To: Dr. Oman

From: Randall Holgate, Noah Kincheloe, Jessie Russell, Brittney Rogers, and Wesley Garcia

Date: February 26, 2021

Subject: Red Feather Implementation Memo

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Red Feather is an organization that primarily does work on the Hopi Reservation and with the Navajo Nation. A problem that the people currently face is that there is no adequate heating source for a lot of homes on the reservation. On the Navajo Nation and Hopi Reservation they have been primarily using wood and coal stoves as the main heat source. This creates problems due to the lack of coal, which makes an inconsistent heat source. Another problem is that coal and wood stoves create a poor air quality which can increase the amount of asthma related health problems. Since it can hurt the lungs of the families living there, it can make it worse if COVID is caught. Another type of heat that is used is propane or natural gas, which can be expensive for long term use. Red Feather Development group has been installing solar furnaces on several homes however those only heat the homes during the day when the sun is shing, which still allows for the problem of inadequate heating at night.

Previous capstone groups have designed solar furnaces that are reliant on the sun to produce heat for daytime use, however this left the problem on how the house would be warmed at night. To solve some of these problems Red Feather Development group would like a design for a thermal storage device that can provide heat for the home at night. The device is meant to store heat in a medium to then release at night. The materials for the device should be locally available materials. Everything used for the system needs to be easy to transport to the home location. The design needs to be durable and able to handle the weather conditions that it will be exposed to. Lastly, the system should be within the price range set by the Red Feather group and their customers.

This memo will discuss the changes that have been made to the project since the start of last semester. Starting with the changes to the original scope of the project in the customer and engineering requirements. Then the memo will have a detailed look at each of the engineering requirements and how the team is going to test to insure they are met. It will then layout the specific changes to the design that have been made and the reason for these changes. Lastly, the memo will breakdown the implementation of how the team is going to build the device. Including a schedule for all manufacturing dates with deadlines the team is targeting.

# 1 Customer Requirements (CRs)

The client for this project is the Red Feather organization. The teams specific contact from them is Terry Smith. When meeting with Terry for the first time, the team composed a set of questions and his responses were then used to design a set of specific Customer Needs. These needs ranged from information regarding the functions of the device and the kind of setting the device would have to perform in. The contact from red feather, Terry, had a lot of information to expand on. The two most crucial pieces of information involved the temperatures the device would need to accommodate and the exact parameters of what the team needed to develop. With this information in hand ten customer needs shown in table 1 below were developed.

**Table 1**: Customer Needs

| Question/prompt | Customer statement | Interpretation/Need |
| --- | --- | --- |
| What is the main problem? | "A solution is still required to keep the home comfortable throughout the night." | Device should provide consistent heat source to keep houses warm at night, storing heat during the day and releasing at night. |
| What is the scope of the project? | "Current solar furnace is Arctica solar. Run by solar panel that runs the thermostat inside and monitors the temperature. System without electricity. Runs thermostat, fan, takes care of all electrical needs." | Device should store heat during the day and release it at night. |
| Where do you primarily work on homes in the reservation? | "Predominantly doing Hopi and western side of Navajo, includes major Navajo areas. Tuba City, Cameron, Leupp, Bird Springs. Currently, temperature drops into 40 degrees in the evening, 100 degrees all the way down into the 40's and 30's. June and July are 100-60. Gets colder as progress into fall. In the summer it is 100-50 degrees. In the fall it is 100-40 degrees. In the winter, goes down to 20's." | Device should be suited to functioning in Western Agency Council and Hopi Mesa regions. |
| How warm does the device need to keep the house? | "The design of thermal storage devices to be used in conjunction with thermal furnace solutions to keep indoor temperatures at or above.<br>50+ deg F are the product deliverables." | Device should maintain comfortable indoor temperature throughout night. |
| What is the budget? | "Comfortable with $1200/$1500 per unit." [Although this is likely in tandem with Arctica Solar Air Furnace, for $500/unit] | Device should be within purchasing capabilities of Red Feather and the relevant clients. |
| Are there any readily available resources? | "Could ask Arctic solar if they would consider donating one [of the solar furnaces] to us to look at. Resources available would-be donations." [Needs to be easily understood by donators] | Design should be straightforward. |
| What are our limits to size and dimension? | "If you start drilling holes in the roof, though, you could cause enormous problems. Exterior wall mounted systems work. Even in those systems, avoid a roof-mounted system. Any attempt to mount something on the roof will present a problem." | Device geometry should fit a variety of housing situations (no roof cave-ins). |
| What are the limits to the available materials? | "Device should be constructed with locally available materials." | Materials should be readily available in the region. |
| Will the device be reliable? | The device needs to consistently work for people in homes without maintenance. | Design a reliable design. |

