical pollutants and physical debris from water sources, and it utilizes a great amount of energy as well. The removal of only one specific contaminant is unideal as the water is still dangerous for consumption. Even if bacteria are removed, the water can still contain various chemical contaminants which are dangerous for consumption. Ozonation is another current technique for purifying water. The process involves breaking down ozone, an unstable chemical compound, into oxygen and free radicals to decrease manganese, iron, and sulfur in the water (Ahmad et al., 2019). Ozonation is effective in removing water contaminants, but the process is highly dependent on the specific water chemistry of the contaminated water. It is meant for a very small-scale purification cycle, it consumes a high amount of energy, and the cost of initial setup of this system is expensive and unaffordable to many (Ahmad et al., 2019). Membrane filtration technology is also an option for water purification. Pore size and distribution facilitate the accuracy of separating pure water from contaminants (Zou et al., 2022). Membrane filtration can be categorized into microfiltration (pore size 0.1-5 microns), ultrafiltration (pore size 0.01-0.1 microns), nanofiltration (pore size 0.01-0.001 microns), and reverse osmosis (pore size less than 1nm) (Smith, 2024). Membranes with larger pore sizes are ideal for the removal of larger contaminants such as particles, cells, and bacteria. Membranes with smaller pores are ideal for the removal of smaller contaminants such as divalent ions, organic salts, viruses, and treating brackish water (Smith, 2024). Although membrane filtration, specifically reverse osmosis and nanofiltration, allows for the removal of various distinct contaminants simultaneously, the smaller pore sizes require more energy to maintain steady water pressure through the membrane for efficient filtration. Membrane technologies, such as microfiltration and ultrafiltration require less energy for water pressure, but they are only able to remove contaminants of a larger size, so not all contaminants will be removed through this process. Membrane technology has the potential to be an ideal source of water filtration, but the energy requirement for efficient filtration is a major drawback. Distillation is another method of water purification that involves a heating element, condensing unit, and collection unit. This method can remove a wide range of contaminants, such as heavy metals, bacteria, viruses, and other harmful substances due to the differing boiling points of water and contaminants (Visico, 2023). When the contaminated water is heated, the pure water evaporates, leaving behind the contaminants. One of the main disadvantages of this system is that some chemicals have similar boiling points to water resulting in water that is still dangerous for human consumption. Also, this process requires energy to heat the contaminated water to promote evaporation (Visico, 2023).

Overall, one of the common drawbacks of existing water purification technologies is the large amount of energy required to power the systems. Such technologies can be functional in wealthy nations, but are unrealistic in remote areas that do not have the economic standpoint to afford the necessary amount of electricity and are the most vulnerable to unclean water sources. Utilizing electricity is not an ideal choice for water purification due to the environmental impacts. The generation of electricity emits large amounts of air contaminants, such as nitrogen oxides, that contribute to smog and air pollution. With this, the ideal choice for the required energy needed to purify water would be solar energy, as it is a globally sustainable and affordable option (Wang et al., 2019). Solar panels do not facilitate carbon dioxide emissions and can generate energy from a natural source which is the sun (Wang et al., 2019). The main advantage of a natural source of energy is that it is highly affordable, as the solar panel itself is the only aspect that requires money. The energy itself is produced for extended periods of time with no additional cost. However, a significant disadvantage to solar powered water purification system is that the solar panel would need to maintain direct contact with sunlight for the device to generate enough power to function, which is unrealistic in the cases of environmental factors such as rain, clouds, and nighttime. A way to combat this issue is to implement a battery that would be charged by the solar panel. With this, when there is no direct sunlight, the water purification device will continue to function and produce clean water utilizing the energy stored in the battery. The other common drawback of the current water purification technologies is that many are only able to remove specific contaminants, which results in water that still contains dangerous substances. With this, incorporating the most ideal components of various current water purification techniques into one will result in the removal of a greater number of contaminants in the water, such as chemicals, bacteria, and physical debris.

