Introduction to Engineering Design with Professional Development 1

Final Report for
Water Filtering Rain Barrel

Team: 4
Section 5
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Executive Summary

On Earth, water is vital for all life to exist. Freshwater, the type of water the human species needs for survival, is an exceedingly scarce resource; only 2.5% of the water on our planet is freshwater. A significant consideration for all kinds of civilizations — past, present, and future — is to have a stable supply of freshwater for multiple uses. In most developed countries, water municipalities have been established to take care of the general population's needs for freshwater. However, this isn't the case for everyone on Earth. Certain areas aren't as developed and require alternative ways to collect, store, and use fresh water. Even in more advanced areas of the world, a number of health, cultural, societal, environmental, and economic considerations make water a major factor in daily life.

Apart from rivers, lakes, and aquifers, rain is a major source of freshwater for society. The general concept of collecting rainwater for everyday uses is nothing new, however, our team wanted to further iterate and combine existing technologies to bring rainwater collection, storage, and usage to the next level. After research, brainstorming, and discussion of attributes such as customer requirements and relevant existing technologies, it was decided that existing residential rainwater collecting systems can be improved in a couple of key ways.

The first improvement that our team pursued was to attach a filtration system to a basic rain barrel to filter our sediments and adjust acidity/alkalinity to make the collected water safer to use for agricultural and other domestic uses — aside from cooking and drinking since all rainwater is now contaminated with "forever chemicals". The second improvement our team pursued was attaching different sensors to measure water quality and quantities. This system would be powered by renewable solar energy and be displayed on a screen for easy monitoring. The final improvement pursued was implementing a siphon pump to dispense water to waist level to make dispensing collected rainwater more ergonomic.

The result of our team's effort was an overall successful first prototype of a water filtering rain barrel with monitoring sensors. Apart from one of the sensors not working, every other aspect of our design functioned as intended. All of the project objectives were reached, and the various technical specifications were met.

Despite our successful first prototype, there are a few different ways our water filtering rain barrel can be improved for future iterations. One improvement is using higher quality sensors for improved accuracy. The next improvement would be to make the filtration system more compact. Another improvement would be looking into the use of an electric pump over a manual siphon pump for water dispensing to improve ease of use. The final improvement and probably biggest improvement is general waterproofing of all the electrical components since our product will be exposed to severe storm elements.

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1 Introduction

In the current age, access to clean water is a rising concern amongst homeowners due to climate change and food/drink shortages across the globe. Water filters are seen as an existing solution to access clean water, so our team decided to combine filters with rainwater collection to make access to clean water more affordable. The problem we identified is that many existing consumer rain barrels are not affordable, require connection to at-home piping systems, and don’t display water quality data to users. The goal of the water filtering rain barrel is to design a rain barrel that improves water quality and is accessible to a wide range of consumers.

2 Project Objectives & Scope

- In the 6-week allotted time, the team will design, build, and test a prototype of a water filtering rain barrel that improves upon existing rain barrel technology.
- For the prototype, several materials and components will be bought from stores and not made from scratch, except for items such as the wooden base. This is due to time and resource constraints and achieving a feasible and practical design.
- In a real-world design process, some of these purchased components such as sensors, can either be made in-house or outsourced. The ability to scale up our project for mass production requires more time to research ways to streamline the design and overcome possible logistical issues.
- A fully marketable and successful product requires rigorous testing to meet the high standards of the target customer demographic, high standards and diverse real-world conditions. Such rigorous testing is outside of the scope of the project.
- The project's goal is to provide a basis for further iterations of the design process. Therefore, factors such as durability and life-cycle analysis will not be investigated.
- The final product will not be fully assembled for demo day. This is due to foreseen logistical constraints such as only being able to use 1 gallon of liquid. By having some subsystems separated, successful demonstration will be easier to achieve.

2.1 Mission Statement

Objective: To enable users to harvest and utilize clean rainwater for various everyday uses, not including drinking or cooking

Table 1 - Mission Statement

Benefits	Allows the user to collect and utilize clean rainwater for outdoor purposes.
Goals	● Will be completed in approximately a month ● Will be affordable for consumers
Primary Markets	● Homeowners ● Farms
Secondary Markets	● Architects ● Disaster Relief Agencies
Assumptions	● Water will be filtered to non-potable standards ● All electronic components will be powered using renewable energy
Stakeholders	● IED Project Group 4 ● RPI School of Engineering

2.2 Customer Requirements

A summary of the listed Customers Requirements and their importance is listed below. The ranking is from 1, the least important, to 5, the most important.

Table 2 - Summary of the Customer Requirements

	Customer Requirement	Technical Specification	Importance(1-5) 1=Least, 5=Most
	Made from Eco-friendly and Durable material	Sustainability, Non-Harmful Materials	5
	Abides by the most restricted water harvest law in US	Water Intake Capacity Limit	5
	Data collected can be shown to customers in a clear and concise way and implemented using Arduino IDE	Clear & Simple Data Display	5
	The power source is environmentally friendly	Sustainability	5
	Made from Eco-friendly and Durable material	Sustainability, Non-Harmful Materials	5
	Can be attached to a home’s gutter system.	Home Compatibility	5

	Customer Requirement	Technical Specification	Importance(1-5) 1=Least, 5=Most
	Use by general public	Affordability, Ease of Use	4
	Can be operated from waist level	Mobility, Ease of Use	4
	Can be moved easily	Portability, Weight	3
	Can be used by teens and adults	Age, Ease of Use	3
	Can hold enough water to support a garden	Weight & Size	3

As we can see from Table 2, our most important customers' requirements and technical specifications of the projects are Sustainability and Ease of use. In our view adhering to the concept of sustainability is important, and customers want the product to be easy to use. Another important customer requirement is being home compatible. Customers want the product to be ready to use and does not require further construction. The last three customer requirements are of the lowest priorities because it will be hard to adjust our project based on the requirements and time constraints.

The table below identifies the target customers, the reason as well as the ranking. Rank is from 4, least important, to 1, most important.

Table 3 - Target Customers where 1 is Most Important

	Target Customers	Reason	Ranking
	Household	Households would use the water barrel to collect rainwater. General usage includes gardening, cleaning, and possibly drinking water.	1
	Farmers	Farmers would be used to collect water. Use for agriculture products and possibly animal drinking usage.	2
	Building Designers / Architecture	Able to attach rain barrels to houses or apartments. Provide the capability for the complex to collect and utilize rainwater.	4
	Disaster Relief Agency	Rain Barrels can be used in disaster-affected areas to provide clean water.	3

When identifying target customers, we want our product to be used in every household possible. That is why in Table 2, we have home compatibility as one of our main priorities for our project. Another reason is that households are most affected by our product due to being able to collect and water and use it for multiple purposes. Other potential customers, Farmers, Building Designers, and Disaster Relief Agencies, have potential use for our product based on what they use for it. We rank them based on the reason they use them and the feasibility of each potential customer to benefit from our product. Other factors include environmental aspects.

2.3 Technical Specifications

Like the Customers Requirement table from 2.2, this table lists the technical specifications. The importance is also listed out as well.

Table 4 - Interpreted Customer Needs where 5 is Most Important

	Customer Requirement	**Technical Specification**	**Importance(1-5) 1=Least, 5=Most**
	Made from Eco-friendly and Durable material	Sustainability, Non-Harmful Materials	5
	Abides by the most restricted water harvest law in US	Water Intake Capacity Limit	5
	Data collected can be shown to customers in a clear and concise way and implemented using Arduino IDE	Clear & Simple Data Display	5
	The power source is environmentally friendly	Sustainability	5
	Made from Eco-friendly and Durable material	Sustainability, Non-Harmful Materials	5
	Can be attached to a home's gutter system.	Home Compatibility	5
	Use by general public	Affordability, Ease of Use	4
	Can be operated from waist level	Mobility, Ease of Use	4
	Can be moved easily	Portability, Weight	3
	Can be used by teens and adults	Age, Ease of Use	3
	Can hold enough water to support a garden	Weight & Size	3

Based on Table 4, for each customer's requirement, we list out a technical requirement. Ease of Use appears most often and ranks among the highest against other technical specifications. This is consistent with the ranking of our Customer's Requirements. We want the barrel to be used by everyone even without prior knowledge. Sustainability is also a key technical specification that is high in the ranking. Our project is based on the concept of Sustainability and helping people provide reliable clean water to anyone who uses our barrel. Some of the least important technical specifications like weight and age would involve adding more subsystems to solve the issue. This will mean an increase in cost as well as more time needed to build the necessary substem. Unfortunately, due to time constraints and budget, we would not be able to solve this issue in this project thus we rank those technical specifications lower in importance.

3 Assessment of Relevant Existing Technologies

In the design of our rain barrel, we researched existing technologies. The vast majority of rain barrels on the market are simply rain barrels with no additional features. They collect the water that runs off of gutters, then store and dispense it without changing the water. Examples of competitive products like these are shown in Table 6. The bare shell of these models heavily influenced our design, but with some key additions. We also did additional patent research to review the strategies closer.

Table 5 - Competitive Benchmarking

Competitive Product	Title / Description	Relation to this project
Rain Barrel with spigot	55 Gal. Rain Barrel Green with Brass Spigot	Similar design to our base, but this barrel is designed to sit freely outside and collect falling rain.
Rain Barrel with the ability to attach hose	55 Gal. Black Rain Barrel	Similar overall design to our barrel. It connects to a gutter system and loosely filters water, then can dispense it using a spigot.

Both products outlined in Table 5 can dispense water using a spigot near the bottom of the rain barrel. The first product, the green barrel, is designed to sit away from structures and collect rain freely as it falls [7], while the black rain barrel is designed to connect to a gutter system [2]. These products both include a spigot for easy dispensing, good portability, and affordability as outlined in the customer requirements. However, these products do little to filter water, and they cannot have the water dispensed at waist height like some of our customers would like.

Patents were also reviewed as a part of the research process. However, many of the patents for rain barrels are just for the design of the barrel, not any internal mechanisms. The patents with the most relevant features are displayed in Table 6, including one example of an ornamental design patent.

Table 6 - Patent Research for Related Technologies

Patent Number	Title / Description	Relation to this project
US8950428B2	Automatic rain barrel	This barrel can automatically dispense the amount of water needed, even drawing water from municipal sources.
CA2134021C	Rain barrel	This design can coarsely filter water as it flows into the barrel, then collects in a collection basin.
USD738590S1	Rain barrel	The ornamental design of a rain barrel.

The last patent listed is one example of a patent just for the overall barrel design, while the other two patents have more relevant internal features. The first barrel is called an “Automatic rain barrel.” Its main feature is that it can dispense an exact amount of water needed for activities like running a sprinkler. If there is insufficient rainwater, the barrel will draw from the municipal water supply to collect the necessary amount, then dispense [8]. While this product can make rainwater use easier, it does not address the customer needs that we collected. This product is also able to safely integrate electronic components into a water collection system. The second patent is for a barrel design that coarsely filters out contaminants like leaves and twigs, then collects the water in a collection basin. The user can remove the filter to fill a container by submersion, or water can be dispensed using a spigot. This is the only product that includes a filter, but the filter only functions to remove large particulates from the water. This means the water could still have chemicals and other small contaminants. However, the large filter is an important component to consider so that the large debris does not clog the filter.

4 Professional and Societal Considerations

Our team applied the engineering design process to produce solutions that meet the specified needs with consideration for the topics found in Table 7 - Engineering Solutions Impact.

Table 7 - Engineering Solutions Impact

Area of Impact	Impact	Description of Impact
Public Health and Safety	Y	● Our rain barrel improves upon existing rain barrel designs by integrating a filter and electronic components to monitor water quality ● The sand/carbon filter and water quality testing will make the water collected safer to use for gardens and other uses such as bathing, laundry, washing vehicles, etc. (NOT drinking or cooking)

Area of Impact	Impact	Description of Impact
		• We must make sure to advise users that additional treatment would be necessary if they want to drink the filtered rain barrel water or use it for cooking • We still want to make sure that there aren't tiny rocks or bugs, for example, in the water they use. Water left outside could breed mosquitos and having a filtration system could prevent any potential bugs/diseases from getting into the water • We have to make sure that water doesn't touch the electrical components • By ensuring that electric components are separated from the water, we ensure that members aren't potentially electrocuted. That can raise a safety concern, but we have preventative measures such as silicone caulk and waterproof tape to prevent water from seeping onto the circuits. • We must make sure that unfiltered water doesn't intermix with the filtered water
Global	Y	• In some countries, because water is so inaccessible, the water usage prices are much higher, which can affect the amount of money households use on water, as stated in the economic section • Access to clean water is very important, especially when we consider it on a global scale, there are hundreds of families still without access to clean water • Rainwater collection varies by country and state laws, so our product may not apply in many parts of the globe. • A more high-tech rain barrel can encourage more people to invest in the technology • Outside of personal use, industries can take advantage of a large network of rain barrels for business usage

Area of Impact	Impact	Description of Impact
		● Wouldn't be as beneficial for those living in arid environments ○ In a different perspective, can actually be most beneficial for these areas that don't get a lot of rainwater ● There's currently a chip shortage, so having our rain barrel utilize electronic components doesn't help the situation ● Can be beneficial in developing countries that don't have a more established water municipality ● Our first prototype is very much DIY-like so manufacturing in a large-scale would be less of an issue ○ Can even give instructions on how to build our rain barrel (although wouldn't be profitable for us)
Cultural	Y	● Certain cultures do feel more aligned with the earth in terms of taking care of it ● The rain barrel is an environmentally friendly method of water collection without the downsides of using tap water like widespread contamination when there are issues with pipes ● Users can use this filtered water without invasive piping to go through sacred land which respects the cultures of indigenous people ● We can also use culture *in another sense* when we talk about where people of certain cultures live, environmental discrimination, such as redlining, and how certain resources may be inaccessible due to systematic racism/discrimination ● We can consider community gardens, a movement that has been going on since the Black Panthers to feed communities that weren't being considered during food shortage ● Food deserts still exist today and many communities of minority backgrounds, particularly black and indigenous communities,

Area of Impact	Impact	Description of Impact
		are disproportionately affected more than others ● Community gardens are being brought up as a solution to the current fear of food shortages ● Clean water can make all the difference in a successful community garden as dirty water can stunt the growth of plants and/or lead to their death ● The impact of the filter can be an extremely positive one when you think about the society we live in and the ways in which racism/discrimination literally has roots in <u>every single aspect</u> of society, including environmental racism and inaccessibility to healthy food ● Clean water could mean a healthy garden and a healthy garden could mean food for communities that don't have as much access to healthy food or will be considered last during an impending recession. ● In many parts of the United States, people often take the water they have readily available to them for granted ● Investing in rain barrel technology can make consumers more environmentally conscience and encourage a cultural shift to be more sustainable ● Utilizing our rain barrel can help develop a sense of independence and individuality for the consumer in that they are reducing their reliance of outside resources such as water municipalities ● Our rain barrel requires more maintenance than a traditional rain barrel, which could turn off consumers to the idea of rainwater collecting or give them the wrong impression of a high upfront cost
Societal	Y	● There may be an increase of users who use the rain barrel to an extreme and *solely* rely on filtered rain-collected water for all uses such as showering, cooking, cleaning, and drinking

Area of Impact	Impact	Description of Impact
		(although advised not to unless followed by a second filtering method) ● Rain barrels would not be the most beneficial in cities/apartment complexes ● Rain barrels can encourage more people to live "off the grid" or reduce their carbon footprint ● Rain barrels would benefit those wanting to live in tiny homes (like me) ● Rain barrels can make gardening more accessible to people who didn't pursue gardening before because of higher subsequent water costs ● Rain barrels can further the divide between the haves and have nots (i.e., those who can afford the initial investment of a rain barrel, those who can't afford a gutter system, those living in apartments)
Environmental	Y	● The filtered water can be used to nurture gardens with non-polluted water and can be overall good for the ecosystem that is being watered ● When considering users who would feel comfortable enough to drink the filtered water, the filter can lead to a decrease in the number of users buying plastic water bottles as they have filtered water from home they can use instead ● Cutting water usage for multiple households can have a net positive impact on the water distribution system ● Can help conserve water during droughts ● Will help catch stormwater runoff before it causes problems, such as ○ Water pollution: stormwater collects many contaminants such as pesticides, chemical fertilizers, animal feces, etc. which eventually goes into natural bodies of water ○ Storm drain clogs: runoff collects debris such as leaves, sticks, and mud, which

Area of Impact	Impact	Description of Impact
		can cause clogs in storm sewers ● Prevent flooding and soil erosion in areas with too much rain ● Provides water for plants that are free from fluoride, salts, and other additives ○ Not applicable if someone lives in the countryside with a well pump for water ● Keeping too much rainwater out of streams and rivers could disrupt natural ecosystems ○ Many states limit how much rainwater one can harvest because of this ● Climate change can have a major impact on our water supply down the line, so people harvesting their own rain will help them become more self-sufficient
Economic	Y	● In terms of the economy, our product can increase the number of users that do not buy filtered water and use less tap water as well ● In some households, users may rely on rainwater for all aspects of water use, and thus, shifting to rainwater as a primary source of water can lower their overall water bill ● It also doesn't come with the downsides of possible contaminants that affect people citywide, like the lead contamination that affects black & brown families in Flint, Michigan ● Some may argue that filtered water may not have as high of an impact on the water bill in households, but considering the impending recession, a water bill may make all the difference in a low-income household ● The use of a rain barrel, or even a system of multiple rain barrels, can cut water costs for those who use water for things other than drinking or cooking ● Saving some money on water can add up in the long run ● The extra technology in the water filtering rain barrel outlined in this report might not be worth it

Area of Impact	Impact	Description of Impact
		to some consumers who aren't worried about roof contaminants in the water they collect ● People would need a gutter system for a rain barrel to be viable, therefore needing to invest in one if they don't have one already

5 System Concept Development and Selection

The system concept for the rain barrel was developed with our customer needs and technical specifications in mind. The customer needs guided development. The inspiration for the project came from experience with gardening and the prior existence of rain barrels, though they neglect water quality.