| | | |
|---|---|---|
| Will the device remain intact if dropped or damaged? | The device needs to withstand normal, everyday conditions, including different applications of force and different ranges of weather. | Create a durable and robust design. |

The most important needs were that the device should provide consistent heat, store heat during the day, release it at night, and should be capable of keeping a comfortable indoor temperature. It's worth noting that the customer needs that had the highest importance were those pertaining to the effectiveness of the device. Next were qualities about the device's functionality on the reservation based on material availability in the Hopi region. This includes it being easy to operate, straightforward, low cost, and being reliable.

The customer needs from the preliminary report in ME 476C did not change last semester. However, a greater importance was placed on testing the concept and design versus having a fully operational solar thermal device. This made it so that the solar thermal panels could now be represented by heating bands that the device then needs in order to store the heat in the medium for the duration of the day. This was so that the full potential of the thermal storage device could be tested rather than testing thermal solar panels. This made it so that the budget was less of a problem, the time constraints were easier to meet to test the concept, and that once the solar thermal panels or a solar furnace were added to the design it would be able to function properly with some corrections.

# 2 Engineering Requirements (ERs)

The team derived nine engineering requirements shown in table 2 below from the ten customer needs. There needs to be an engineering requirement measuring the temperature inside the home and outside the home. This ensures the device can keep the home at a comfortable, warm temperature, as one customer need presents. It also checks for the usefulness of the device in different climates, from the information that the Navajo Nation and Hopi reservations climates range from an outside temperature of 20 degrees to 60 degrees when the device would be heating during the night. Another important measurement is heat output from the device, taken by applying the heat equation, simplified to:

$$Q = mc_p\Delta T \quad (1)$$

In which Q is the Heat Energy in BTUs, m is the mass of the medium fluid, in pounds, is the specific heat in BTU/°F/lb., and is the change in temperature, in Fahrenheit. If is negative, heat is lost, and if is positive, heat is gained. The target ER is 10,000 BTU/h.

During the Fall 2020 semester one of the engineering requirements included that the budget be within $1,500, which is the target ER, for the device alone. However, this engineering requirement has been increased where it is now $2,000. This comes from a desire for the device to be affordable and reliable for the Navajo and Hopi reservations. To create a straightforward design which is not too complex, the team required the device to have a maximum of 12 unique parts. For this purpose, the fewer the parts required indicates a better mechanical design. Due to the need for a device that adapts and functions on a variety of styles of homes, the team requires the device to meet certain device dimensions and weight, so that it is not unavailable to certain types of homes. The target ER is for the device to be within 4 ft. by 8 ft., which is the size of a typical truck bed, and less than 500 lbs.

Because resources are difficult to deliver to the customers' locations, and to address the customer need of using readily available materials, the team uses distance as a metric for how justifiable it would be to use different resources for our device. Later the team will also look at how often a resource is needed for the device, thus determining how often this delivery time will occur as a barrier to the customer. The target ER is a maximum of 150 miles, which can be measured using an odometer.

Another important engineering requirement is for the device to be durable and robust, withstanding different weather conditions. This is tested by submerge the electronic components case within a bucket of water to see if the water is sealed out. The target ER for water that the case can be submerged in is 5 gallons.