Section II: Specific Aims

This proposal's objective is to develop a water purification device that utilizes both distillation and membrane technology powered by an energy system containing a solar panel and battery. The long-term goal is to provide communities around the world that have limited access to clean water and electricity with an affordable device that removes dangerous contaminants from existing water sources to produce clean water. This will allow for less disease and mortality rates associated with drinking contaminated water which will improve the well-being and health of many communities around the world (WHO, 2022). Where the central hypothesis of this proposal is to design and build the most efficient and effective device for removing contaminants from water with the resources available. The rationale is that if my design is effective in water purification and can function for extended periods of time with just solar energy, it can be manufactured at a large scale and sent out to communities in need to offer relief to the pressing issue of limited sources of clean water. The work we propose here will enhance our understanding of solar-powered water purification technologies and promote advancements in tackling global climate change associated with utilizing electricity for cleaning water and water pollution.

Specific Aim 1: Design and build a device that removes contaminants from unclean water sources to produce clean water safe for human consumption.

Specific Aim 2: Develop an energy system with a solar panel and battery that allows the device to function during periods of time without direct contact with sunlight due to environmental factors.

The expected outcome of this work is a functional device that removes contaminants from water to make it safe to drink using only a solar panel and battery for the energy source. Overall, this will allow for people with limited access to clean drinking water and electricity an affordable, reliable, and environmentally friendly source for the vital life requirement of water, which will decrease death rates caused by waterborne diseases worldwide.

Section III: Project Goals and Methodology

Relevance/Significance

The earth is in an immense deficit of clean drinking water that demands solutions. The majority of water sources on Earth are made up of ocean or polluted freshwater, which causes a major scarcity of a human need. Based on the World Health Organization, in 2020, only 74% of the world's population had access to clean drinking water (Smith., 2024). Many people are forced to drink water full of dangerous contaminants. The risk of morbidity and mortality facilitated through waterborne diseases is immensely high and causes serious health issues in various communities (Nwabor et al., 2016). Many communities, specifically in rural areas, do not have access to sufficient sources of electricity that are needed for many water purification devices to function. Even those that do have access to electricity for water purification, it is not the ideal energy source as it causes emissions that are detrimental to the environment and atmosphere. These issues regarding clean water and energy sources are problematic to many people across the globe, which is why this project proposal is necessary for improving the situation for communities in need.

Innovation

Currently, water purification technologies exist, but they require large amounts of energy to function, and some of these technologies are only able to remove some specific contaminants. Along with this, existing studies only focus on one specific technique and do not approach the topic of water purification from an overall view (Aziz et al., 2024). This proposal demonstrates innovation by combining membrane technology with distillation techniques, as well as using solar energy to tackle the major drawbacks of already existing water purification technologies. By doing so, this proposal will help tackle current disadvantages in the field to promote a stronger understanding of water purification technology.

Methodology

The methodology will include the engineering design process to tackle the issues of removing contaminants from unclean water. An initial design will be created, and a prototype will be built out of easily accessible materials for quick testing. For example, a hot plate, glass containers, flasks, cylinder tubes, ice packs, and petri dishes are easily accessible and can be built into a water purification device that can be easily evaluated and iterated. An easily detectable contaminant such as methylene blue will be utilized for preliminary testing with spectrophotometry which is a process that uses ultraviolet and visible light to measure the absorbance of a chemical compound in a sample (Hulupi et al., 2023). Upon multiple iterations of the design, a final design will be developed utilizing specific 3D printed components as well as already existing components as well. The amount of energy required to power the device will be determined by utilizing a multimeter or a voltmeter, and an appropriate solar panel will be acquired to maintain the appropriate amount of energy needed. A battery will be acquired as well, to connect to the solar panel and device. Constructing all the electrical components to the water purification device will be the next step in the process. Upon the construction of the final design with the solar panel and battery, the full system will be tested outdoors with various contaminants. Levels of contamination will be assessed using test strips.

