Sustainable Energy for Rural Uganda

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Final Design Report

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Project Review

The project goal is to provide a sustainable energy solution for smallholder farmers surrounding Lake Bunyonyi in rural Uganda. The project focused on a sustainable, environmentally friendly, and reliable solution to provide villagers with access to electricity for phone charging and lighting. Long term goals include electricity for more commercial uses, but is not a primary objective at this time.

People living within the villages surrounding lake Bunyonyi near Entusi Resort in South Western Uganda primarily use kerosene as their main source of household energy. Kerosene is a flammable hydrocarbon liquid commonly used as fuel for kerosene lamps, domestic heaters, and a means of cooking in Uganda [1]. Kerosene contributes to many negative health effects that, over time, can have a potentially fatal effect on the lives of users. The inhalation of kerosene for short periods of time (about an hour) can cause nausea, increased blood pressure, and irritated or bloodshot eyes. It has also been found that breathing in kerosene can have negative effects on the nervous system. After prolonged exposure, some of the long-term side effects include chronic headaches, light-headedness, poor coordination, and difficulty concentrating [2]. These long-term health issues can increase the chances of death at a younger age.

The community impacted by the project are farmers with families living off of limited income in an extremely rural location. The villagers' only method of banking is via cell phones, so when they are without a cell phone, or location to charge it, they are without their money. This is a serious problem providing that the majority houses do not have access to electricity. Providing a reliable source of electricity will greatly simplify villagers' lives, save them money, allow an improvement in education, and increase the health of individuals. Overall, this engineering project has the capability of creating an astounding increase in quality of life for the villagers surrounding Lake Bunyonyi.

This design project was brought to us by the Global Livingston Institute (GLI), a Colorado-based company, whose goal is to find innovative approaches to international development and to build partnerships between communities. The staff at GLI have spent many hours in communication with our team and were a huge source of information as we worked on finding a solution for the design problem they presented to us.

One of the most significant constraints in this project description is the income of the villagers. Currently, income of a single person is approximately $1.00 a day. Another large constraint within our project is coming up with a solution that can be fully sustained by the villagers and will last for a long time without maintenance or repair. This constraint has pushed our team to not only look for inexpensive solutions but also simpler solutions that will create an energy outcome feasible for the villagers to use. In order to better understand the energy needs of the villagers, a trip was planned, and information was gathered by the team. A variety of useful information was gathered, and is discussed at length in the following sections.

In order to meet the requirements and criteria, our team came up with several solutions with regards to solar power, biomass utilization, hydropower, and kinetic energy production. This report serves to outline the design process, and final solution the team selected. Ultimately, with the assistance of GLI, the team selected a micro-hydro power system for the communities surrounding the lake.

Application of Design Methodology

The team's design process is best described as a fluid process, and continues to be that way as we move through the final days of the process. The first step of investigating solution options was accurately defining the problem, and setting out a list of design constraints. The information we were originally given was researched further to better understand the constraints we were working within which also shed light on other aspects we had not considered. GLI had information they were willing to share with our team about the power consumption of the community members, home and family size, and similar data. This gave us a starting point for our design as we continued researching best practices for sustainable development.

Further, because of the nature of our project, one of a humanitarian engineering perspective, the community is the most important consideration for our design and our design constraints. A considerable amount of time and effort was invested in investigating humanitarian engineering literature such as the Bridger and Luloff criteria [3]. These criteria can be seen in Table 1 below which outlines the criteria and how each was considered during our design process.