The barrel will work by either sitting freely where rain can collect or establishing a gutter diverter to divert water from the consumer's roof. The water will then run through a filter to remove contaminants that the water collects from the atmosphere. The water will then be stored in the barrel, where it can be dispensed from a pipe at waist height. While the water is in the barrel, sensors on the bottom will give information about the water quality and volume. The sensors will connect to the display, and all electronics will be powered by solar panels.

6 Subsystem Analysis and Design

The barrel will be divided into six subsystems, and each group member will be in charge of one. The subsystems are as follows: water data collection, water filtration, water dispensing, display, energy generation, and energy distribution. A visual depiction of the systems is included in Figure 4.

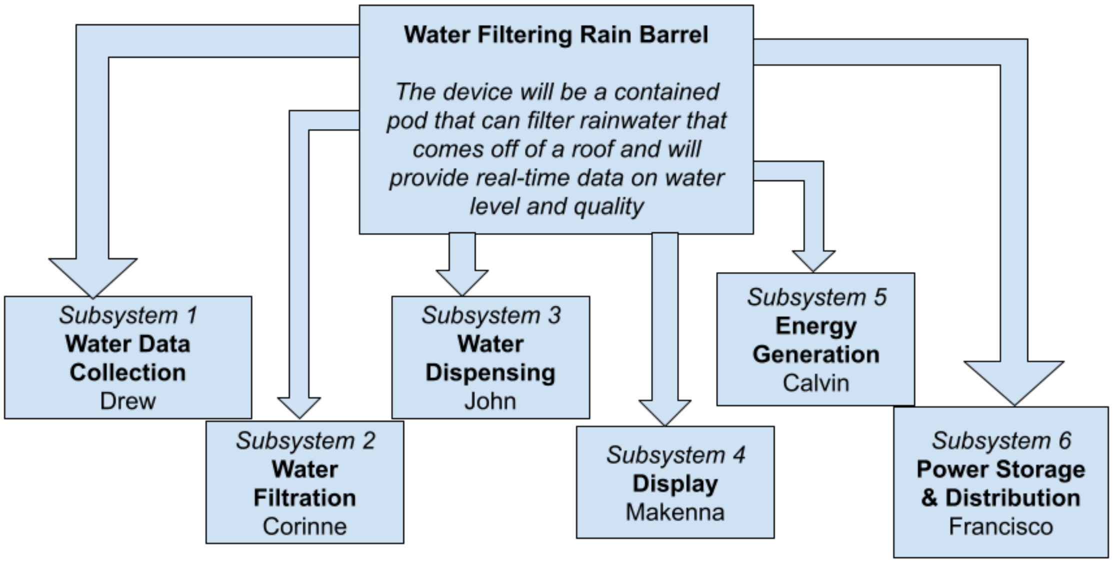


Figure 1: Hierarchical Subsystem Diagram

6.1 Water Data Collection

The water data collection subsystem aims to collect metrics to be displayed to a consumer. These metrics are collected through a system of three sensors, all connected via the power storage and distribution subsystem to the display. The metrics will allow consumers to gauge how the quality of their collected and filtered rainwater and how much is stored within the barrel.

The three metrics to be displayed to the consumer are turbidity, pH, and volume, which will be discussed in more detail below. Each of these sensors outputs a voltage sent to the display to be converted through code to a viewable value for the user.

6.1.1 Turbidity

Turbidity is a measure of water clarity and is the more valuable of the two quality metrics and is measured in units of nephelometric turbidity units, otherwise known as NTU. Turbidity inside the water filtering rain barrel is measured by a turbidity sensor (pictured below), which works by scattering light off of particles suspended within the water. The more light that is scattered and not reflected back, the higher the turbidity value. This means that a lower value of turbidity indicates clearer water.

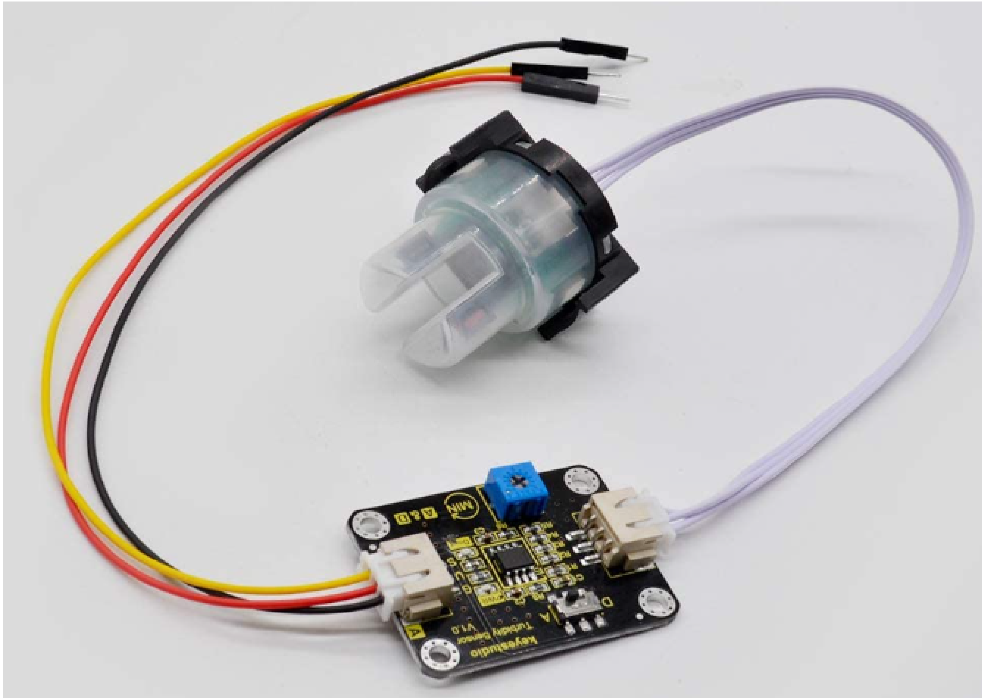


Figure 2: Turbidity Sensor

The choice to measure turbidity came out of the need to have an accurate value to measure water clarity. The other way we thought of as a team was to have an acrylic stripe down the side of the barrel to be able to visually see clarity. However, this would likely compromise the structural integrity of the barrel, so it was decided to go with a sensor for this metric.

6.1.2 pH

The next metric, pH, is the concentration of acids or bases within the water in the barrel. This was measured by a pH probe (pictured below), which works by the use of an electrode on the tip of the sensor. This electrode can generate a voltage corresponding to the concentration of hydrogen ions (H^+), which cause a solution to be acidic, and hydroxide ions (OH^-), which cause a solution to be alkaline.

Figure 3: pH Probe

This metric was chosen as a very important quality factor with filtered water. The pH of the water should, ideally, be near neutral at approximately 7, which would be safe for the intended uses of this product. This metric is also important to show to the consumer to assess the filter's health. If the filter works properly, the pH should always be neutral. However, if the pH is ever not near neutral, the water will not be safe to use, which is why this data is important to display to the consumer.

6.1.3 Volume

Volume measures how much water is contained within our product at any given time. This part of the subsystem has evolved over time, originally being calculated from a pressure sensor that would sit at the bottom of the barrel along with the turbidity sensor and pH probe. The pressure sensor would measure the pressure at the lowest water level, which could then be used to determine the height of water. This water level height could then be used with the dimensions of the barrel housing to determine the overall volume of water that is within the barrel. This seemed like the best idea for determining volume, however, we soon realized that the sensors we were able to find at a price that would fit our budget would be too inaccurate and therefore not practical for our design.

From this, we found a new sensor we could use, which was simpler to work with. This new sensor was the load cells (metal squares pictured below at the four corners of the base piece) which would directly measure the barrel's weight and the water contained within. These sensors work by measuring the load (force) weight of the barrel and will output a voltage corresponding to the weight in kilograms. This mass, minus the mass of the barrel dry, can then be divided by the density of water (1000 kg/m^3) to get volume in cubic meters.

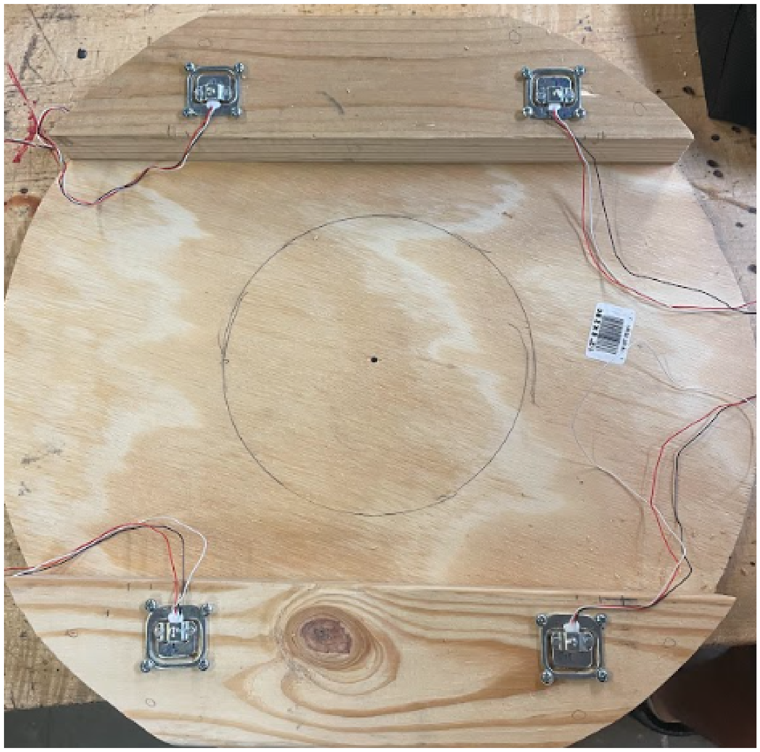


Figure 4: Load cells on Base

Being able to display the volume of water is important to our team as we believe that consumers would find it helpful to know how much water they have in the barrel that they can use.

6.1.4 Testing and Results of Sensors

We tested each sensor in a specific and unique way. These tests were based on the following questions. First, can the turbidity sensor accurately distinguish clear water from cloudy water? Second, can the pH probe accurately measure the pH of a liquid? Finally, can the load cells accurately measure the weight of an object of known mass?

Starting with the turbidity sensor, this was tested by placing the clear part of the turbidity sensor, shown in figure 2, first in visually clear water and then in visually dirty water, as shown later in figure 8. The expected result of this test is a very low value for the clear water near to zero, and a considerably higher value for the dirty water depending on how many suspended particulates there are. The results of this test were very satisfactory and produced the expected values.

Moving onto the pH probe, this sensor was tested by inserting the probe into two liquids of known pH and measuring the output. These two liquids were water, with a pH of 7, and lemon juice, with a pH of 2-3. This test was very successful once the pH sensor had properly been calibrated, and resulted in values very close (within ± 0.1-0.2) to the expected values.

Finally, the load cells were planned to be tested by comparing the weight of a team member as measured by the load cells and then by an accurate scale. Unfortunately for our team, the load cells did not function as intended and were unable to be tested due to an unknown error. In future design research, this error will be fixed and evaluated when making future design considerations.

6.2 Water Filtration

The water filtration subsystem aims to filter water that runs into the rain barrel. Water that runs off a roof can carry many contaminants, such as bacteria, heavy metals, pesticides, and herbicides [3]. Filtering this water will make the water safer to use.

The filtration method that I decided to use was a mixture of sand and activated carbon. Slow-sand filtration is a filtration method that is commonly used in pool maintenance. Water flows through the sand to remove physical contaminants called suspended solids. An alternative method of sand filtration will be used to manage the volume of stormwater the barrel is likely to handle. I chose to have the water flow through the sand naturally, which would remove most contaminants.

Activated charcoal was chosen for its ability to remove chemical contaminants from water. Activated charcoal is made from plant matter that is heated in such a way that pores form on the carbon. Carbon can make four atomic attachments at once, so it is uniquely adept at removing contaminants with a charge.

The scope of the prototype filter only makes the water safe to use on plants, not safe to drink. There are multiple reasons for this. One reason is that filtering out biological contaminants is very complex and expensive, which would decrease the product's affordability. Another reason is that certain states only allow rainwater to be used for non-potable or non-drinking purposes. Therefore, it did not make sense for the prototype to be able to filter out biological contaminants.

The original design for the filter included a large flat dish that would be filled with sand, then housing for carbon in the base of the barrel. However, this approach was not feasible, as the filter would be too heavy to house in that manner. Additionally, the carbon was not well integrated into the design. Sketches of this preliminary design are included in Figure 5.

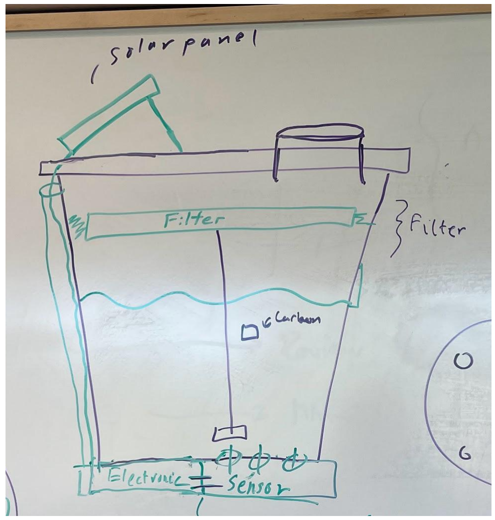


Figure 5: Preliminary Sketch of filter design

Our updated design featured a filtration pipe, where inflow water would flow in, run through the filter, then flows into the collection basin. This filter would combine the sand and carbon into one design rather than two separate parts without compromising filtration ability. It also included mesh that can hold the layers in place and prevent large debris from entering the filter. The mesh on the top will be larger so that water can easily flow through. The mesh that holds the carbon layer is large enough that sand and water pass through, but the carbon cannot bubble up into the other layers. The mesh on the underside of the filter is mesh size 60, which is small enough to hold sand. Sketches of this design are included in Figure 6.