Specific Aim #1: **Design and build a device that removes contaminants from unclean water sources to produce clean water that is safe for human consumption.**

Determine the ideal design for a water purification device using a nylon membrane, heater, condensing unit with cooling system, and clean water collection container. The objective is to remove various contaminants such as chemicals and microorganisms from water to make it safe for human consumption. The approach, as stated previously, is to first prototype different condensation units and positions of the membrane using accessible items that will allow easy iterations. Each design will be tested using methylene blue, which is a chemical that can be easily detected using a spectrophotometer. Upon testing various prototypes, the one that can remove methylene blue from water in the most efficient and effective way will be built using specific 3D printed and strategically chosen materials to replicate the design of the chosen prototype. After the final construction, the device will be tested using various chemicals and contaminants using test strips that can detect if specific contaminants are present. The ideal result of this experimentation is zero contamination in the water upon using the device. But any decrease in contamination will be a sign that the device is able to function, but more research and iterations of the design need to be done for full removal of all contaminants. Our rationale for this approach is that by removing contaminants from dirty water, more people around the world will have access to clean drinking water, which will result in significantly less illness and deaths.

Justification and Feasibility

The preliminary tests using methylene blue and spectrophotometry can be justified by the work done by Hulupi et al in 2023. Their work provides validation of analytical methods with spectrophotometry to determine the level of methylene blue in a sample.

Table 1. Measurement of the absorbance of a standard methylene blue solution

No.	Sample	Concentration (mg/L)	Absorbance
1	Blank	0	0.000
2	Standard 1	2	0.103
3	Standard 2	4	0.224
4	Standard 3	6	0.324
5	Standard 4	8	0.423
6	Standard 5	10	0.552

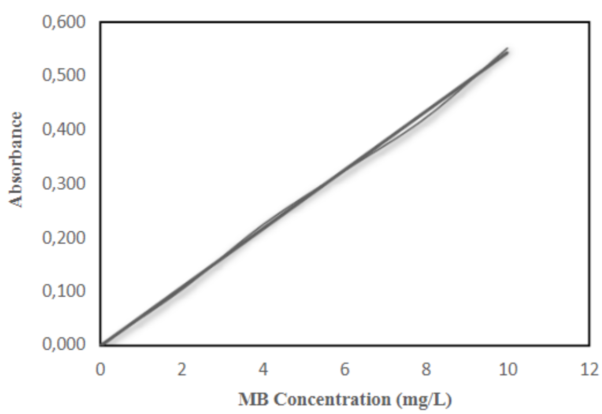


Figure 1. Methylene blue standard solution calibration curve

Figure 1 depicts data and results by (Hulupi et al., 2023)

Methylene blue is a pollutant in natural water sources that is toxic to aquatic life and dangerous for humans (Hulupi et al., 2023). Spectrophotometry, which uses ultraviolet and visible light to measure the absorbance of a chemical compound, was used to detect methylene blue in a sample. Results, as shown in **figure 1,** showed that the higher the methylene blue concentration, the more light absorption occurs. This research shows that spectrophotometry is a reliable tool to use to depict the presence of methylene blue. Therefore, I will utilize such techniques in testing my prototype designs.

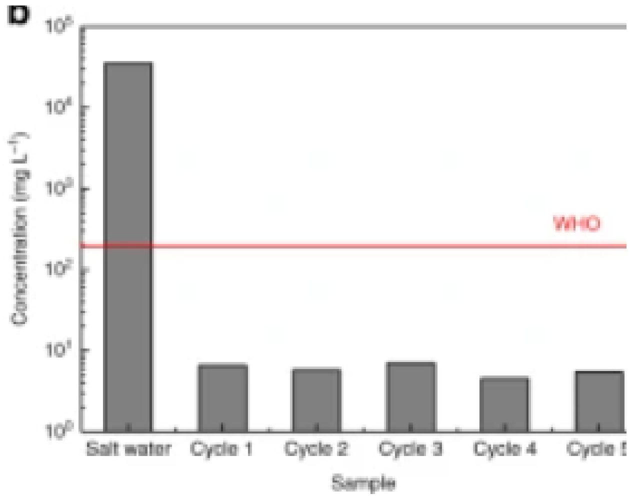


Figure 2 Graph of results by Wang et al 2019

Along with this, membrane distillation technology is commonly utilized in water purification research, such as the work done by Wang et al in 2019. They developed a solar photovoltaic membrane distillation device that can remove salt from water while producing electricity simultaneously (Wang et al., 2019). During testing, results showed that the concentration of salt in a sample drastically decreased below the World Health Organization standards, as shown in **figure 2**. Based on the graph, the concentration of salt decreased by about 5 times, which shows the success of membrane distillation technology.