Table 1: Bridger and Luloff criteria with coinciding design considerations

Criteria	**Design Considerations**
Increasing local economic diversity	● Stimulate the local economy ● Be mindful of creating/increasing wage gaps ● Design within economic constraints of families
Self reliance	● Sustainable by the community ● Can be maintained by the community
Reduction in the use of energy	● Reduce use of kerosene and biomass burning due to health and environmental effects ● Create a sustainable form of energy for people and environment
Careful management and recycling of waste products	● No waste with solution once it is implemented ● Not bringing or introducing unnecessary materials or waste

Protection and enhancement of biological diversity	● No significant environmental disruption ● Mitigation of any land alteration or movement ● Limiting displacement
Careful stewardship of natural resources	● Using locally sourced materials ● Limiting imports from outside companies

The team then began gathering information from the community. This was done in three ways: using data already gathered by GLI, creating a survey to be conducted by GLI employees in the communities, and ultimately visiting the communities and gathering data in person. The team began the process of crowd-funding through the Gold Mine Campaign Program. A small commercial and a web page were set up to raise funding for a research trip to Uganda.

As mentioned previously, the most important stakeholder is the community. According to Bernard Amadei, author of *A Systems Approach to Modeling Community Development Projects*, he references Ben-Eli's "five core principles of sustainability" to model a systems approach to sustainable community development [4]. Figure 1 shows the graphic from Amadei's book. In order to justify a solution for the farmers in rural Uganda, each design ideation explored the solution as it fit into these five principles. It served as a criteria to weigh the suitability of each solution, and ultimately select one approach.

Figure 1: Sustainable development plan for community design

The combination of the Bridger and Luloff criteria with the below Sustainable Development Plan gave the team sufficient background knowledge and a solid basis for moving the project through to ideation and design phases. There are a number of ways that sustainable energy can be provided to the community. The ones that the team investigated in depth were solar, micro-hydro, and biogas power which will be further explained in a later section.

As aforementioned, the team raised funds to send a group to visit the communities in Uganda which came to fruition at the beginning of february with three of our group members taking a week long trip to do on-site research and meet with the communities we had been designing for for the last seven months. Over the five days we were able to meet with people and gather information a great amount of information was gained not only about resources or locations for the project, but on the aspirations that something like this could make a reality for so many people.

With that, it was found that many community members saw the possibility of reliable power as an opportunity to start business. This was information that we had not heard before and thus wanted to investigate further. Every person that we met agreed that a new source of power would ideally allow them to expand or even create new businesses such as barber shops and salons and running equipment for sewing, farming, and welding. Along with that knowledge there was a lot of research into the local resources that were nearby which are listed in Table 2 below. Resources not listed that were also present were nozzles, cement, timber, roofing, bricks, and other similar products. Pictures of various resources can be found in Appendix A.

Table 2: List of local resources with corresponding size and cost

Resource* **	**Size**	**Cost**	**Notes**
Tanks	3,000 L	$150	
	5,000 L	$270	
	10,000 L	$650	Largest found in Kabale
Piping	1.5 in	$5 /20 feet	Thickness: PN4
	2 in	$7 /20 feet	Thickness: PN4
	4 in	$11 /20 feet	Thickness: PN4
	6 in	$50 /20 feet	Thickness: PN4
	10 in	$103 /20 feet	Thickness: PN6

			Import from Kampala**
	12 in	$160 /20 feet	Thickness: PN6 Import from Kampala**
Solar Panels	100 W	$63	Store in town
	120 W	$75	Store in town
	150 W w/ batteries	$555	Store Entusi Resort got their panels
*** all resources found in Kabale unless otherwise noted **price does not include transport costs			

Engineering Analysis

Biogas

The efficient use of resources is a critical aspect of providing a sustainable solution. Given that the key stakeholders are rural farmers, leveraging excess crop yields attracts the use of biogas. Biofuel is a source of fuel derived from living matter; in many instances, this comes via the form of wood, manure, algae [5]. One can retrieve the energy from biofuel either through biomass or biogas. Biomass implementation involves burning organic matter, typically to create bioethanol. The alcohol can have various means for application. Since the fermentation process of alcohol is complicated, requires extensive materials for adequate production, and cannot reasonably produce electricity, the team did not consider the use of biomass to alcohol method as a sustainable solution.