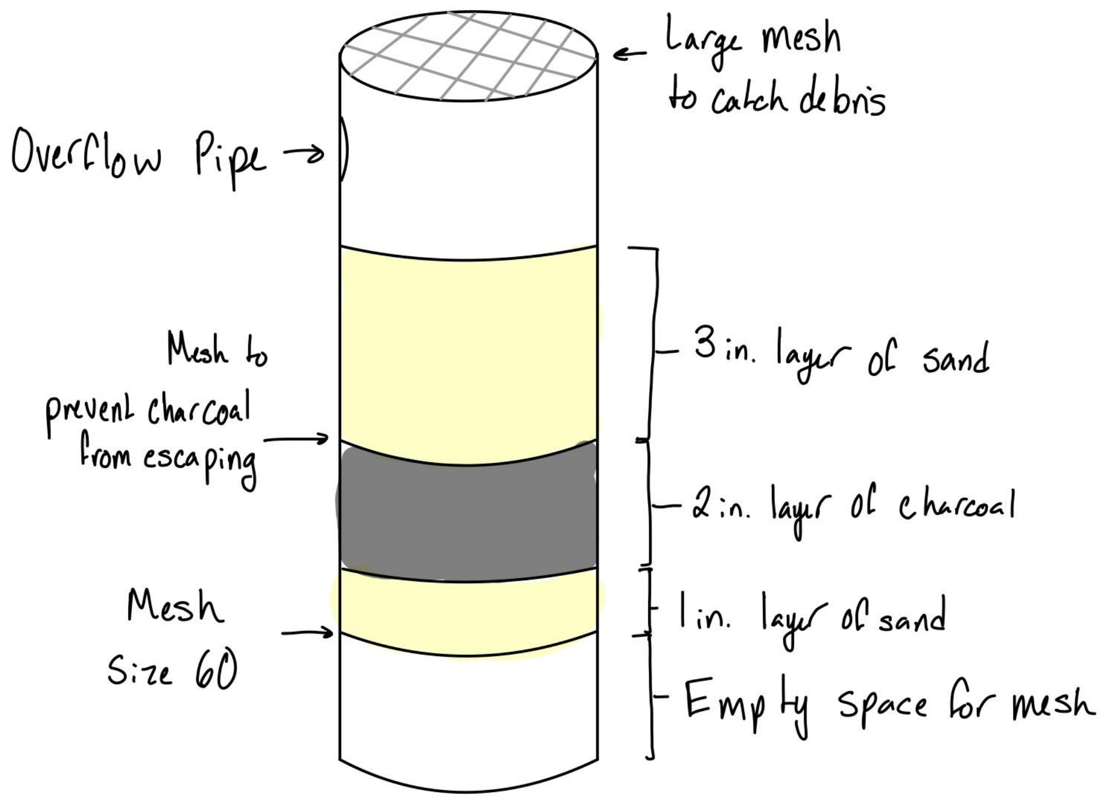


Figure 6: Final Filter Design Sketch

One of the considerations made in filter design was weight. While the carbon was not likely to hold water, sand is prone to hold onto water, which makes the sand heavier.

$$m = d * V$$
$$V = \pi * r^2 * h$$
$$V = \pi * (6in)^2 * 4in = 452\ in^3$$
$$d = 0.074\ lb/in^3$$
$$m = d * V = 0.074 * 452 = 33.5\ lbs$$

It was determined that the ideal height of sand in the barrel is 4 inches of the sand total, making the sand portion of the filter approximately 33 pounds. The rest of the components weigh approximately 10 pounds combined so the overall filter weight is about 40 pounds, which the lid of the barrel can hold.

The final iteration of the filter follows the prototype sketch very closely. A photo of the final design is included in Figure 7.

Figure 7: Final Filter Prototype

6.2.1 Testing

The filter was tested by mixing dirt into water, then adding vinegar to raise the pH of the mixture to around 4, which is about the pH of acid rain. This water is poured into the filter, and we measured the water quality metrics before and after. Photos from the prototype demonstration are included in Figure 8.

Figure 8: Testing Results

As shown in the photo, the filter achieved all required specifications. The water was visibly clear, and the pH was brought from a 4 (indicated on the orange strip) to a 7 (indicated by the green strip).

6.3 Water Dispensing

The water dispensing subsystem covers the essentials of a basic rain barrel. The subsystem pertains to the inflow, outflow, and overflow of water. There must be an effective flow from the gutter downspout and filtration pipe to the barrel for the inflow. For the outflow, the subsystem must be able to bring water to waist level for ease of use and there should be different options for dispensing water. For the overflow, water must be directed away from the home foundation in the event that the barrel or filtration pipe reaches water capacity.

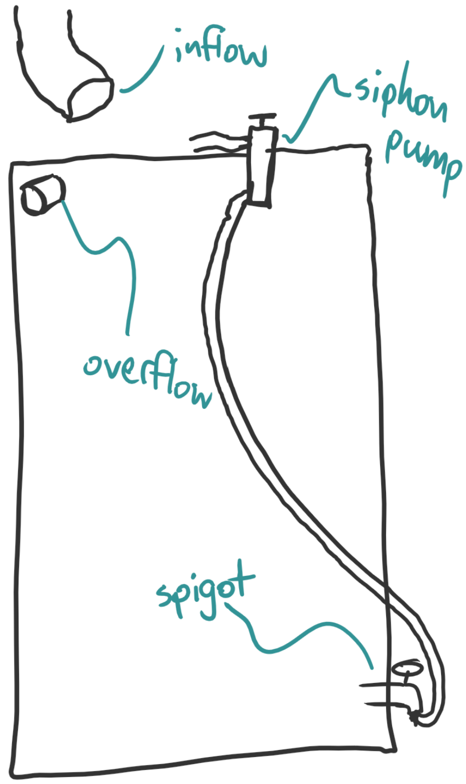


Figure 9: Initial concept sketch

Figure 9 shows the original, rudimentary concept sketch of the main components of the subsystem. The existing rain gutter would be modified using a gutter downspout diverter (not included) so that rainwater can flow to the barrel. After water is filtered and accumulated in the barrel, the water can either be pumped to waist level with the siphon pump or can be dispensed conventionally out of the spigot by removing the adapter nozzle that connects the siphon tube to the spigot. The main overflow pipe can be seen near the top of the barrel. The overflow pipe is angled off-center from the front of the barrel so that excess accumulated water is released away from the house foundation. This is an important design consideration, as excess water overflowing towards the home can deteriorate the house foundation over time.

Not shown in figure 9 is the water filtration pipe and attached overflow tube. The filtration pipe was originally going to be inside of the barrel. However, after more brainstorming and discussion, this option would not be feasible due to the filtration pipe's weight and size. Instead, it was decided to put the pipe on top of the barrel, as shown in figure 9.

Figure 10: Main Components of Water Dispensing Subsystem

Figure 10 shows the main components of water dispensing. There are the perforations in the lid for inflow, the spigot and siphon pump for the outflow, and the PVC pipe and tube for the overflow.

There were a couple of different engineering design considerations pertaining to water dispensing. For the inflow, either a grid of smaller holes or one large hole could be used for the lid. The metric was flow rate versus structural integrity of the lid. Even though one large would have a higher flow rate, it was determined that the structural integrity would be more compromised. Therefore, as shown in Figure 10, a grid of smaller holes for inflow was used.

For the outflow, either an electric pump or manual siphon pump could be used to bring water up to waist level. The metric was feasibility versus practicality. Although an electric pump would be feasible and would require less work to operate, it was decided that a manual siphon pump would be more practical for our application.

For testing the outflow system, enough water was added to the barrel to be able to be pumped into a 5-gallon bucket. The target specification was to fill ¾ of a 5-gallon bucket (3.75 gallons) in under 5 minutes. With ¾ cups of water dispensed per pump and an average strength 22-year-old pumping at 60 pumps per minute, an effective flowrate of 2.3 gallons per minute was achieved. This means that the manual siphon pump met target specifications.

For testing the overflow system, a heavy storm was emulated using a sink at full force to “shock the system” with a large inflow of water. The target specification was that water doesn’t overflow from the top of the filtration pipe when presented with a large inflow of water. During testing, the overflow tube for the filtration pipe successfully diverted water once the water level reached the tube and water didn’t spill over the top. This is important because, as touched on before, excess water flow must be diverted away from the home’s foundation to prevent deterioration.

Although water dispensing is one of the simpler subsystems, its role as the foundation of a basic, functional rain barrel is important so that the rest of the subsystems can shine.

6.4 Display

How The Display Connects to The Other Circuit Components

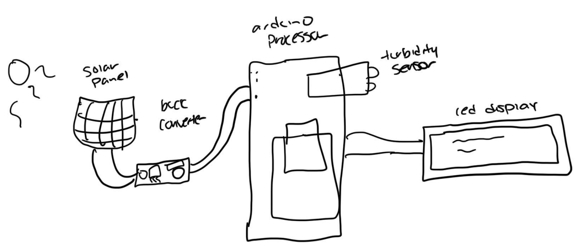


Figure 11: Circuit Components sketch

The initial idea was to use solar energy to power the arduino processor. We would use a buck converter to limit the amount of voltage powering the arduino processor as we considered the possibility of our solar panel generating more energy than the arduino processor requires. Connected from the arduino processor, we have the turbidity sensor and the lcd display. The lcd display will output the data inputted from the turbidity sensor.

The Circuit Diagram

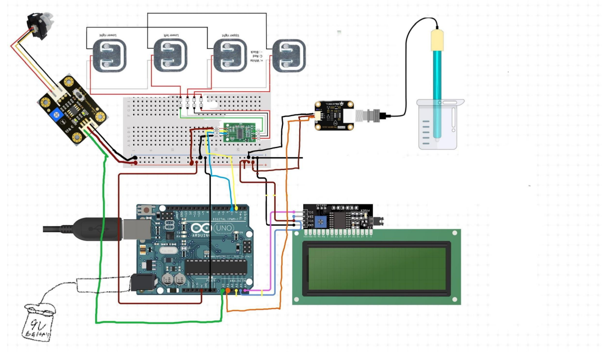


Figure 12: Circuit Diagram

Within our circuit diagram, we had included multiple other sensors in our circuit. We included the turbidity sensor, pH sensor, and load cells with our Arduino processor and LCD display. Our sensors are all connected in parallel on our breadboard with our Arduino processor and LCD display so our 5V voltage source will be evenly distributed amongst our sensors and LCD display.

We ensured that this was the case by connecting an M1K Board to the breadboard. Through the Alice Desktop Voltmeter simulator, we were able to see that the voltage supply was indeed 5 V across all of the sensors.

The Implementation

1. **The LCD Display.** We ensured the proper connection of the LCD Display to the Arduino processor. Proper connection means that the ground pin and voltage pins are in parallel with the respective ground and voltage pins of all other components on the breadboard.

2. **The PH Sensor.** The PH Sensor takes voltage input from the sensors that correlate to the actual PH value itself. Within the code, we take in the voltage value outputted by the sensor and use a formula to convert the voltage to PH. As shown in the code, we then calibrated the PH Value by taking the average of the values inputted.

```
//Algorithm for pH
for(int i=0;i<10;i++)        //Get 10 sample value from the sensor for avg value
{
  buf[i]=analogRead(phSensorPin);
  Serial.print("i: ");
  Serial.print(i);
  Serial.print("buf: ");
  Serial.print(buf[i]);
  delay(5);
}
for(int i=0;i<9;i++)        //sort the analog from small to large
{
  for(int j=i+1;j<10;j++)
  {
    if(buf[i]>buf[j])
    {
      temp=buf[i];
      buf[i]=buf[j];
      buf[j]=temp;
    }
  }
}
avg=0;
for(int i=2;i<8;i++)
  avg+=buf[i];

Serial.print(avg);
float phValue = abs((float)(7-avg/571.4))*100 ;
if (phValue > prev && prev != 0.0)
{
  phValue = phValue - (phValue - prev);
}
else
{
  phValue = phValue + (phValue - prev);
}
```

Figure 13: pH sensor code

As shown in the photo above, the pH sensor takes in an analog input, it's averaged and then converted from voltage to pH using the formula pH = (7-avg/571.4)*100.

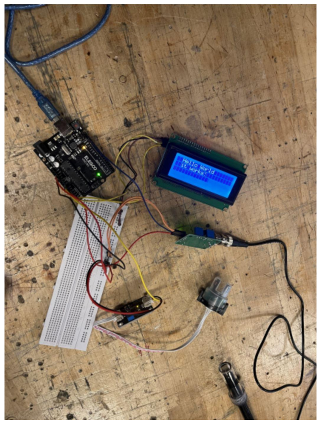
3. **The Turbidity Sensor.** The Turbidity Sensor takes input of how cloudy a liquid is in relation to the amount of light it can sense inside of it. In the code, we directly output the value of the sensor and convert it to NTU.

```
//Algorithm for Turbidity
 int tbd = map(analogRead(turbiditySensorPin), 0, 750, 100, 0);
```

Figure 14: Turbidity algorithm

As shown in the figure above, we took in the value of the analog read which directly correlates with the cloudiness of the sensor. The cloudier the liquid being measured, the higher the value of the turbidity.

The Final Test



```
//Prints Turbidity
lcd.clear();
lcd.setCursor(0,0);
lcd.print("Turbidity:");
lcd.print(tbd);
lcd.print("NTU");
//delay(10);

//Prints PH
lcd.setCursor(40,0);
lcd.print("PH:");
lcd.print(phValue);
//delay(10);
```

Figure 15: Code and test results

We used Arduino IDE to take in the sensors for each value in our code and then printed the corresponding values to the LCD display.

6.5 Energy Generation

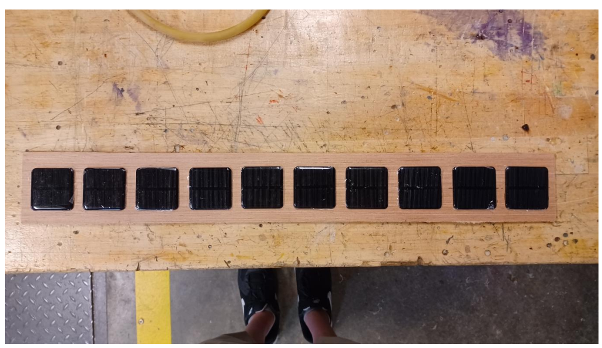


Figure 16: The Power Generation subsystem was designed by Calvin Chan.

Using Sustainability as our design concept, we came up with multiple ideas for what this subsystem would be. Our first design would be a water turbine, as seen in Figure 17, that would attach to the barrel and generate electricity to power the circuits and display.

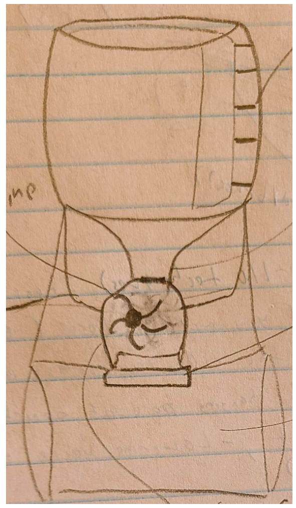


Figure 17: Water Turbine Concept Sketch

We decided not to go with that design because it would be difficult to generate enough power as well as hard to attach and wire the motor generating the power to the circuits and display.

The second design was to attach solar panels to the top of the barrel and attach the solar to the circuits and display to power those subsystems. We went with this design because it would be easier to make as well as a cost-efficient way to produce renewable energy. Finally, there would be less trouble attaching wires to the circuits and display. A design we have was to run the wire through tubes attached to the side of the barrel, that way it would be safe from any potential electrical hazard. Figure 16 is a picture of our final design.

The requirement for our energy generation subsystem was that it must produce enough power to operate our sensors, Arduino, and display. Makenna and Francisco estimated that the total power usage of the whole system would be 5 to 10 Volts. Given those specifications, we would need a bunch of low-voltage solar panels connected in series. In a series configuration, the voltage is double allowing ten 2V solar panels being able to generate 20V of power.

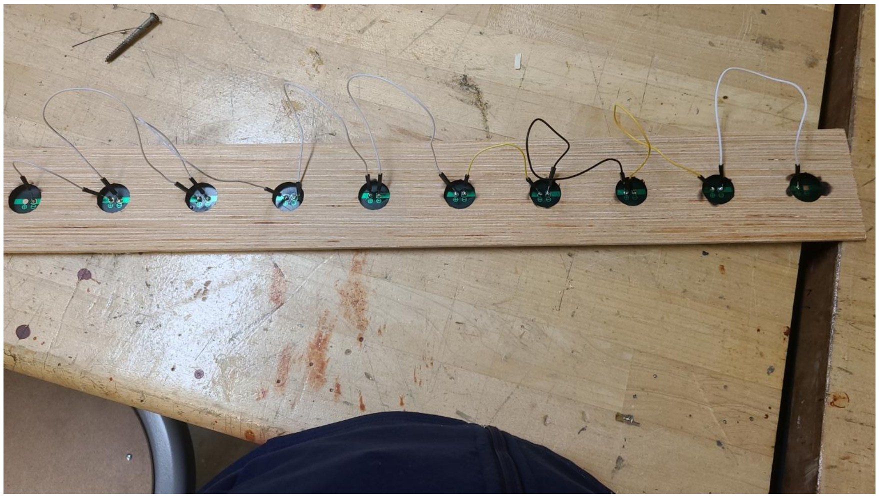


Figure 18: Solar panels wired in series

When attaching the solar panel to the barrel we decided that we would use angle support to hold the solar panel at the lid of the barrel. The angle would cause the solar panel to receive as much possible sunlight allowing consistent power generation. Figure 18 is a picture of the solar panel wire in series.

When testing our solar panels, our test would be using a multimeter attached to each end of the solar panel to check the number of volts generated. The amount of voltage generated would be recorded and tested to our specifications. We estimate about a max of 20V generated of which we only need the solar panel to produce about 10V of power. The test would be done in sunlight conditions outside.

RESULTS

Figure 19: Generated voltage from testing

Our final test results were a success for the solar panel and the energy generation subsystem. As can be seen, in Figure 19, the multimeter indicates the solar panel produces around 20V of power. Testing conditions during that day were cloudy and not full sunlight conditions. This is a good sign as it allows for the barrel to produce power even during non-ideal weather conditions. Overall the subsystem passed the test with satisfactory results.