Considering the results of Wang et al, membrane distillation is an effective technique for removing contaminants from water. Although this proposal does not include the removal of salt, testing various contaminants such as chemicals using membrane distillation, will enhance research in the field of water purification.

Summary of Preliminary Data.

	nylon	nitrocellulose	control (no membrane)
grams of condensation with petri dish	44.1305g	44.1172g	44.2245g
grams of pure water condensation	0.2528g	0.1455g	0.5888g

subtract weight of petri-dish (43.9717 g)

Figure 3 Testing membranes for vapor permeation data results table

Membrane distillation technology can utilize membranes made of different materials, which can result in different outcomes. Therefore, it is important to test which membrane can evaporate water the fastest, since that is an important factor for water purification. A dish with 50mL of distilled water was brought to a boil (100 C) on a hot plate with the setting at 2.8. The water was evaporated through a nitrocellulose membrane, nylon membrane, and no membrane (control) for 3 minutes each and the condensation was collected on a petri dish. The condensation for each trial was weighed with the petri dish, and then the weight of the petri dish (43. 9717g) was subtracted to find the mass of just the condensed water. The nylon membrane evaporated 42.9% as much water as the control in 3 minutes. With this, the nitrocellulose membrane evaporated 24.7% as much water as the control in 3 minutes. The control is the fastest way to evaporate and condense water since there is no membrane to slow down the process. Without a membrane, 0.5888g of water evaporated in 3 minutes. With this, the closer the amount of water that was collected in 3 minutes using each membrane to the amount of water that was collected without a membrane, the more efficient the membrane is in evaporating water. The nylon membrane evaporated 42.9% as much water as the control, which is more than the 24.7% of water that the nitrocellulose membrane evaporated, so the nylon membrane is more efficient.

	absorbtion	wavelength	color
distilled water	8184.017	380.80nm	colorless
Mb mixture (450mL distilled water) (5mL MB)	1633.833	643.70nm	blue
After evaporation through membrane	8864.500	380.8nm	colorless

Figure 4 Testing the ability of a nylon membrane to remove methylene blue from water.

Upon the decision to move forward with the nylon membrane as opposed to the nitrocellulose membrane, it is important to test if it is effective in removing contaminants from water, since that is crucial aspect of water purification. Methylene Blue is a chemical that has a high light absorbance; therefore, I used spectrophotometry to evaluate the absorption of methylene blue in water before and after using nylon membrane distillation. For this experiment, 450mL of distilled water was combined with 5mL of methylene blue, and the solution was heated, evaporated, and condensed using a hotplate, ice pack, petri dish, and a glass container. A spectrophotometer was utilized to detect the amount of absorption and wavelength that occurred with the distilled water, methylene blue mixture, and the methylene blue mixture after membrane distillation. Since the distilled water and the methylene blue mixture post membrane distillation presented the same wavelength of 380.80nm, and similar absorptions of 8184.017 and 8864.500, the conclusion can be made that entirety of the methylene blue was removed from the initial methylene blue and water mixture. Since the resulting substance was immensely like the original distilled water, the membrane distillation was successful for water purification. Along with this, there was a significant change in color that was observed throughout the experimentation. The methylene blue mixture was a vivid blue color at the start, and after purification the result was colorless, which also goes to show that the methylene blue was successfully removed. Overall, this preliminary data shows that the nylon membrane is most effective in permeating vapor, and it is also successful at removing contaminants, so it is a appropriate component of water purification to move forward w

Expected Outcomes.