**Table 2:** Engineering Requirements

| Engineering Requirement | Derived from this Customer Need. | Method of measurement | Unit of Measurement | Target ER | Testing Procedure |
|---|---|---|---|---|---|
| Device maintains consistent house air temperature (60deg F) | Device should maintain comfortable indoor temperature throughout night. | Thermometer or Temperature Sensor for temperature of air | Fahrenheit BTU/h | 60F 10,000 BTU/h | Over a 14-hour period, the device outputs 10,000 BTU/h |
| Device works in environments with outside temperatures ranging from 20 degrees to 60 degrees Fahrenheit. | Device should provide consistent heat source to keep houses warm at night, functioning within standard season range of Navajo Nation and Hopi Reservation temperatures. | Thermometer or Temperature sensor | Fahrenheit | 20-60F | Run device for several day/night cycles with projected lows around 20 F; if device maintains minimum heat output over 20 or sub 20 F nights, it passes the test. |
| Device stores heat in an effective method. | Device should provide consistent heat source to keep houses warm at night AND device should store heat during the day and release it at night. | Heat equation, using mass, material qualities such as the specific heat of the medium fluid, and a measured change in temperature. | Fahrenheit | 175F | Measure the temperature of the water of the storage tank. Over 14 hours, does it maintain 175 F? |
| Device budget is within $2,000. | Device should be within purchasing capabilities of Red Feather and the relevant clients. | Pricing | Dollars | $2,000 | Bill of materials |
| Device has no more than 12 unique parts. | Design should be straightforward. | Counting | Unitless | <=12 | Bill of materials |
| Device able to install onto a variety of homes. | Device geometry should fit a variety of housing situations (no roof cave-ins) | Device dimensions and weight | Feet, Lbs. | 4ft.x 8ft <500 lbs. | Measuring tape Bill of materials |
| Materials should have minimal delivery (transit) time. | Materials should be readily available in the region. | Transit time of materials | Miles | <150 miles | Odometer |

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|---|---|---|---|---|---|
| Device should work without interruption or maintenance. | Design a reliable design. | Amount of time device works without stopping. | Days | 7 days | Device functions without stopping for at least one week. |
| Device should be able to withstand all weather conditions. | Create a durable and robust design. | Amount of water on the electronics case that can be withstood over time. | Lbf, Volume of water | 5 gallons of water | Submerge the electronic components case within a bucket of water to see if the water is sealed out. |

## 2.1 ER #1: Home temperature

### 2.1.1 ER #1: Effectively heat the home - Target = 60 degrees Fahrenheit

This engineering requirement was decided on because the team wanted to make sure that their device created a place that could make a home comfortably warm.

### 2.1.2 ER #1: Effectively heat the home - Tolerance = +/- 5 degrees Fahrenheit

This tolerance was decided on by considering the loss due to a change in degree and the capabilities of the device to always match exactly 60 degrees.

## 2.2 ER #2: Environmental Resistance

### 2.2.1 ER #2: Device Operates Outside - Target = 20 to 60 degrees Fahrenheit

This design range was decided on after considering the average low and high temperatures for the region during the winter months the device would likely be used in.

### 2.2.2 ER #2: Device Operates Outside - Tolerance = +/- 10 degrees Fahrenheit

This tolerancing was chosen to provide the device with a buffer in case the temperatures do reach further extremes. With this tolerancing in mind the device can still function in colder/hotter climates. It will just operate less efficiently.

## 2.3 ER #3 Effective Thermal Storage

### 2.3.1 ER #3: Stores and holds Thermal Energy - Target = 175 degrees Fahrenheit

This target value was deemed necessary as it allows for the required thermal energy to be stored and does not exceed the limits of how much heat the tank can withstand before damage.

### 2.3.2 ER #3: Stores and holds Thermal Energy - Tolerance = +/-5 degrees Fahrenheit

This tolerancing was chosen as it represents a fair assessment of the kind of ranges, we might see before the system becomes less efficient.