6.6 Power Storage and Distribution

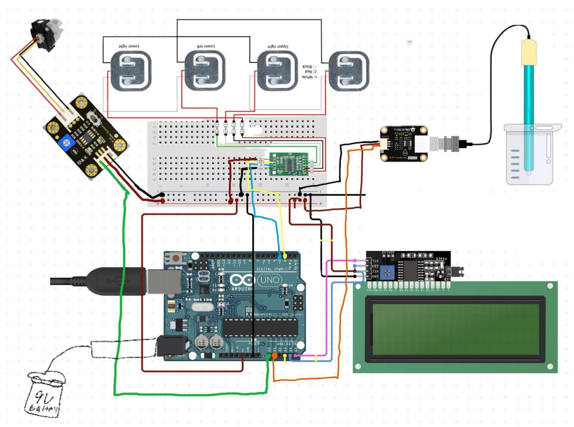


Figure 20: Circuit Diagram

Francisco's subsystem focused on wiring all sensors, the Arduino, LCD display, and breadboard. Using the above diagram, as well as videos, Francisco was able to wire all components together. Being that this would require patience, Francisco met early with the display, sensor, and structural team to begin discussing how the wiring would be ensured to provide reliable power and fit into the structural components of the rain barrel. Below are images of the first meeting's work:

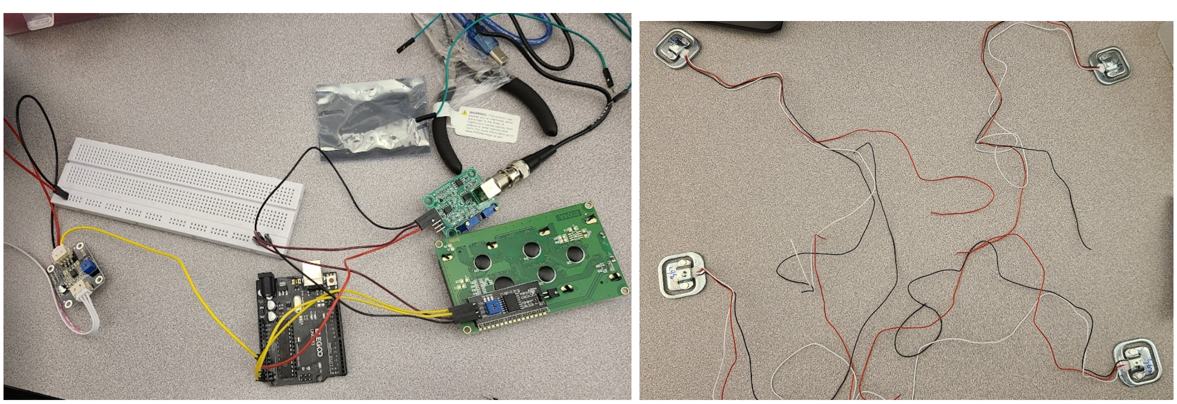


Figure 21: Initial work on circuits and load cells

And below, the images of the final results:

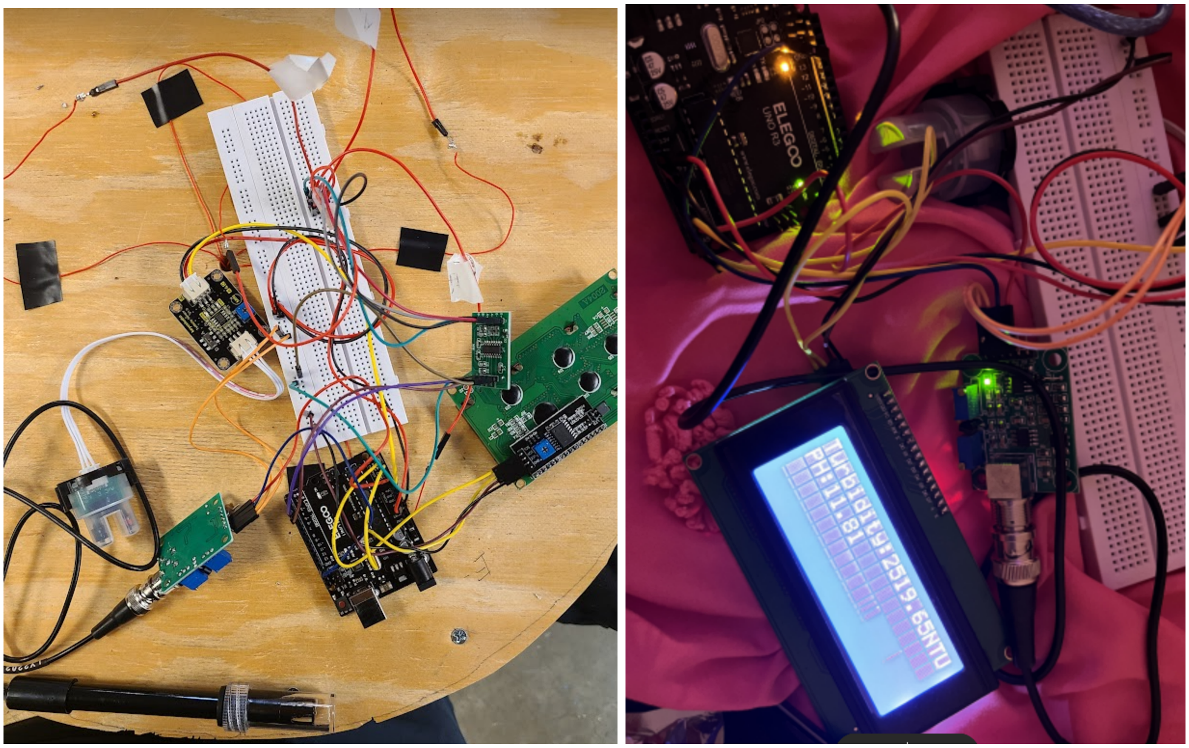


Figure 22: Final results

While the wiring worked, Francisco, with Makenna's advice, decided to include the voltage value across the circuit. The ALICE software lists values below:

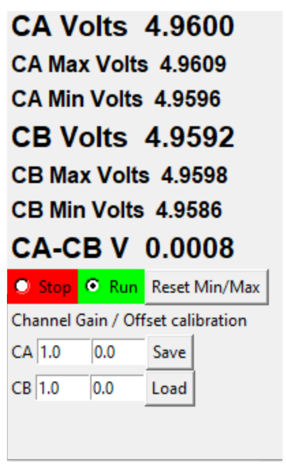


Figure 23: Voltage output

Since the load cells were something the team was not familiar with, it was important to ensure that resistance was being detected on the E+/- and A+/- sides, which are essentially the diagonal polarities that would connect at all four corners.

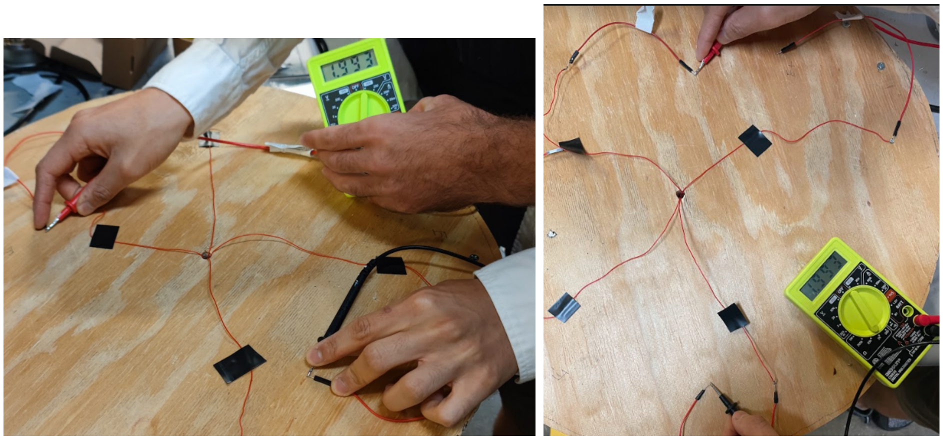


Figure 24: Load cell testing

Francisco finally worked on the solar cells by wiring them in series.

Figure 25: Solar panels wired in series

7 Results and Discussion

7.1 Results

Overall, almost all aspects of the project's subsystem functioned as expected.

1. Water dispensing proved to be successful, as the siphon pump was able to pump enough water in a reasonable time. Even with heavy water inflow, there was no overflow over the filtration pipe. Finally, there were no leaks, so this prototype proved to be robust.

2. Water filtration was beyond satisfactory, as the filter was able to take water with a pH of 4(around the value of acidic rain), and then filter it to reach a pH of 7, which is that of filtered water.

3. Despite testing being done on a cloudy day, power generation using solar panels was able to create the maximum threshold voltage of 20V by wiring them in series. This would mean the product would be able to function even in times of rough precipitation.

4. The sensors proved to be the most complicated of the components. While connecting them to the circuit was simple, it was the task of getting the correct values on the display that was the most difficult. The pH and turbidity sensors even malfunctioned on demonstration day, however, by recording their functionality prior, the team was able to demonstrate that these sensors worked. The load cells, however, were not able to be fixed. Being that the team was working with a limited budget and knowledge of these sensors, it was difficult to diagnose the underlying issues that led to problems in the sensors, particularly the load cells.

5. The LCD display was able to display data clearly, however, because the load cells did not end up being successfully implemented, the code was not able to register anything for input, and there was no value for volume.

6. Circuitry required lots of patience, especially because it required soldering. However, by testing the wiring of all the sensors, as well as the Arduino and LCD display, and getting proper values, the team was able to have a circuit that had current flowing through it smoothly.

7.2 Significant Technical Accomplishments

Perhaps the most significant technical accomplishment was getting the pH and turbidity sensors to work, as nobody on the team was experienced with them before this project. It was fascinating to see how seemingly simple components were able to take in so much information and deliver the value that we wanted.

One technical aspect which helped the team learn was the load cells. Again, no team member had any experience with these sensors, so the troubleshooting process was very difficult. However, by watching many videos and performing tests, the team was better able to understand how the load cells took in the information and how they were designed to be wired in an orderly way. Proper wire management was a lesson that the team was able to successfully derive. It would have most likely helped to purchase a more expensive set of load cells, however, that would have been out of the budget for the project.

8 Conclusions

All of the team members learned valuable lessons over the 6-week project. We learned vital information about the design process that we will bring through our careers, and we also learned about effective teamwork.

Our final prototype functioned well, with only one component failing to work. The system can filter water to a neutral pH and free of particulates without overflowing the filter, dispense the water, and provide information about the water quality. Our testing and demonstration showed that the prototype achieves full functionality in three of the six subsystems and near full functionality in the remaining three.

To create a robust design that met our customer requirements and specifications, the team had to work closely together to maximize our strengths. The group had to communicate effectively and support each other to succeed, skills that will be vital in the workforce.

The next step for the prototype would be to investigate more effective ways to combine the subsystems in one solid product. There is also work to be done on optimizing the filter for filtration and weight.

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9 Appendix A: Selection of Team Project

Our team originally wanted to address the problem of water and energy access in disaster relief areas. After brainstorming initial concepts for a disaster relief pod, we realized that the design was too complex to design and build in one semester, especially to the quality that vulnerable populations would need. We decided to focus on the water collection and filtration aspects of the pod, while retaining the energy generation in a reduced capacity. This led to the idea of a rain barrel that could filter water and provide information about water quality, while being powered with renewable energy. This shift is shown in our concept selection matrix, shown as Table 8.

Table 8: Concept Selection Matrix

	Concepts					
	A	B	C	D	E	F
Selection Criteria	**Rain Barrel**	**Disaster Relief Pod**	**Heat Pump**	**Amphibious Solar Still**	**Recyclable Sorting Bin**	**Pill Dispenser**
Safety	1	0	0	0	1	1
Cost-effective	1	0	1	0	0	0
Feasibility	1	0	-1	-1	0	1
Sustainability	1	1	1	1	1	-1
Reliability	1	1	1	0	1	0
Weather-proof / Endurance	1	1	-1	0	-1	-1
Weight	0	-1	0	0	0	1
Simple to use	1	0	-1	0	1	1
Multi-purpose	0	1	-1	0	1	-1
Easy to fix	1	0	-1	0	0	1
Compact	1	-1	0	0	1	0
Sum of +1's	9	4	3	1	6	5
Sum of 0's	0	0	0	0	0	0
Sum of -1's	0	-2	-5	-1	-1	-3
Net Score	9	2	-2	0	5	2
Rank	1	3	5	4	2	3

10 Appendix B: Customer Requirements and Technical Specifications

The below chart is the list of all Customer Requirements gathered through survey, emails, phone calls and other social media platforms. Their associated Technical Specification as well as Target Value are included as well.

Table 9: Customer Requirements & Technical Specifications

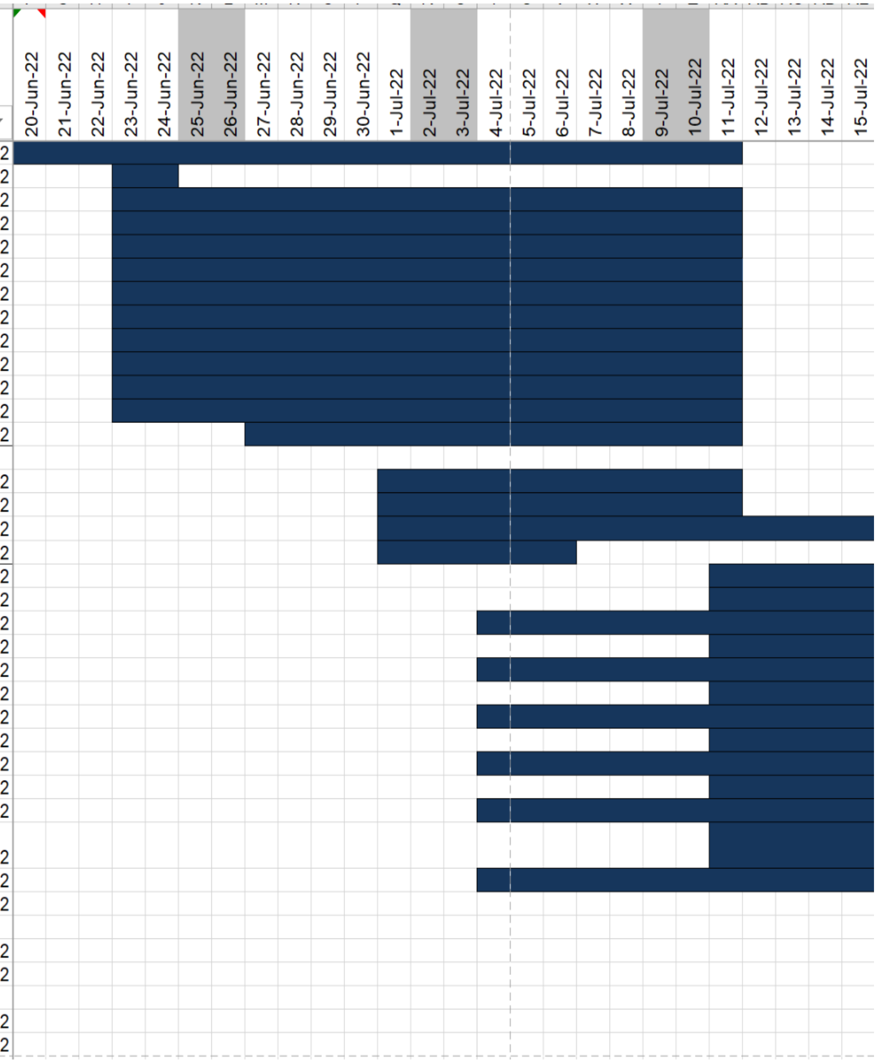
	Customer Requirement	Technical Specification	Target Value / Range of Values
I	Use by general public	Affordability, Ease of Use	Less than $200 in retail price
II	Can be moved easily	Portability, Weight	30 lbs Max
III	Can be attached to a home’s gutter system.	Home compatibility	Up to 10’x12’x10’
IV	Can be used by teens and adults	Age, Ease of Use	13 years old & up
V	Can be easily operated	Strength	5 lbs or less to operate
VI	Can be operated from waist level	Mobility, Ease of Use	~4-5 feet from floor
VII	Made from Eco-friendly and Durable material	Sustainability, Non-Harmful Materials	Made by 100% recyclable plastic
VIII	Abides by the most restricted water volume harvest law in US	Water Intake Capacity Limit	Less than 110 gallons of water allowed
IX	Abides by the most restrictive water quality harvest law in US	Clear & Simple Data Display	6.5<pH<7.5 Water is visually clearer
X	Data collected can be shown to customers in a clear and concise way and implemented using Arduino IDE	Sustainability	Arduino LCD Display (20 cols x 4 rows)
XI	The power source is environmentally friendly	Weight & Size	90-100% of the energy generated is Solar and/or Hydro-Powered
XII	Can hold enough water to support a garden	Water Intake Capacity Limit	250lbs of water min