The overall outcome of this aim is to develop an effective and efficient method for purifying water consisting of membrane distillation, heater, condensing unit, and other minor components. This knowledge will be used for providing a reliable clean water source to communities around the world who only have access to contaminated water.

Potential Pitfalls and Alternative Strategies.

We expect nylon membrane distillation to remain successful in removing contaminants from water, but if it shows to be not the ideal technique, membranes with different pore size and materials, and differing methods for passing water through the membrane will be tested. Also, if certain contaminants are not removed by the system, further iterations of the design will occur. If those contaminants are still present in the resulting water, then the contaminants that the system is effective in removing will be focused on and improved.

Specific Aim #2: **Develop an energy system with a solar panel and battery that allows the device to function during periods of time without direct contact with sunlight due to environmental factors.**

Determine the most effective energy system consisting of a solar panel and battery to power the water purification device even during times when there is no direct contact to sunlight. The objective is to provide an affordable and environmentally friendly energy source that can function through different natural conditions that occur. The approach, as stated previously, is to utilize a multimeter or a voltmeter, to determine the appropriate energy requirement for the solar panel to fulfill. A battery will also be acquired and attached to the solar panel and the water purification device.

Justification and Feasibility

The goal is for the solar panel to charge the battery, which will power the device. Then when there is no sunlight, the remaining energy in the battery will continue to charge the water purification system. Research on the efficiency of solar charging batteries has been done Gurung et al in 2018.

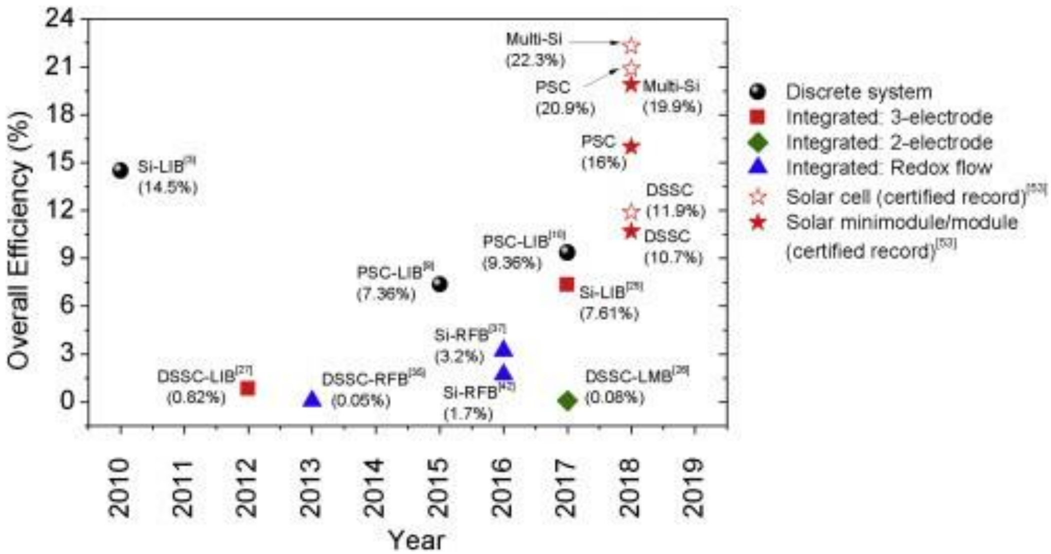


Figure 5 the efficiency of different types of solar powered batteries over a ten-year span graph by (Gurung et al., 2018)

Redox flow batteries, as depicted in **Figure 5**, provide scalability, flexibility, high lifetime, low operating cost, and high energy storage compacity (Gurung et al., 2018). These batteries are charged by solar energy, and they have ideal characteristics that can be utilized for the proposed water purification device. Over time, the efficiency of solar powered batteries has increased, with the last recorded year of 2019. Since the current year is 5 years past the experiment, an upward trend can be predicted, which means that batteries now are highly efficient. Utilizing an efficient battery in the solar powered water purification system is crucial, and the research done by Gurung et al aids in choosing an appropriate battery.

Summary of Preliminary Data.