## 2.4 ER #4 Budget

### 2.4.1 ER #3: Cost under $1,500 - Target = $1,250

The client was able to increase the overall budget to $1,500 from the $1,000 that was set last semester. The team believes the cost should not exceed $1,250 based on the current Bill of Materials.

### 2.4.2 ER #3: Cost under $1,500 - Tolerance = +/- $250

The maximum cost for this project is now set at $1,500, but the team is set to design towards only using $1,250 to allow a contingency of $250.

## 2.5 ER #5 Straightforward Design

### 2.5.1 ER #3: Low Total Part Count - Target = 12 parts in total

It was decided that the device should be twelve parts to keep the design from becoming unnecessarily complex and keep the building time as short as possible given the multiple functions of the device.

### 2.5.2 ER #3: Low Total Part Count - Tolerance = +/- 2 parts

While the device is still held to a manageable number of parts, it is realistic that the number of parts required will be in flux as the team discovers what does and does not work. This tolerance realistically considers how the design may change.

## 2.6 ER #6 Easy Installation

### 2.6.1 ER #3: Minimum Size and Weight - Target = 4ft x 8ft and Less than 500 lbs.

This target was decided on as it became clear the device would be set up a small distance away from the home and after calculations were taken for how much water would be required in order to store the thermal energy.

### 2.6.2 ER #3: Minimum Size and Weight - Tolerance = +/- 6 in. And +/- 20 lbs.

These dimensional tolerances were decided given the flux of the design and that the total weight and size may shift by a small margin.

## 2.7 ER #7 Delivery Time

### 2.7.1 ER #3: Minimal Transit Time - Target = Less than 150 miles

This requirement was decided on to ensure that the device could be effectively available to the people that need it. It was decided that 150 miles would be reasonable to reach people who are living throughout the reservation.

### 2.7.2 ER #3: Minimal Transit Time - Tolerance = +/- 25 miles

While our target can consider everyone on the reservation the device would be projected to go to, this tolerance accounts for anyone else who may get the device installed.

## 2.8 ER #8 Reliable Design

### 2.8.1 ER #3: Works without Stopping - Target = 7 continuous days

Due to the nature of the device needing to collect heat during the day and give it off at night, it is expected to operate all 7 days of the week.

### 2.8.2 ER #3: Works without Stopping - Tolerance = +/- 12 hours

The tolerance chosen for this Engineering Requirement is mostly present to account for time where the device is made to sit idle due to any number of factors.

## *2.9 ER #9 Dealing with Weather*

### 2.9.1 ER #3: Electronics Work When Wet - Target = 5 gallons of water

The target of five gallons is meant to account for the large amount of rain and snowfall that can occur in the region where the device will be used.

### 2.9.2 ER #3: Electronics Work When Wet - Tolerance = +/- 1 gallon

This tolerance of 1 gallon is primarily used in order that the device be able to function even under the more extreme and rare weather occurrences.

# 3 Design Changes

As a result of teamwide concerns surrounding project time and remaining budget, as well as input from both clients and advisors, the team made several significant changes to the project design. These primarily relate to project scope and expenditure reduction. The first major change, implemented towards the end of the Fall 2020 semester, was a significant reduction of the project's scope. The team, with help from their non-academic advisor, made the decision to remove the solar furnace component of the design as well as related support systems. This gave them more time to focus on the primary component of the system, that is the thermal storage device.

The team's second major design change occurred at the start of the Spring 2021 semester and was largely motivated by budgetary concerns. The team decided to forego purchasing the first heat exchanger, the liquid to air heat exchanger, in favor of building their own using bent copper pipe. This was done due to the cost of the heat exchanger, and how expensive it is compared to the copper piping. After seeing how viable this option was, they also decided to make the liquid-to-liquid heat exchanger using a similar copper coil design method. By doing this the team was both able to conserve more budget and have a greater control over the dimensions of both heat exchangers. Along with these changes we have designed the two heat exchangers to be placed on top of each other inside of a metal duct work. This design change was chosen for the way that it will minimize the space taken up inside the tank and better secure the heat exchangers once inside the tank.