Table 10: Target Customers Table

	Target Customers	Reason	Ranking
	Household	Household would use the water barrel to collect rainwater. General usage includes gardening, cleaning, and possibly drinking water.	1
	Farmers	Farmers would be used to collect water. Use for agriculture products and possibly animal drinking usage.	2
	Building Designers / Architecture	Able to attach rain barrels to houses or apartments. Provide the capability for the complex to collect and utilize rainwater.	4
	Disaster Relief Agency	Rain Barrels can be used in disaster affected areas to provide clean water.	3

Appendix C: Gantt Chart

Project Name	Status	Owner	Start	End
Memo 1	100%		6/16/2022	7/11/2022
Reach out to customers	100%	Drew/Corinne/John	6/23/2022	6/24/2022
Problem Statement	100%	Corinne	6/23/2022	7/11/2022
Customer Requirements	100%	Makenna	6/23/2022	7/11/2022
Concepts and Benchmarking	100%	Francisco	6/23/2022	7/11/2022
Proposed Solution	100%	Corinne/John	6/23/2022	7/11/2022
Project Plan	100%	Calvin	6/23/2022	7/11/2022
Materials	100%	Drew	6/23/2022	7/11/2022
References	100%	John	6/23/2022	7/11/2022
Customer Requirements Table	100%	Makenna	6/23/2022	7/11/2022
Concept Selection Matrix	100%	Francisco	6/23/2022	7/11/2022
Preliminary Parts List	100%	Drew	6/23/2022	7/11/2022
Customer Requirements Table	100%	Calvin	6/27/2022	7/11/2022
Memo 2	100%			
Sketch of Subsystem Designs	100%	Individual	7/1/2022	7/11/2022
Materials List	100%	Drew/John	7/1/2022	7/11/2022
Write out subsystem goals	100%	Individual	7/1/2022	7/15/2022
Update Gantt Chart for Memo 2	100%	Corinne	7/1/2022	7/6/2022
Developing Prototype	100%		7/11/2022	8/11/2022
Subsystem (1) - Water Data Collection	100%	Drew	7/11/2022	8/11/2022
Subsystem (1) - Material Acquisition	100%	Drew	7/4/2022	7/25/2022
Subsystem (2) - Water Filtration	100%	Corinne	7/11/2022	8/11/2022
Subsystem (2) - Material Acquisition	100%	Corinne	7/4/2022	7/25/2022
Subsystem (3) - Water Dispensing	100%	John	7/11/2022	8/11/2022
Subsystem (3) - Material Acquisition	100%	John	7/4/2022	7/25/2022
Subsystem (4) - Display	100%	Makenna	7/11/2022	8/11/2022
Subsystem (4) - Material Acquisition	100%	Makenna	7/4/2022	7/25/2022
Subsystem (5) - Energy Generation	100%	Calvin	7/11/2022	8/11/2022
Subsystem (5) - Material Acquisition	100%	Calvin	7/4/2022	7/25/2022
Subsystem (6) - Power Storage & Distribution	100%	Francisco	7/11/2022	8/11/2022
Subsystem (6) - Material Acquisition	100%	Francisco	7/4/2022	7/25/2022
Subsytem Assembly	100%	Drew, Corinne, Calvin	7/22/2022	8/11/2022
Milestone 2	100%			
Demo Day Presentation	100%	Drew, Corinne, Calvin	8/1/2022	8/11/2022
Subsystem Testing	100%	Drew, Corinne, Calvin	8/1/2022	8/11/2022
Milestone 3				
Powerpoint Presentation	100%	Drew, Corinne, Calvin	8/6/2022	8/18/2022
Memo Competition	100%	Drew, Corinne, Calvin	8/6/2022	8/18/2022



Project Name	Status	Owner	Start	End
Memo 1	100%		6/16/2022	7/11/2022
Reach out to customers	100%	Drew/Corinne/John	6/23/2022	6/24/2022
Problem Statement	100%	Corinne	6/23/2022	7/11/2022
Customer Requirements	100%	Makenna	6/23/2022	7/11/2022
Concepts and Benchmarking	100%	Francisco	6/23/2022	7/11/2022
Proposed Solution	100%	Corinne/John	6/23/2022	7/11/2022
Project Plan	100%	Calvin	6/23/2022	7/11/2022
Materials	100%	Drew	6/23/2022	7/11/2022
References	100%	John	6/23/2022	7/11/2022
Customer Requirements Table	100%	Makenna	6/23/2022	7/11/2022
Concept Selection Matrix	100%	Francisco	6/23/2022	7/11/2022
Preliminary Parts List	100%	Drew	6/23/2022	7/11/2022
Customer Requirements Table	100%	Calvin	6/27/2022	7/11/2022
Memo 2	100%			
Sketch of Subsystem Designs	100%	Individual	7/1/2022	7/11/2022
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Developing Prototype	100%		7/11/2022	8/11/2022
Subsystem (1) - Water Data Collection	100%	Drew	7/11/2022	8/11/2022
Subsystem (1) - Material Acquisition	100%	Drew	7/4/2022	7/25/2022
Subsystem (2) - Water Filtration	100%	Corinne	7/11/2022	8/11/2022
Subsystem (2) - Material Acquisition	100%	Corinne	7/4/2022	7/25/2022
Subsystem (3) - Water Dispensing	100%	John	7/11/2022	8/11/2022
Subsystem (3) - Material Acquisition	100%	John	7/4/2022	7/25/2022
Subsystem (4) - Display	100%	Makenna	7/11/2022	8/11/2022
Subsystem (4) - Material Acquisition	100%	Makenna	7/4/2022	7/25/2022
Subsystem (5) - Energy Generation	100%	Calvin	7/11/2022	8/11/2022
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Subsystem (6) - Power Storage & Distribution	100%	Francisco	7/11/2022	8/11/2022
Subsystem (6) - Material Acquisition	100%	Francisco	7/4/2022	7/25/2022
Subsytem Assembly	100%	Drew, Corinne, Calvin	7/22/2022	8/11/2022
Milestone 2	100%			
Demo Day Presentation	100%	Drew, Corinne, Calvin	8/1/2022	8/11/2022
Subsystem Testing	100%	Drew, Corinne, Calvin	8/1/2022	8/11/2022
Milestone 3				
Powerpoint Presentation	100%	Drew, Corinne, Calvin	8/6/2022	8/18/2022
Memo Competition	100%	Drew, Corinne, Calvin	8/6/2022	8/18/2022

Although our team had many strengths, there were some weaknesses. Utilizing the Gantt Chart was one of the major areas our team could improve upon. Although our Gantt Chart covers the basics and did help us get a general idea of timelines and due dates, it is not as detailed as it could be and was not updated frequently/not observed on a regular basis throughout the design process. In terms of lessons learned, it would be beneficial for the team members to spend more time fleshing out the Gantt Chart in the beginning and making it a habit to update or make revisions to it on a regular basis, such as two or three times a week. Our team realizes that there are many benefits of using a Gantt Chart for complex projects with many moving parts such as our water filtering rain barrel, however, not all those benefits can be realized without a general commitment to utilizing a Gantt Chart to its fullest potential.

Appendix D: Expense Report

Below are charts that indicate the cost of all parts. The expenses themselves are classified in terms of their subsystem. All shipping costs are $0 due to free shipping, in-store purchases or paid subscription.

Water Data Collection:

Items	**Quantity**	**Unit Prices**	**Subtotal**	**Shipping**
PH Sensor	1	$35.88	$38.75	$0
Turbidity Sensor	1	$13.98	$15.10	$0
Load Cells (4 pack)	1	$7.99	$8.63	$0

Water Filtration:

Items	**Quantity**	**Unit Prices**	**Subtotal**	**Shipping**
Filtering sand	50 lbs	$36.80	$39.84	$0
PVC Pipe	1	$8.97	$9.69	$0
Charcoal	1	$31.70	$31.70	$0
Flour sifter	1	$11.99	$11.99	$0

Display:

Items	Quantity	Unit Prices	Subtotal	Shipping
LCD Display	1	$12.99	$14.03	$0
Arduino Processor	1	$17.99	$19.43	$0

Energy Generation / Storage:

Items	Quantity	Unit Prices	Subtotal	Shipping
Solar Cells (10 pack)	1	$14.99	$16.19	$0
9V Rechargeable Battery	1	$14.99	$16.19	$0
Buck Converter	1	$6.99	$7.55	$0
Battery Pack	1	$6.99	$7.55	$0
Breadboard	1	$20	$21.78	$0

Water Dispensing System:

Items	Quantity	Unit Prices	Subtotal	Shipping
Brute 44 Gallon Barrel	1	$54.82	$59.21	$0
PVC Pipe (Overflow pipe)	1	$1.51	$1.63	$0
Threaded Garden Hose Adaptor Fitting	1	$11.33	$12.24	$0
Adjustable Clamp	1	$1.49	$1.61	$0
Threaded Adaptor Fitting	1	$16.41	$17.72	$0
Spigot	1	$7.61	$8.22	$0
Charcoal Fiber Screen Mesh	1	$9.80	$10.58	$0
Siphon Pump	1	$11.00	$11.88	$0

Miscellaneous Hardware:

Items	Quantity	Unit Prices	Subtotal	Shipping
Wood	5	$45.82	$49.49	$0
Nuts/Bolts/Washers	30	$5.12	$5.53	$0

Total Subtotal Cost: $444.39

11 Appendix E: Team Members and Their Contributions

11.1 Calvin Chan

- Design subsystem power generation
- Milestone 1 memo
- Powerpoint & Presentation for Milestone 1
- Milestone 3 memo
- Milestone 3 powerpoint
- Testing and Building of other subsystem
- Sketches for subsystem

11.2 Makenna Noel

- Created circuit diagram
- Troubleshooted sensor hardware implementation
- Coded and tested sensor data to output on LCD display
- Coded software implementation of sensors
- Troubleshooted software implementation of sensors
- Milestone 1 & 3 memo
- Powerpoint for Milestone 1 & 3

11.3 Francisco Sandoval

- Wired Sensors, arduino, and LCD display with breadboard
- Wired Solar Panels in series
- Soldering
- Helped in construction of base to implement load cell sensors
- Helped to install solar panels
- Milestone 1&3 Memos

11.4 Andrew Voli

- Milestone 1 memo and presentation
- Assisted in assembling physical prototype
    - Building base, attaching pump, and attaching solar array
- Milestone 3 memo and presentation
- Designed and selected sensor systems
- Provided transportation
- Collected customer needs and feedback from consumers
- Contributed knowledge of assembly, construction, tools, machines, and fluid mechanics
- Acquisition of materials

11.5 John Wallace

- Milestone 1 memo & presentation
- Water dispensing subsystem
- Helped with building base and other tasks that team members needed help with
- Milestone 3 memo & presentation

11.6 Corinne Wingrove

- Analyzed water filtration methods
- Constructed water filter
- Contributed technical knowledge of water quality parameters
- Wrote sections of Memo 1&3

12 Appendix F: Statement of Work

Statement of Work (v.1 - 06/20/2022) - Water Filtering Rain Barrel

Team
Corinne Wingrove, Drew Voli, Makenna Noel, Calvin Chan, John Wallace, Francisco Sandoval

Semester Objectives
1. Design and construct a rain barrel that can treat water and generate enough power to be self-sufficient.
2. Perform engineering analyses and tests to guide the refinement of the design.
3. Form personal and professional relationships between team members.

Approach
Design and build a rain barrel that can be tested to meet our goals. Observe the barrel and use the lessons learned to refine our design. Take the feedback used to produce a consumer-friendly product.

Deliverables and Dates
1. Concept Presentation (6/30)
2. Concept Memo (7/11)
3. Completed Prototype (8/11)
4. Final Project Presentation (8/18)
5. Final Project Report (8/18)

13 Appendix G: Professional Development - Lessons Learned

Over the course of the project, our members learned valuable interpersonal and professional skills. While the full extent of our newfound skills have yet to be seen, some of them are summarized in table 11, a KPT chart.

Table 11: Keep-Problem-Try Chart

Keep	Problem	Try
The incorporation of a team bonding event/trip	The Gantt chart wasn't as useful as we wanted. It did not help to manage the project, and was a waste of time.	Having a shared group calendar for meetings in advance.
The use of a brain dump folder as a space for coming up with new ideas and implementation of our systems	Not referencing our notes for the design process as much as we could've for any obstacles we hit during the ideation process.	Maybe having a shared budget from day one and putting on a visa card to use among the group specifically for the purchases we need. (Also having individual budgets so we don't spend more than needed). Any money not used for equipment will be divided evenly and sent back to everyone.
The incorporation of a whenisgood to organize meetings based on our availability.	Not focusing on the project early on.	

14 Appendix H: Software / Technology Used

14.1 Collaboration Among Team Members

- Cisco WebEx Teams and Meetings
- Google Drive

14.2 Subsystem Design

- AutoCAD
- Siemens NX

14.3 Programming

- Visual Studio Code – Integrated Development Environment
- Pycharm
- Arduino IDE

14.4 Subsystem Testing/Simulation/Emulation

- Siemens NX
- AutoCAD
- Circuit.io - for circuit connections and sensor algorithm simulation
- ALICE: Voltage measurement
- Voltmeter: Resistance for Load Sensors

15 Appendix I: User Manual

15.1 Safety and Proper Use

This product contains sensitive electronics that can be damaged by water. Because of this, follow the guidelines below:

Do not puncture the base of the barrel in any way.
Do not cut or slice any of the external or internal wires.
Do not open the base of the barrel.
Do not drop things into the barrel, as it can damage important sensors critical to the function of this product.

For this product to operate properly, **do not** place objects or items on top of the barrel, this will cause the water volume reading on the display to display wrong information.

Some states have restrictions on rainwater use, consult the information below to find out if your state is among these.

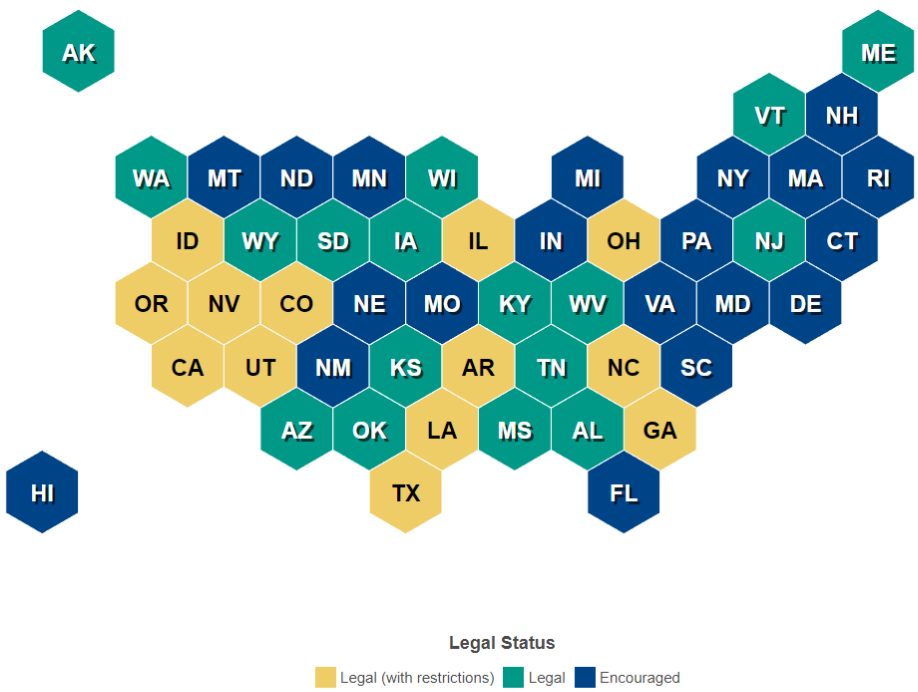

Figure 26: Legal Status of Rainwater Collection by State

For the following states with restrictions:

- Arkansas - Collected rainwater can be used for non-drinking purposes if the rain barrel is designed by a professional engineer licensed in Arkansas, has appropriate cross-connection safeguards, and complies with Arkansas Plumbing Code.

- California - Residential, commercial, and governmental landowners may install, maintain, and operate rain barrels for specified purposes.
- Colorado - Residents are allowed to collect rainwater in two rain barrels with a combined capacity of 110 gallons which can only be used on the property where it was collected and for outdoor purposes.
- Georgia - Rain barrels can only be used for outdoor purposes and is regulated by the Department of Natural Resources in the Environmental Protection Division.
- Illinois - Collected rainwater can only be used for non-drinking purposes, and rain barrels must be constructed in accordance with the Illinois Plumbing Code.
- Kansas - Rainwater harvesting is legal, and no permit is needed if the water is used for purposes such as household use, watering livestock on pasture, or for lawns and gardens.
- Ohio - Rainwater harvesting is legal to drink, as long as the water system is providing drinking water to fewer than 25 people.
- Oregon - Rain barrels are legal, but rainwater can only be collected from systems on rooftop surfaces.
- Texas - The rain barrel needs to be incorporated into the building's design and a written notice needs to be given to the municipality.
- Utah - Rain barrels are allowed on land owned or leased by the person responsible for the collection. Additional regulations exist if a person is registered with the Division of Water Resources. A registered person may store no more than 2,500 gallons of rainwater, and an unregistered person may use no more than two containers at 100 gallons or less per container.