Biogas is like biomass in that energy is collected from some matter; however, their processes and intentions vary. As natural resources, such as excess crops or animal manure, are held without oxygen in a pit, they succumb to anaerobic digestion. This digestion creates various byproducts including carbon dioxide, methane, and a solid substance commonly referred to as Bio-slurry or Digestate. There are some traces of hydrogen sulfide as well [6] At a high level, the intention of biogas electricity production is to generate electricity by harnessing the captured gas to fuel a generator. Biogas compliments agricultural settings as the leftover Bio-slurry is odorless and can be used as an effective fertilizer. The team initially explored design ideas that revolved around the setup shown in Figure 2 below.

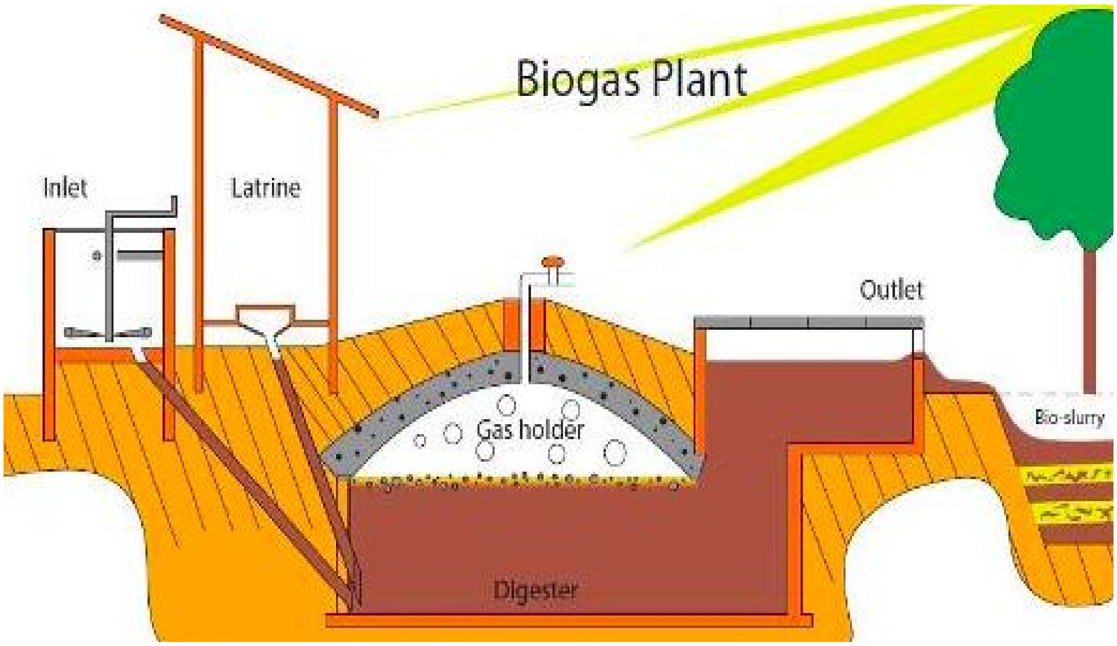


Figure 2: Typical assembly for biogas generation

As shown in the figure above, an inlet container can hold solid resources, such as crops, whereas the latrine is used to collect human excrement. Water can mix with the resources to aid in feeding them into the digester. Though some biogas units exist above ground, the digester and gas holder are placed underground for many large-scale modules to aid in heat generation. It is typical to build these pits out of stone or masonry. As the biomass anaerobically decomposes, the biogas feeds into an exit valve for outside usage. There is an additional outlet to collect the bio-slurry. The team was excited to share these findings with our client. However, as arguably the most important lesson this design project has taught, engineers should listen to their stakeholders, especially when considering human development work. The client warned that some solutions involving human input have been tested in areas surrounding Lake Bunyonyi and failed. Therefore, GLI advised that a solution not involving as much agency on behalf of the stakeholder was more desirable, and with that, the Biogas electricity production method was scrapped.