The third design change was made when building was already underway. Once the team had coiled the first heat exchangers and begun to consider the exact nature of the pipe infrastructure for the tank, they decided that to minimize gravitational losses it would be useful to place the pump, working fluid reservoir, and other key elements above the bulk of the tank. This droves the design for the tank cap, which became the third iteration of the design.

## *3.1 Design Iteration 1: Change in Solar Furnace discussion*

The original system design was far broader in scope and encompassed a great deal more than just the thermal storage device that the team is currently focused on. It included the tank, solar panels, pipe networks, and was generally similar to the current design, with the inclusion of additional heating systems in the form of a solar panel and resistive heater. These elements were not only costly, but they also required a great deal of work to ensure consistent, reliable function. Additionally, the team did not believe it could perform tests to validate and check the design if it had to create a working system with that large of a scope. As a result, the team chose to remove these from the design, as proving the thermal storage device itself was deemed more important to the project. Now, the team is focusing on getting a working heating loop inside the tank with the pump and solar panels to power the pump at night. It is not focused on created a solar heater during the day.

## 3.2 Design Iteration 2: Change in Heat Exchanger discussion

This decision was much easier because it was forced by unexpected budgetary issues. These issues, related to the steep cost of shipping certain other key components, meant that the team would not be able to afford both heat exchangers. Making the team's own heat exchangers would save over $100, and the heat exchanger could be manipulated to fit the team's design. They decided then to replace the liquid to air heat exchanger with one that they bend and fit themselves, as shown in **Error! Reference source not found.**.

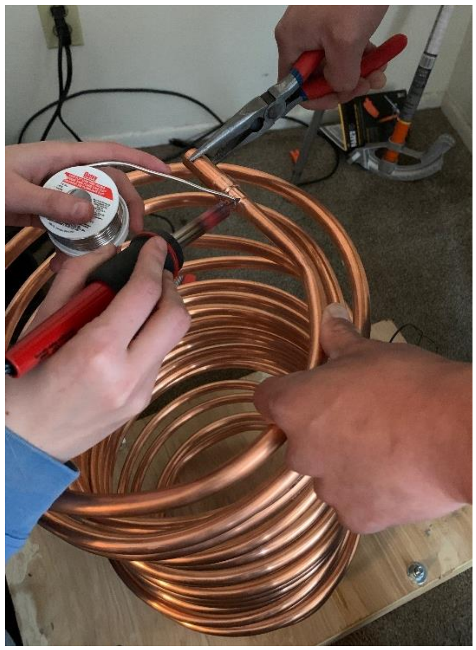


*Figure 1: Heat Exchanger Coiling and Soldering*

After a successful creation of the first heat exchanger, the team decided to also build the second, liquid to liquid heat exchanger themselves as well. Thus, both heat exchangers have a spiral design and are stacked on top of one another within a heating duct inside the tank. The heating duct holds up the top, liquid to air heat exchanger with piping through the middle, so that the heat exchanger is not suspending in the air and compressing the bottom, liquid to liquid heat exchanger. The duct also contains the heat exchangers within a certain diameter, giving them a frame, so they do not deform or fall to either side. Finally, the duct acts as extra insulation for the heating exchangers, allowing maximum heat transfer for the thermal storage design. The heating duct can be seen with the heat exchangers and supporting piping in Figure 2. Though the team's budget has since increased, this will still help them maintain a safety cushion in case of emergency.

*Figure 2: Heating duct with heat exchangers inside of it*

## 3.3 Design Iteration 3: Tank Cap Addition discussion

The decision to move the pump, heater, and other tank support infrastructure from the ground near the tank to the top of the tank was made largely in the interest of minimizing pump loss. The original design had the pump placed at the base of the tank, which would require it to overcome the force of gravity before even entering. With the addition of a cap, with ample platform space for pump, heater, battery, and other components, this problem ceases to be an issue. A CAD mock-up of the cap can be seen in Figure 3.