15.2 Setting Up Your Rain Barrel

For your new rain barrel to work optimally, you should follow these steps.

1. Find the side of your house with a downspout and a large section of roof leading down to the gutter.
2. Make sure this side of the house gets plenty of sun.
3. Once you have determined a location for the barrel, place the barrel on a level surface, ensuring the metal bumps on the base are contacting whatever surface the barrel is being supported by.
4. Make sure the barrel is facing in such a way that the overflow pipe (black pipe on back of barrel) is not facing the house.
5. Install your filter (the black tube) on the top of the barrel. This filter must be different from the last filter if this is the second year of using this product.
6. Modify your downspout with a downspout diverter (not included) and route it to the top of the pipe on the top of the barrel.
7. Align the solar array to face where the sun will be in the sky.
8. Wait for rain and enjoy your purchase!

15.3 Storage and Resetting

Depending on where in the country you reside, you may have to winterize your barrel earlier than expected. To assess this, you should follow the month-by-month guide below.

Continuous United States:

January

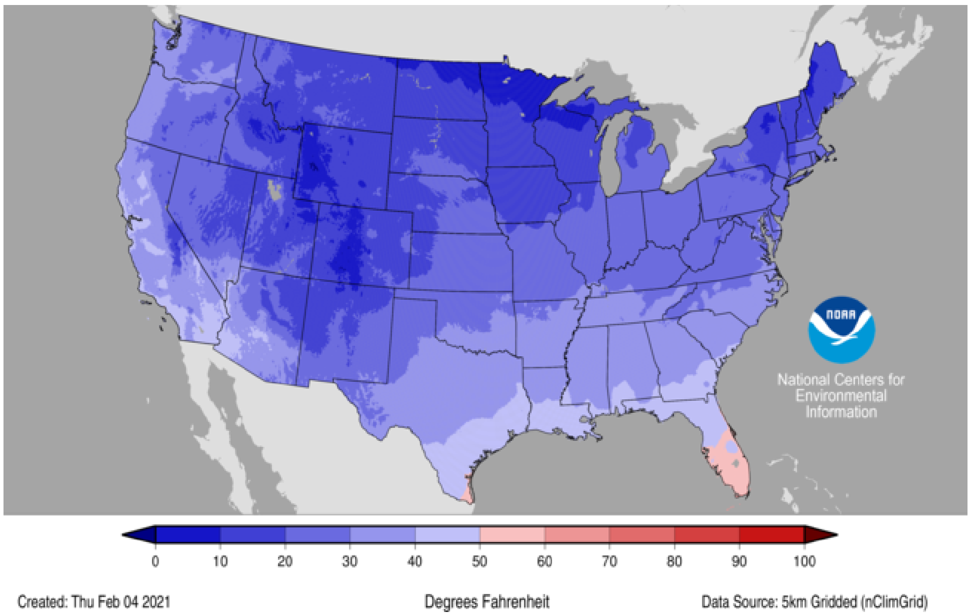

Figure 27: Average Minimum Temperature for January

February

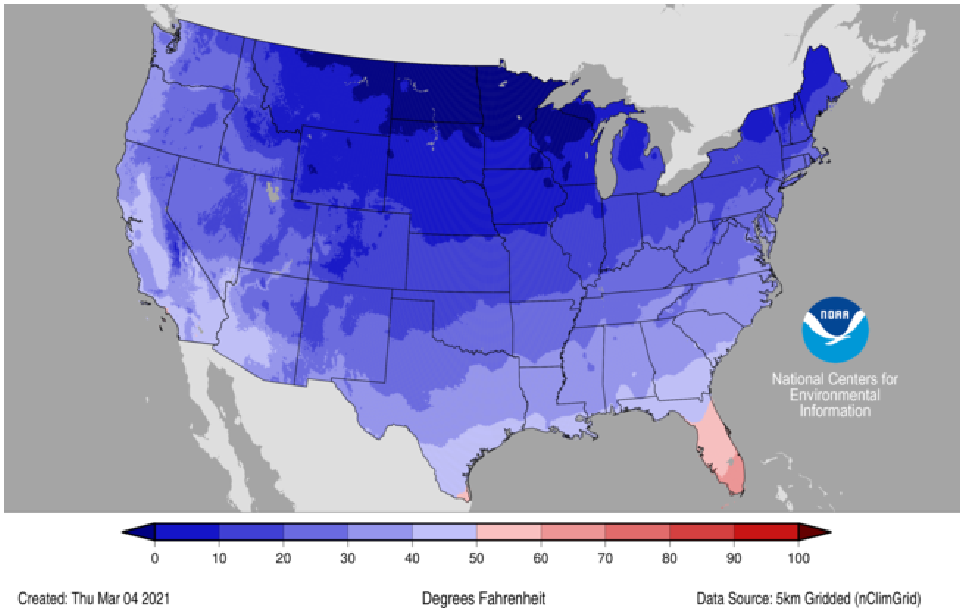

Figure 28: Average Minimum Temperature for February

March

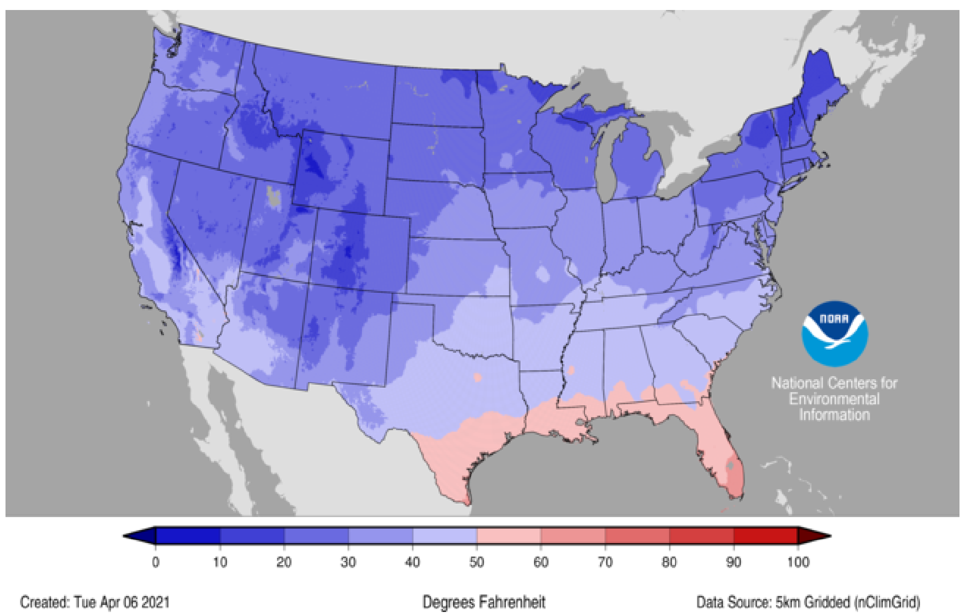

Figure 29: Average Minimum Temperature for March

April

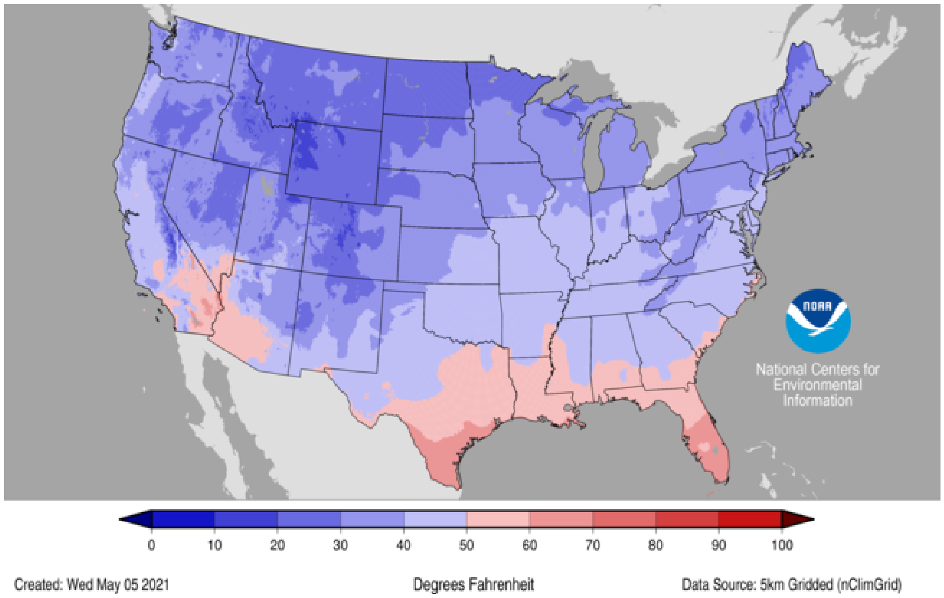

Figure 30: Average Minimum Temperature for April

May

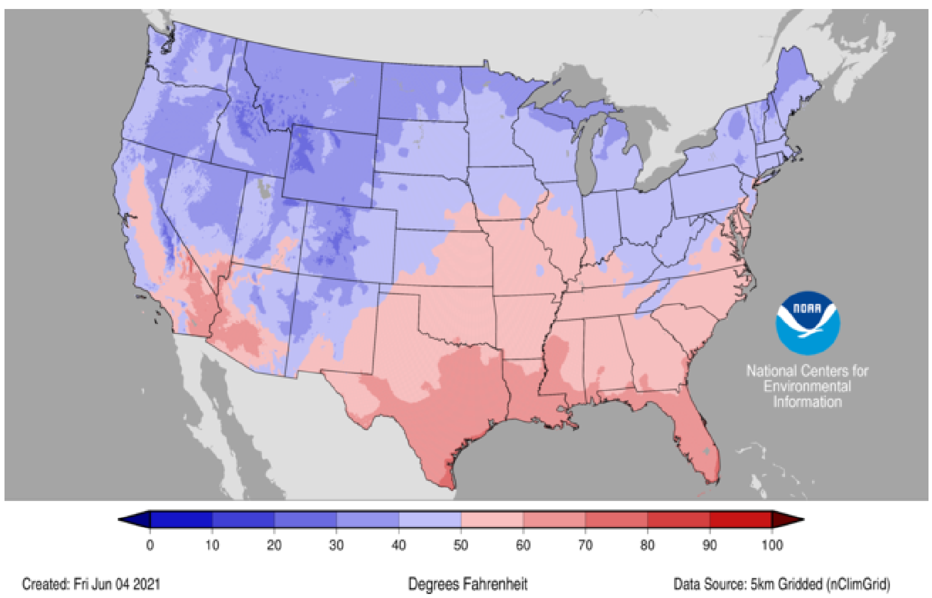

Figure 31: Average Minimum Temperature for May

June

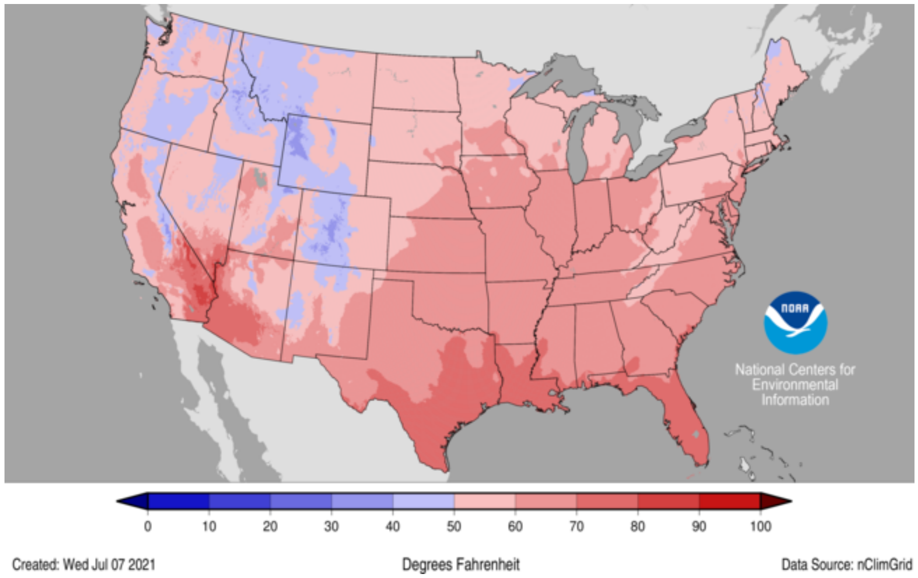

Figure 32: Average Minimum Temperature for June

July

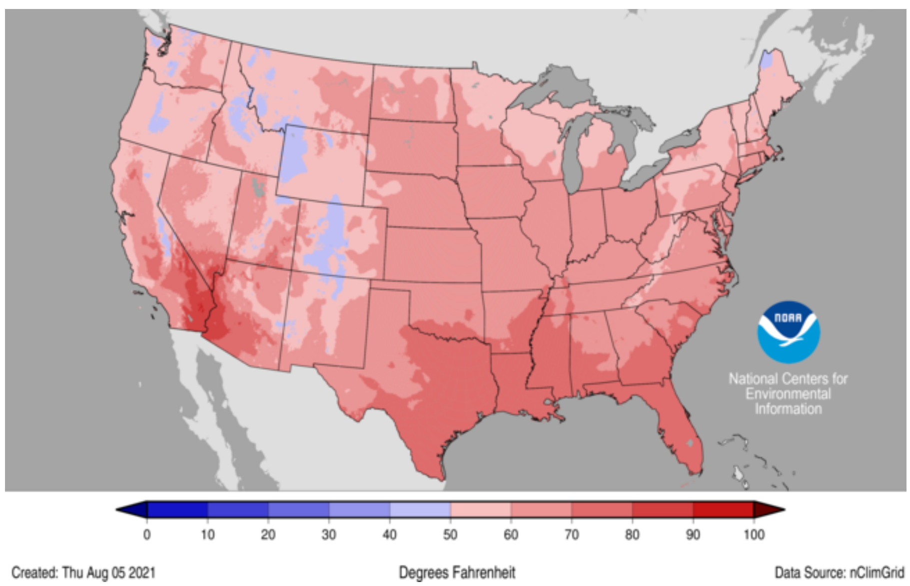

Figure 33: Average Minimum Temperature for July

August

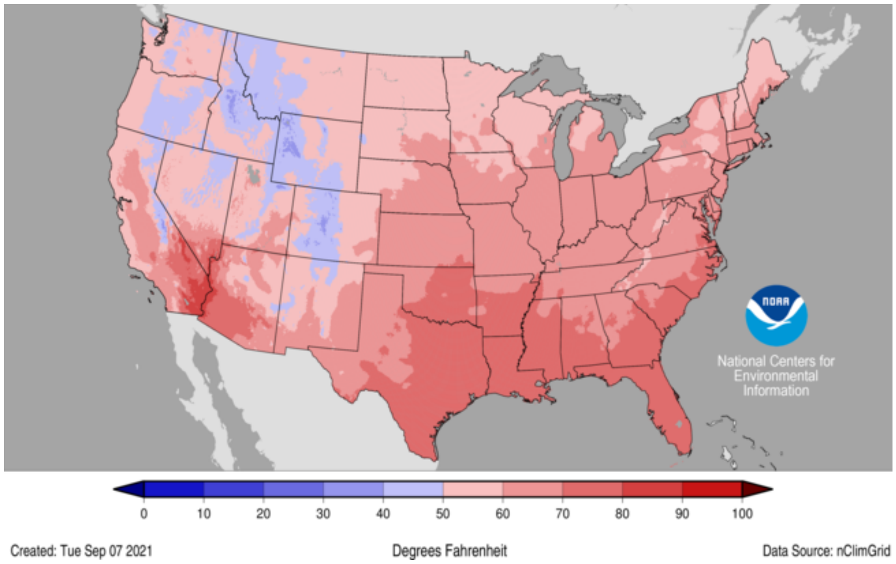

Figure 34: Average Minimum Temperature for August

September

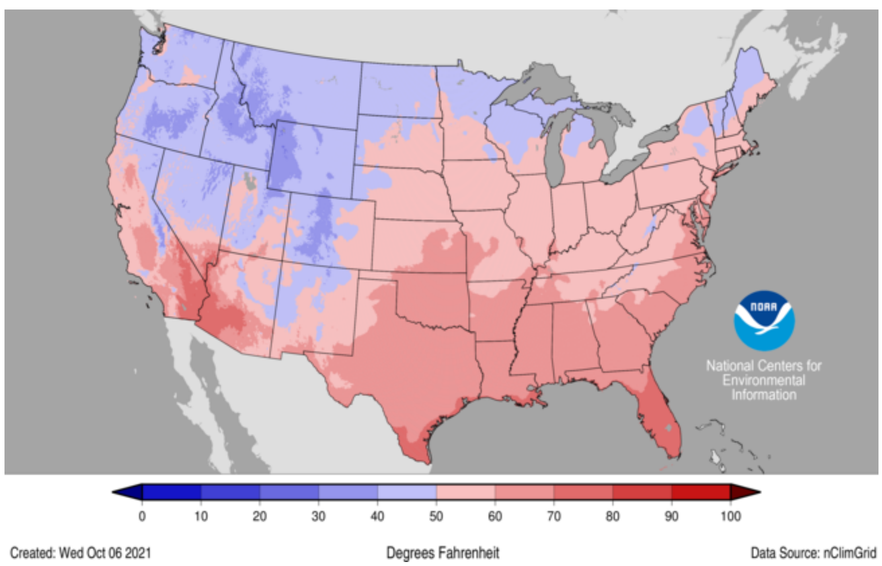

Figure 35: Average Minimum Temperature for September

October

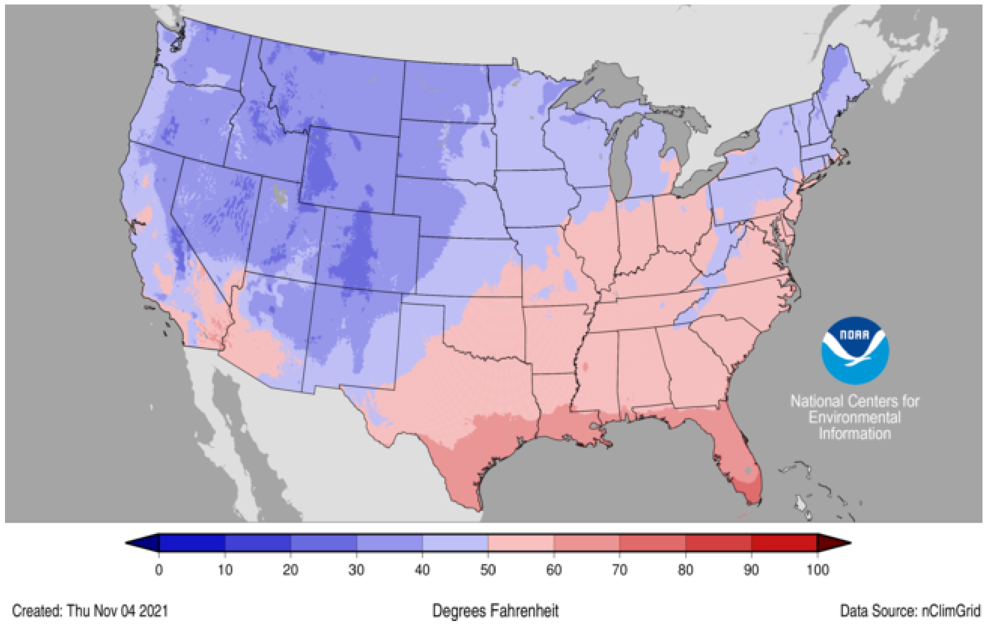

Figure 36: Average Minimum Temperature for October

November

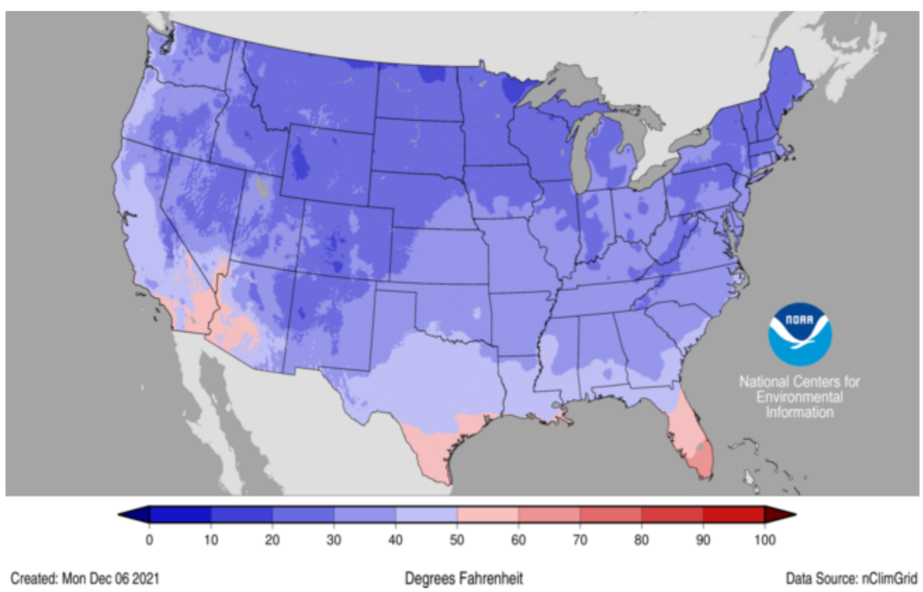

Figure 37: Average Minimum Temperature for November

December

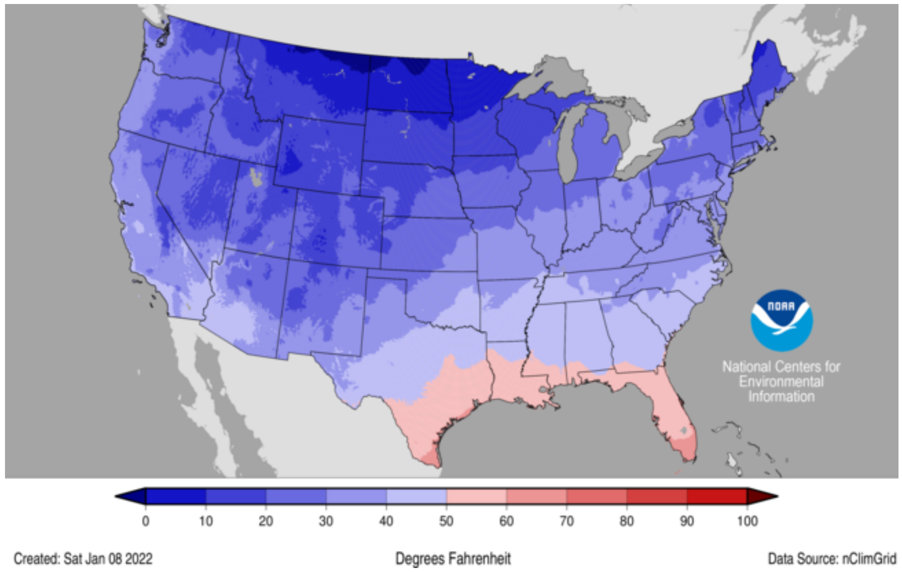

Figure 38: Average Minimum Temperature for December

If you live in a zone where the average minimum temperature falls within or below the 30-40℉ temperature zone, you should not have your barrel set up this month.

Alaska:

Same as above, if you live in a zone where the average minimum temperature for your area falls within or below the 30-40℉ temperature zone, you should not have your barrel set up this month. However, the zone colors change and are not the same as for the contiguous US.