Kinetic to Electric

The use of enough kinetic energy in combination with copper wire and a magnet, in accordance with Faraday's Law, would produce the required energy to power a light source and charge a phone. The kinetic energy would be produced through the cranking of a shaft, or bike, or some other mechanical element to create the needed rotation between the wire and magnets that would induce a magnetic field. The spinning of the coil within the magnets would constantly change the magnetic flux and would produce a voltage that would power the electrical devices (Figure 3). The difficulty of this design would be in the constant need of human supplied power on the mechanical device (i.e. the crankshaft). In order to accommodate this hindrance, the team contemplated the use of a battery.

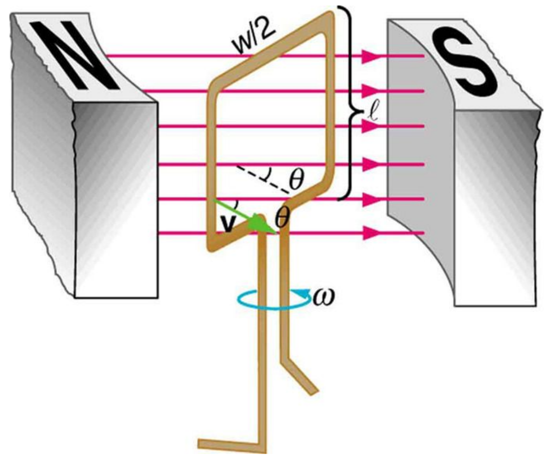


Figure 3: Magnetic Flux and Faraday's Law

The battery would allow for the electrical energy to be stored and the amount of time spent creating that energy through kinetic means would decrease. As was mentioned before, Global Livingston had already implemented an existing solar power solution through Green Light Planet. This solution uses Lithium-ion batteries to store the solar energy created. Therefore, the idea to use the already existing battery storage and solar power with the kinetic to electric energy solution was formed (Figure 4). If the user did not have the solar power solution, the kinetic energy solution would also be able to stand on its own with the use of its own battery for storage and ports of connection for lighting and phone charging.

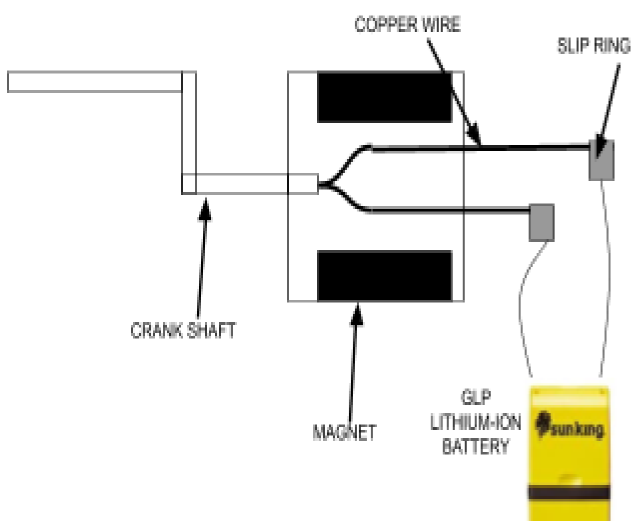


Figure 4: Kinetic Energy with Battery Ideation

Even with the implementation of batteries, the kinetic energy design was deemed unfeasible because of the negative impacts it would create. The first of which being that the design requires that the villagers power the device themselves in order to obtain the electricity. This has the potential of misuse by forcing the children or wives to power the device, deterring from their own activities such as school. This design is also not the direction the team wanted to go in terms of development for these societies, we believed we could provide the villagers with a better solution that wouldn't include labor to obtain electricity.

Individualized Photovoltaics

Greenlight Planet offers multiple products that are meant to provide access to electricity for individuals and small families living without reliable access to the grid [7]. These products are marketed for different applications with the Pro series being marketed for individuals and the Home series being marketed more for families. Both the Pro and Home series have options with larger energy storage capabilities, and thus the question of which model would best serve the villager's demands is raised. In addition, questions regarding how applicable solar photovoltaics would be in the villages around Lake Bunyonyi should also be raised. To identify the extent to which Greenlight Solution's products can meet the requirements laid out by Global Livingston, an analysis of how much useful energy would be available to villagers owning these products was completed.