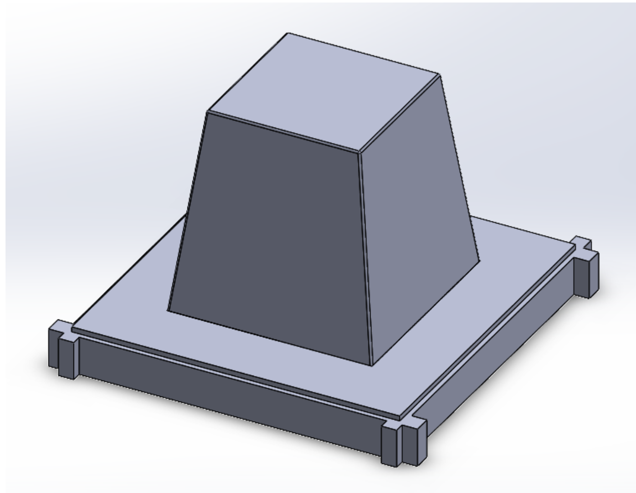


*Figure 3: Tank Cap with Platform Space*

The current plan for this component is for it to be made of a combination of 2x4 wood beams, a cut sheet of plywood, and a sprinkler box. It would also be insulated to minimize heat losses through the top of the tank, and include space for the pump, fluid reservoir, heating tape, and most other support infrastructure. This design change will maximize the effectiveness of the pump, and further contribute to the modularity of the design by making most of the support equipment fit on a single platform.

# 4 Future Work

The team has a plan for completing the design, testing the design, and then presenting the information and data in a final report and presentation. This plan will be implemented using a Gantt Chart and action items for each team member.

## 4.1 Further Design

From this point the team will be focused on completing the electrical components of the device and will start testing procedures on the machine. More specifically we will be exploring whether the pump, fans, Arduino, and Thermocouples are able to turn on and perform their individual functions. From there each main part of the device will be tested. First the heat exchangers will be tested to see how effectively they circulate their respective fluids (Air and Water).

Once the electrical components and the heat exchangers have been proven to operate properly the whole device will be tested to see how well all aspects of the machine are able to function. This will include seeing how well the water in our tank heats up from the liquid-to-liquid heat exchanger, how well the air moving through our tank heats up, and how long the whole process takes to happen.

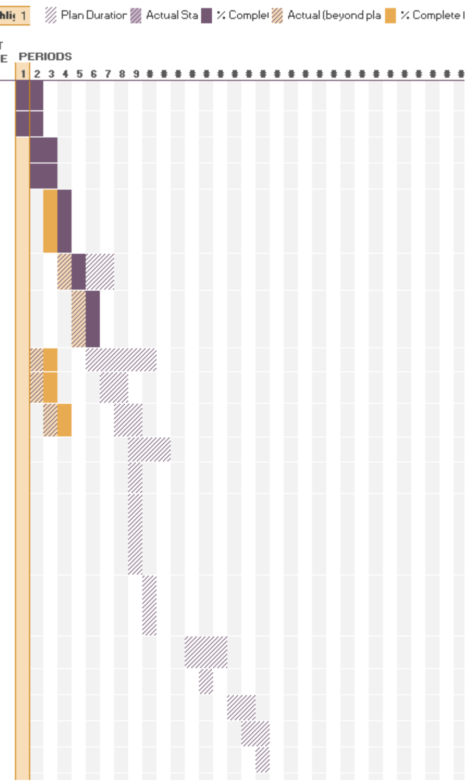
## 4.2 Schedule Breakdown

In the figure below is the Gantt Chart used for scheduling and laying down when the team planned to accomplish necessary tasks for completing the thermal storage device. To accomplish everything this semester many different build, test, and Auto CAD design days were laid out in a timeline that was reasonable and effective.