January

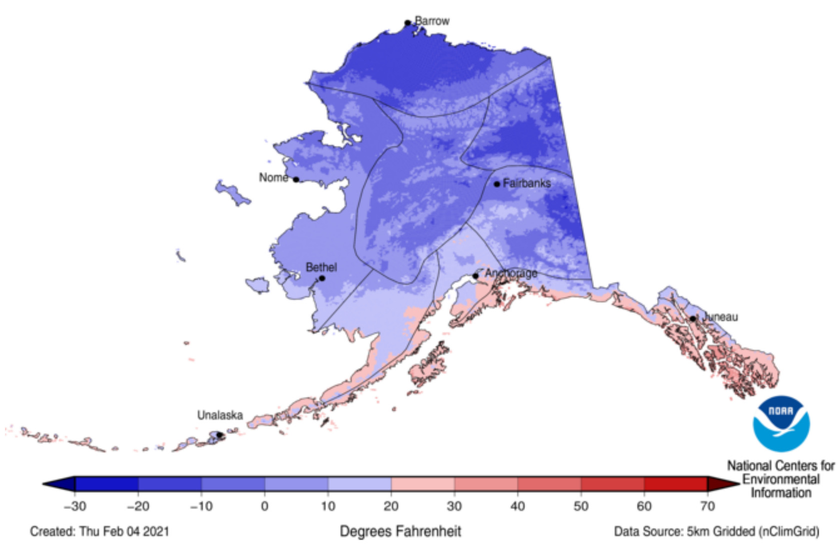

Figure 39: Alaska Average Minimum Temperature for January

February

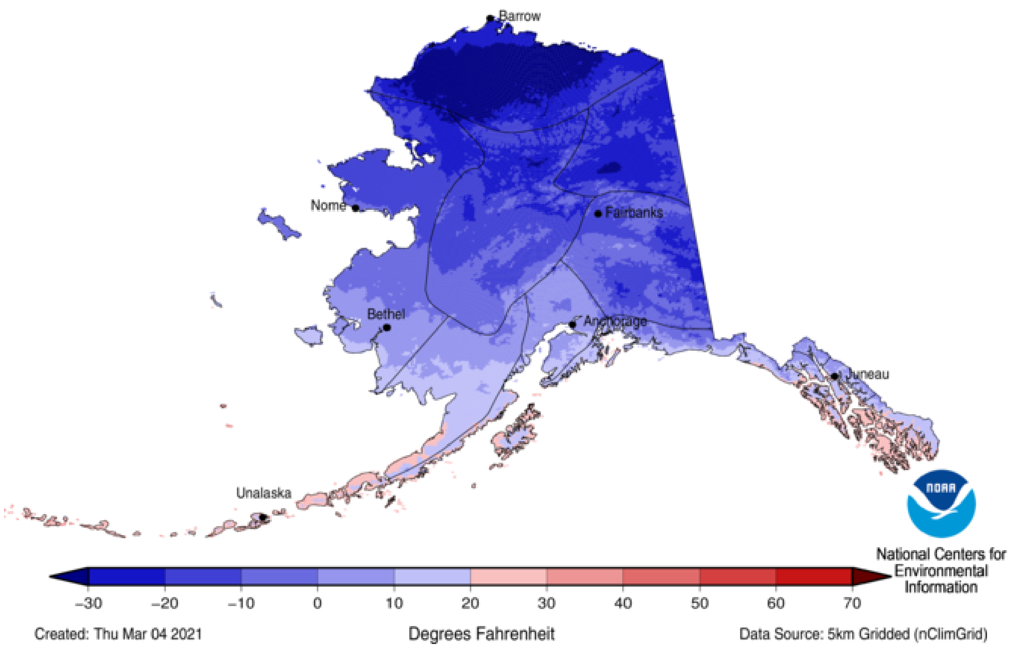

Figure 40: Alaska Average Minimum Temperature for February

March

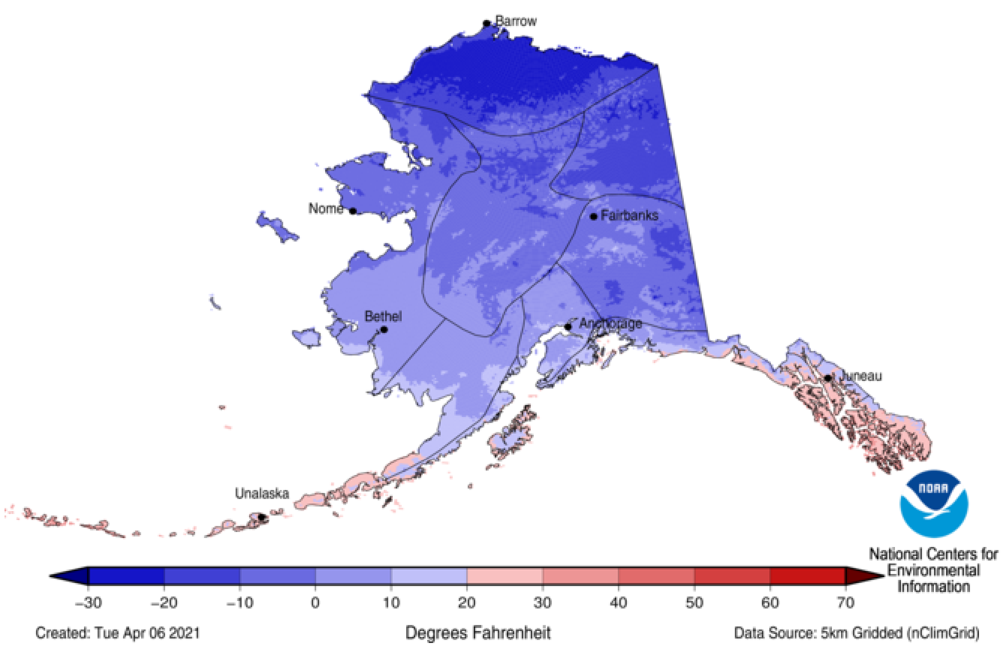

Figure 41: Alaska Average Minimum Temperature for March

April

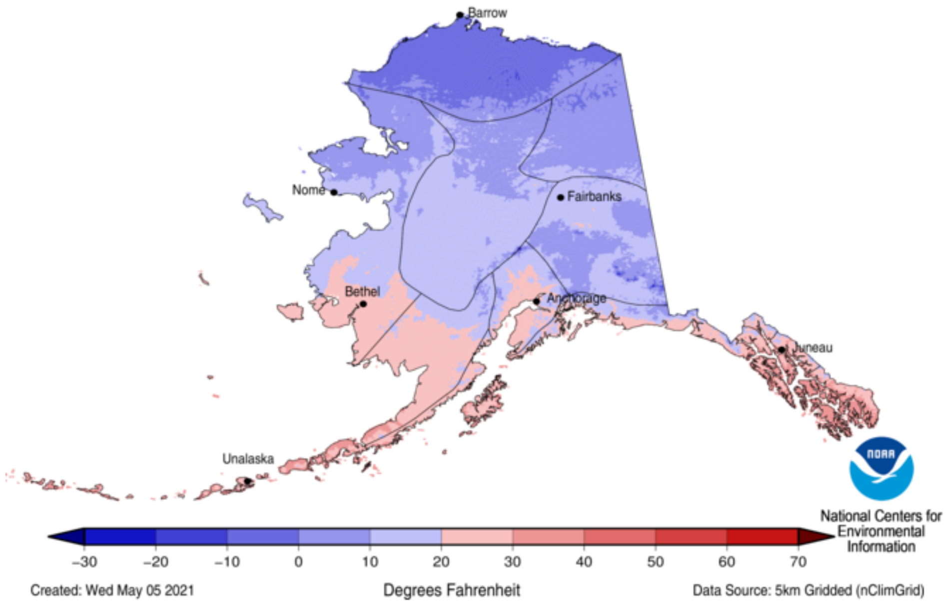

Figure 42: Alaska Average Minimum Temperature for April

May

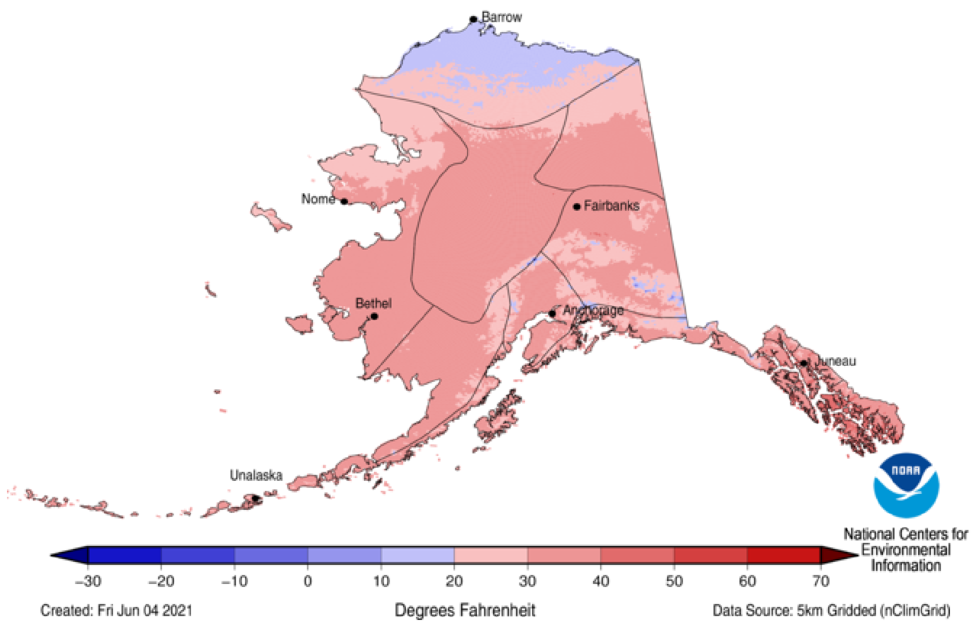

Figure 43: Alaska Average Minimum Temperature for May

June

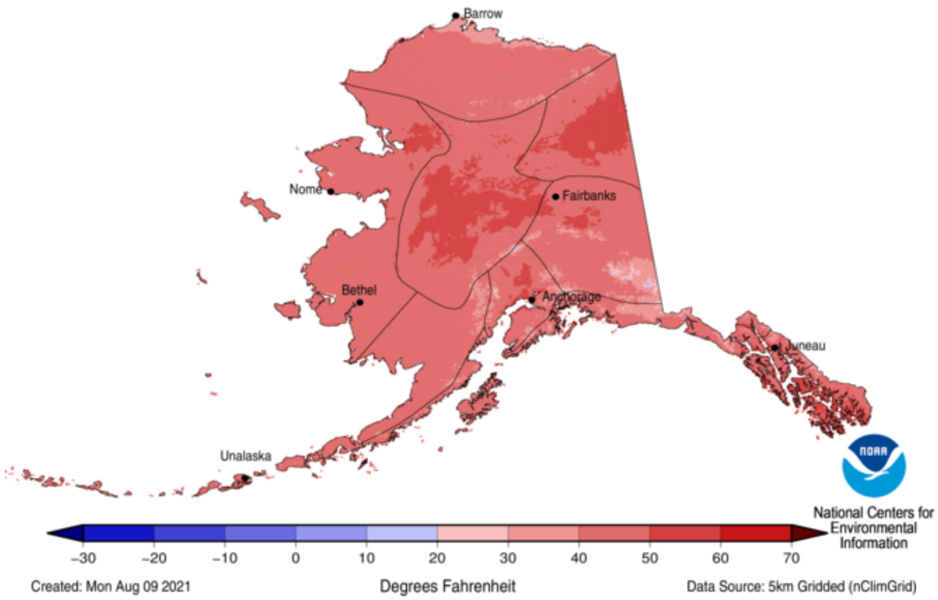

Figure 44: Alaska Average Minimum Temperature for June

July

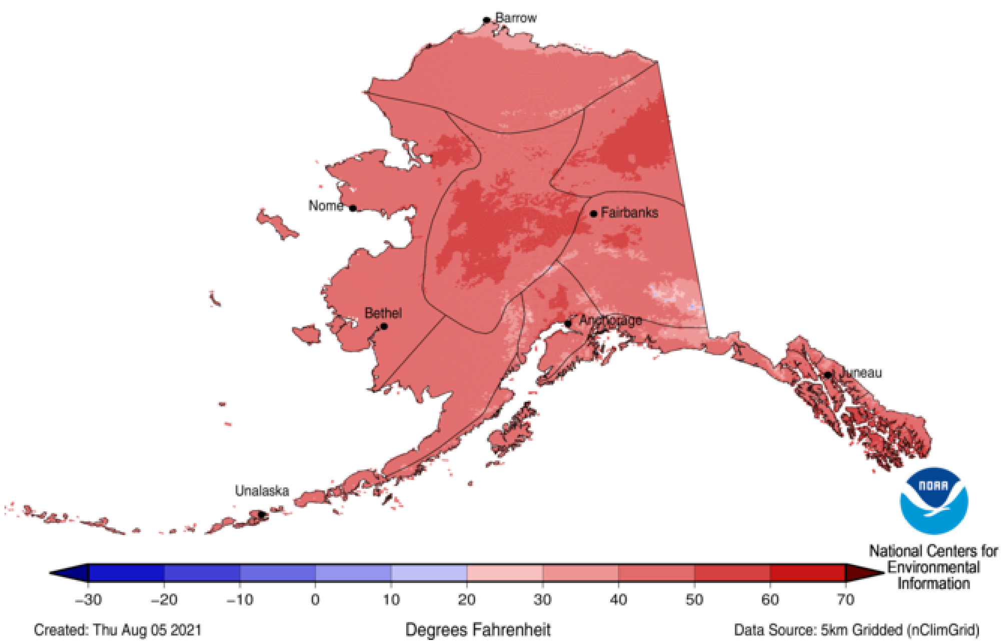

Figure 45: Alaska Average Minimum Temperature for July

August

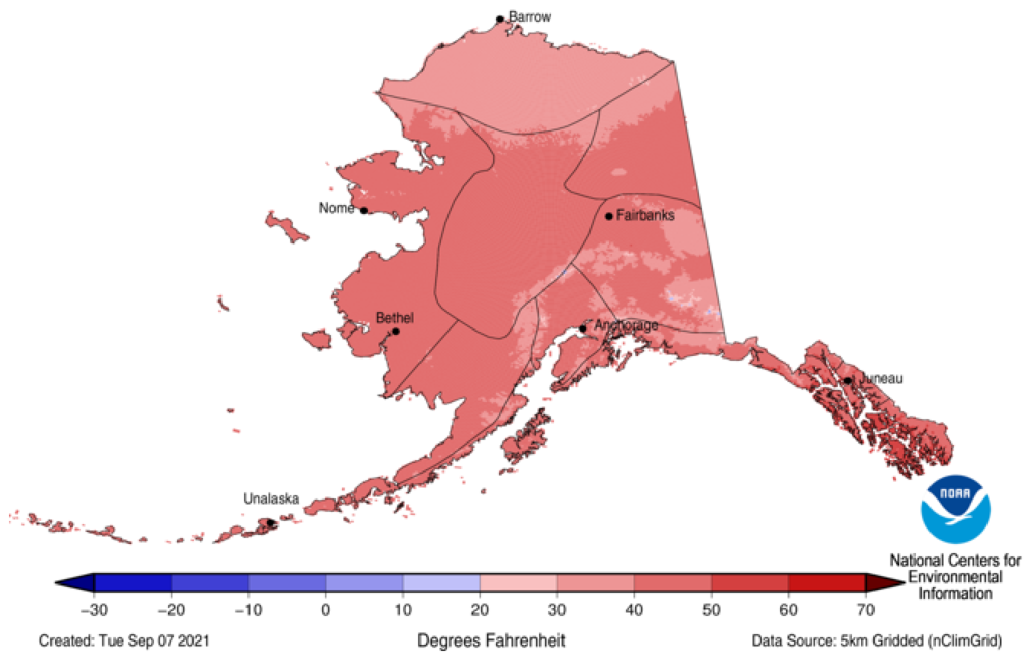

Figure 46: Alaska Average Minimum Temperature for August

September

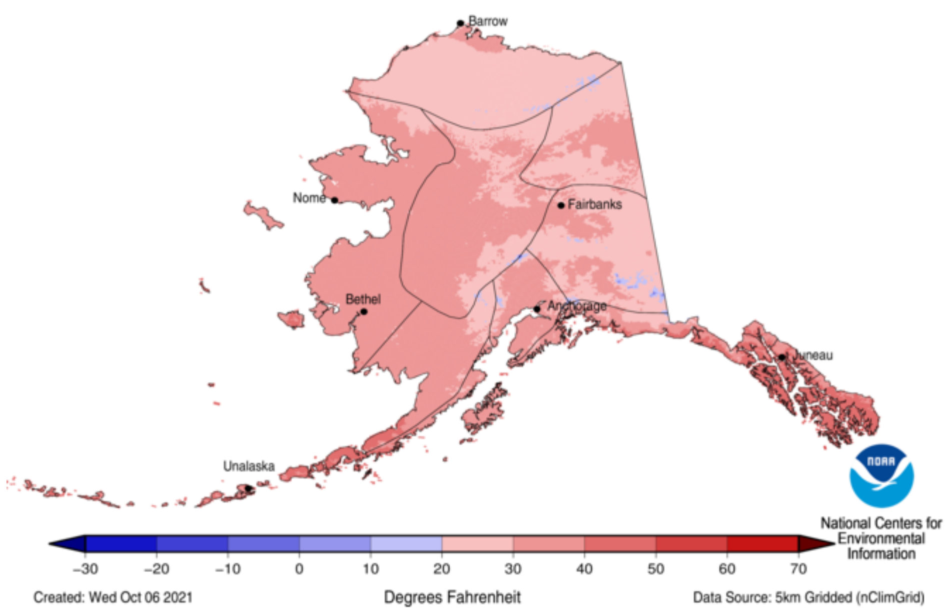

Figure 47: Alaska Average Minimum Temperature for September

October

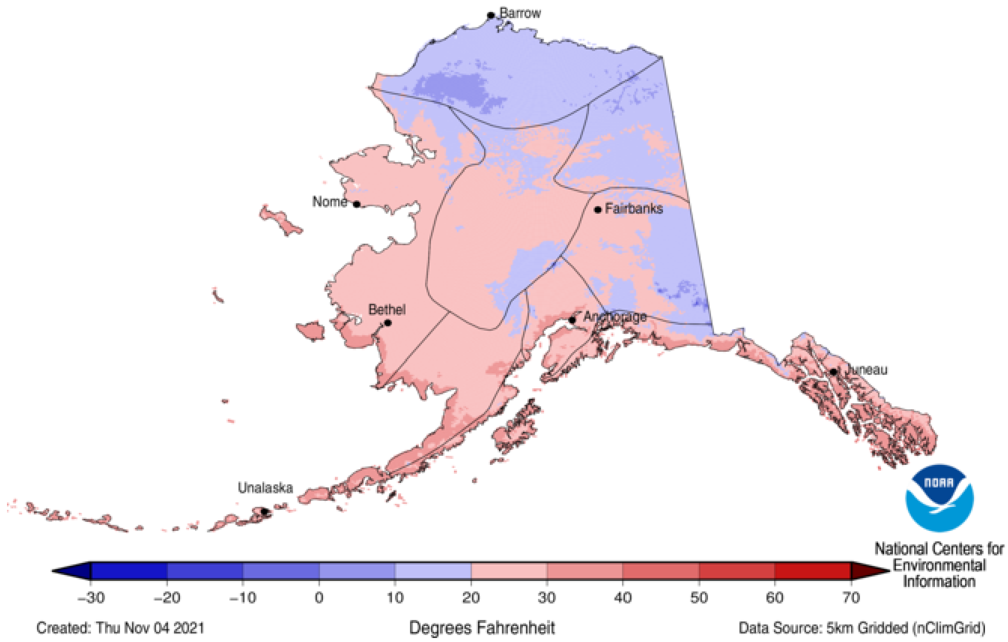

Figure 48: Alaska Average Minimum Temperature for October

November

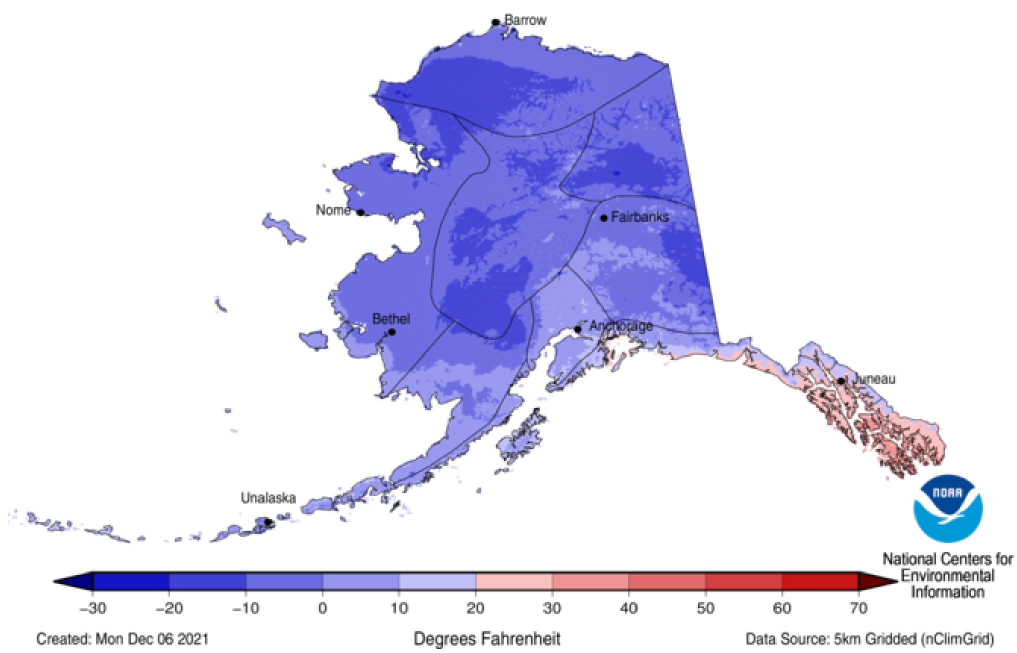

Figure 49: Alaska Average Minimum Temperature for November

December

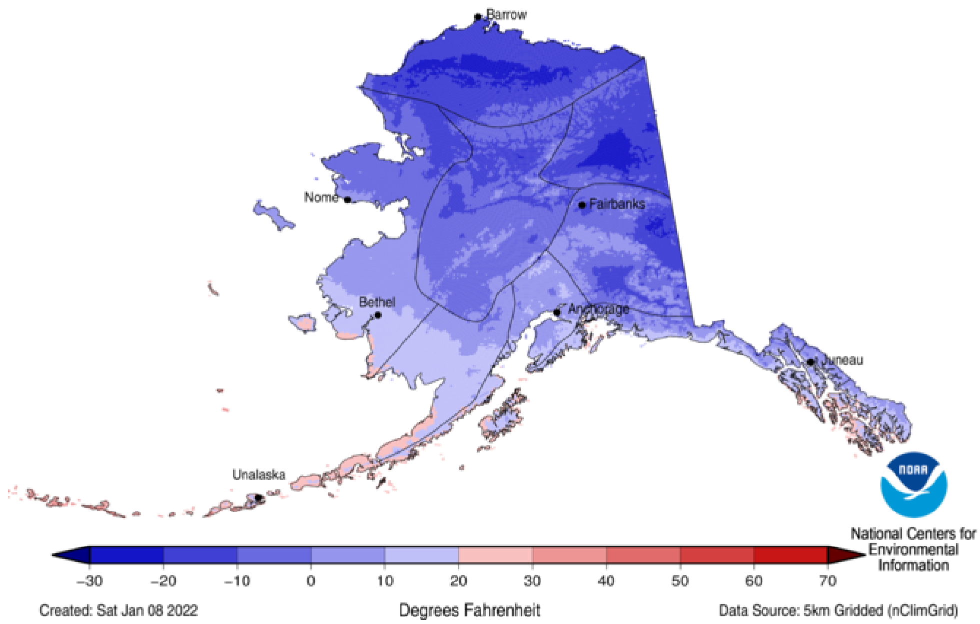

Figure 50: Alaska Average Minimum Temperature for December

Hawaii:

If you reside in the state of Hawaii, you can have your rain barrel almost all year except for certain periods of the winter. We suggest that you check your weather forecast when the temperature starts to drop as a precaution so you do not accidentally damage your rain barrel.

Disclaimer:

The above temperature data was measured in the 2021 calendar year by the National Oceanic and Atmospheric Administration and is subject to change year to year. This user manual will be updated each year but is subject to anomalies in temperature patterns. Due to this, we suggest you keep an eye on the temperature forecast no matter where your rain barrel is. If the temperature is starting to drop below freezing temperatures, take necessary precautions to ensure your rain barrel is not dealt preventable damage.

Winterization:

Once you've determined what month you will take down your barrel, the following steps will guide you.