Preliminary data can be gathered by running a simulation once the required voltage to run the device is determined. Preliminary data can also be gathered by testing the battery and solar panel separately prior to installation on the water purification device. This will help determine how effective the energy system is.

Expected Outcomes.

The overall outcome of this aim is to develop an energy system consisting of a solar panel and battery that will power the water purification device despite not always having access to direct sunlight. This knowledge will be used for the development of an affordable and environmentally friendly water purification device. Many people who struggle with unclean water sources do not have access to enough electricity to clean their water, and electricity production promotes air pollution which is harmful for the environment.

Potential Pitfalls and Alternative Strategies.

We expect the solar panel and battery system to generate enough energy to power the device, but if either of the components for not have the required capacity, a replacement with increased capacity will be acquired to tackle this issue.

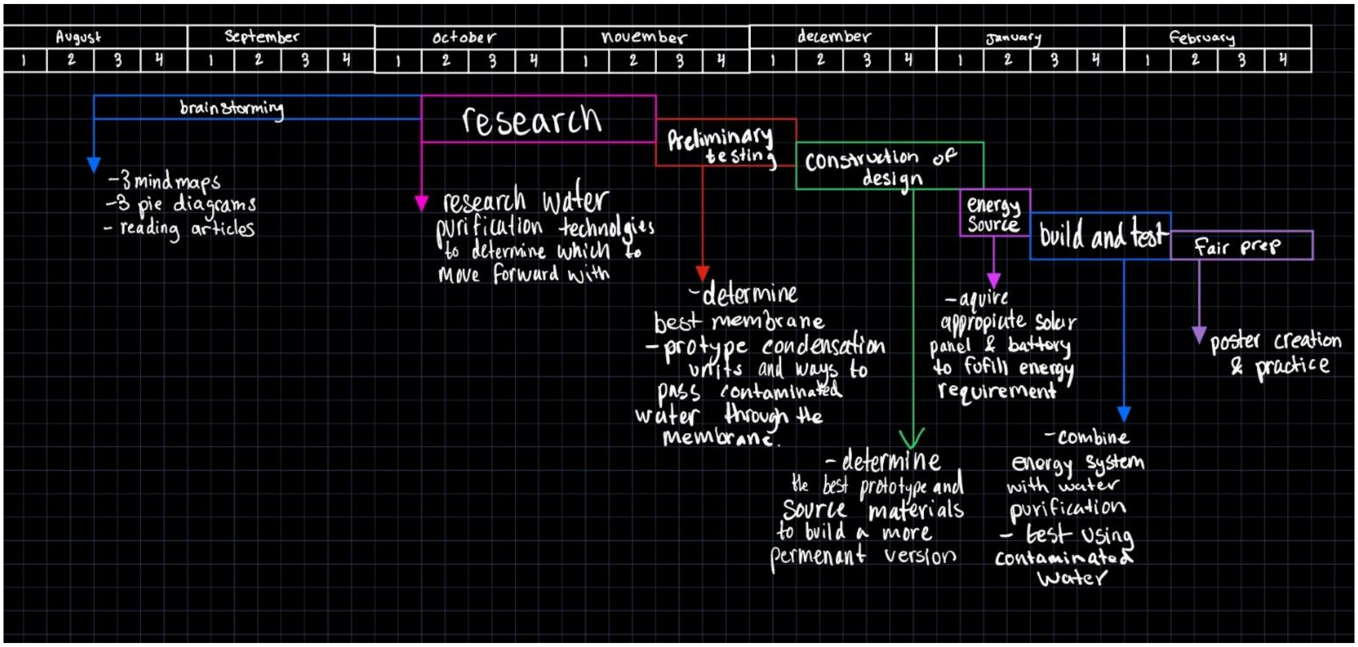
Section III: Resources/Equipment

- Spectrophotometer
- Solar panel and battery
- Contaminated water from local freshwater source

Section V: Ethical Considerations

This proposal will not involve humans or animals in any process. Safety precautions when testing will include proper lab attire, adult supervision, and awareness of public spaces and surroundings.

Section VI: Timeline



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