## Gantt Chart

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

| ACTIVITY | Start Date | End Date | PLAN START | PLAN DURATION | ACTUAL START | ACTUAL DURATION | PERCENT COMPLETE |
|---|---|---|---|---|---|---|---|
| Finalizing and Purchasing Parts | 1/11/2021 | 1/25/2021 | 1 | 2 | 1 | 2 | 100% |
| Self-Learning | 1/15/2021 | 1/22/2021 | 1 | 2 | 1 | 2 | 100% |
| Meet with Clients | 1/18/2021 | 1/29/2021 | 2 | 2 | 2 | 2 | 100% |
| Website Check-up | 1/18/2021 | 1/25/2021 | 2 | 2 | 2 | 2 | 100% |
| Building Session #1: measurements, make H.X. #1 | 2/5/2021 | 2/7/2021 | 4 | 1 | 3 | 2 | 100% |
| Arduino Workshop | 2/12/2021 | 2/28/2021 | 5 | 3 | 5 | | 85% |
| Building Session #2: Modify tank lid, make H.X. #2 | 2/19/2021 | 2/21/2021 | 6 | 1 | 6 | | 50% |
| Update CAD | 2/19/2021 | 3/21/2021 | 6 | 5 | 3 | | 60% |
| Implementation Memo | 2/22/2021 | 2/26/2021 | 7 | 2 | 3 | | 75% |
| Midpoint Presentation | 2/24/2021 | 2/28/2021 | 8 | 2 | 4 | | 100% |
| Tech Analysis | 3/1/2021 | 3/12/2021 | 9 | 3 | | | 60% |
| Testing Procesdures #1 | 3/1/2021 | 3/5/2021 | 9 | 1 | | | |
| Building session #3: Put H.X.'s into tank and put everything together | 3/5/2021 | 3/7/2021 | 9 | 1 | | | 0% |
| Hardware Review #2: Prepping everything working together | 3/12/2021 | 3/15/2021 | 10 | 1 | | | |
| Procedures Analysis | 3/22/2021 | 4/4/2021 | 13 | 3 | | | 0% |
| Testing Procedures #2 | 3/26/2021 | 3/28/2021 | 14 | 1 | | | 1% |
| Final Presentation | 4/5/2021 | 4/9/2021 | 16 | 2 | | | 80% |
| Final Report | 4/12/2021 | 4/18/2021 | 17 | 2 | | | 0% |
| Poster | 4/19/2021 | 4/21/2021 | 18 | 1 | | | 0% |




With this schedule in mind the team also agreed to split up certain duties between themselves and as a team. This was to maximize the efficiency of the team. The main activities done as a group primarily included the finalizing of the devices design and the manufacturing of the device. While Jessie, Wesley, Randall, and Randall worked on this Noah was responsible for updating the website, developing the CAD design, analyzing the system, and helping to develop the bill of materials. Along with these responsibilities Jessie worked on developing the Arduino and scheduling, Brittney was responsible for the implementation of solar panels and bill of materials, Randall also worked on developing the Arduino code and purchased the parts, and Wesley helped with the bill of materials and the analysis of the system.

Going forward, each member will have specific elements of tech analyses to perform. Wesley will analyze the HVAC and piping network of the system. Noah will analyze the first heating loop, which involves heat input to the tank, the pump, and the liquid-to-liquid heat exchanger. Randall will analyze the second heating loop, which includes the liquid to air heat exchanger and the heating within the tank and heating coil, primarily. Brittney will analyze how to connect the solar panels for maximum efficiency. Jessie will analyze the heating tape and how the pump heats up the heat transfer fluid. After the building process, the team will travel to Leupp, where the client wants the design to be implemented. In Leupp, the team will assemble the components of the design and then test it as a fully working device. After testing, remotely Noah will work on finishing the CAD model and updating the website. The team will work together to analyze the tests and then to create an informative final report, presentation, and poster. With all these tasks accounted for the team has made significant progress moving forward with the manufacturing of their device. While there is still plenty of work and analysis to be done with the current schedule set and everything on track things are expected to finish and be completed on schedule.