1. Disconnect the rain barrel from the downspout of your house.
2. Drain the rain barrel completely of water.
3. Remove the filter.
4. Open the barrel and allow it to completely dry in a place where it will not get wet.
5. Once dry, store the barrel in an indoor setting and wait until the spring to set up!

Once you are able to set up the barrel once more, follow the same steps as initially setting up the barrel remembering to replace the filter with a new one as shown below.

15.4 Replacing the Filter

The filter should be replaced every six months. The best time to do this is when the barrel is brought in for winter. The filter should be emptied of the old sand and carbon, which could be disposed of in the garbage. The lower half of the filter should be refilled with two inches of charcoal and one inch of sand, then the mesh should be replaced. The upper layer should be refilled with three inches of sand, then the top mesh layer replaced.

15.5 Understanding Display Data

On the display, three data values are displayed, each corresponding to a sensor reading within the barrel's subsystems. These values are turbidity, measured in NTU, pH, and volume in gallons.

Turbidity is the measure of how clear the water is. This value should be around or near zero. If this value is not zero, open the barrel to inspect the visual clarity of the water and or clear any debris that may have gotten into the barrel.

The pH is a measure of how acidic, think lemon juice or vinegar, or how alkaline, think bleach or soap, the water is. This value should be around 7, which is neutral and the normal pH of water. If this value is not near 7 (within 0.7) you should not use the water. **Never** try to balance the pH by adding acids or bases. To solve the issue of a pH being too high or too low, drain water and let fill again. If the problem persists after this, the sensor is either faulty or the filter will need to be replaced.

The volume is a measure of how much water is in the barrel. Be sure there are no objects on the top of the barrel to ensure an accurate reading of water volume. The max volume will be around 40 gallons.