To assess the solar availability, an atmospheric parameter called all sky insolation incident on a horizontal surface is used. This parameter details the amount of incident solar energy on a perfectly horizontal surface that is contained within wavelengths of light that are usable by commercial photovoltaics. All sky simply means that the solar insolation was measured under any sky condition. If measured every single day, this quantity can be used to determine the useful solar energy for any given day, and then this can be compared against the nominal and heavy load profiles. The dataset was collected from the NASA Prediction Of Worldwide Energy Resources (POWER) data access viewer [8]. The entire Lake Bunyonyi region was selected for data retrieval with data provided at latitude -1.3 longitude 29.9. The average of the two locations was used for the daily solar energy availability on a horizontal surface.

Table 3 summarizes the findings from this analysis. The critical figure is the probability that the daily energy demand could be met for a given load profile. Unless the panels are on the higher end of efficiency for polycrystalline photovoltaic panels, most low energy Home 60 users could easily find themselves in situations where they could not meet some extremely basic energy needs on a given day. However, if the demand of low energy users is simply reduced to half of the initial conservative estimate, the Home 60 at 12% efficiency will meet demand for 96% of days. However, until data is gathered that can explain a villager's daily energy demand, only these high load estimates can be made.

Table 3 - Summary of solar energy availability

Load Type	Daily Demand (Wh)	Probability of Meeting Daily Demand (%)			
		Home 60 - 12%	Home 120 - 12%	Home 60 - 16%	Home 120 - 16%
Low	32	36.0	93.22	78.64	98.03
Medium	68	0.0	6.33	0.0	52.83
High	111	0.0	0.0	0.0	0.1

The primary concern is that the Home 60 and 120 cannot reliably handle loads beyond the residential level. This makes the Greenlight Planet products extremely viable for the homes of villagers, but to a lesser extent the workplace. It is assumed that many villagers, if able to in the first place, would only purchase a single product if able. This single product would be great for a home but then a villager could not get the same necessities in the workplace. Additionally, many of the benefits associated with solar include the ability to sell excess power to other customers on the grid. While the purpose of this product would be to provide electricity solely for the home, the final solution should help open the doors for further sustainable development rather than capping it at basic electrification. Table 4 summarizes the pros and cons identified with the Greenlight Planet products.

Table 4 - Pros and cons of Greenlight Planet products

Pros	Cons
● All products provide an at-home solution. ● Lighting is completely electrified. ● Product ready to go; only a plan for rollout would need to be developed. ● Many villagers are aware and interested ● Sustainable for the duration of the product's lifetime ● Greenlight Planet has field offices for general maintenance and replacements at low to no cost	● Still an expensive investment for the majority of households. ● Does not extend well to commercial applications due to increased energy demand of these applications. ● Cannot be extended to a grid connection ● Excess energy after battery has been charged cannot be utilized ● Pro models only contain one light which can cause issues with who can use the light

Overall, the products offered by Greenlight Planet provide basic access to electricity that most households around Lake Bunyonyi require and Global Livingston has already begun to introduce more of the villagers to the idea of solar power. The product has a lifetime that is substantial enough to where a villager could recoup their investment and Greenlight Planet's field offices make it easy and cheap for those who do have issues to either repair or replace their products. Despite the resounding success that could be seen in the home with the Home line of products, none of Greenlight Planet's products should be considered as the final solution. This solution does not extend to commercial, and therefore, industrial applications. While achieving basic electrification is certainly a goal, the team has also considered options that can be generalized to higher-energy applications so that future development may occur easier.

Microhydro

Hydropower has been around since close to the dawn of civilization. Making efficient use of any body of water will allow a close to limitless energy resource. This is done by harnessing the kinetic energy of water using turbines with the two biggest factors being the height differential also called head and the speed of the flow of the water. Through these two factors, the turbines are rotated which when connected to a generator, also spins magnets creating a magnetic flux which can then be captured to produce electricity using a conductor. Mockup schematics of the design and internal turbine system can be seen in Figure 5 below.

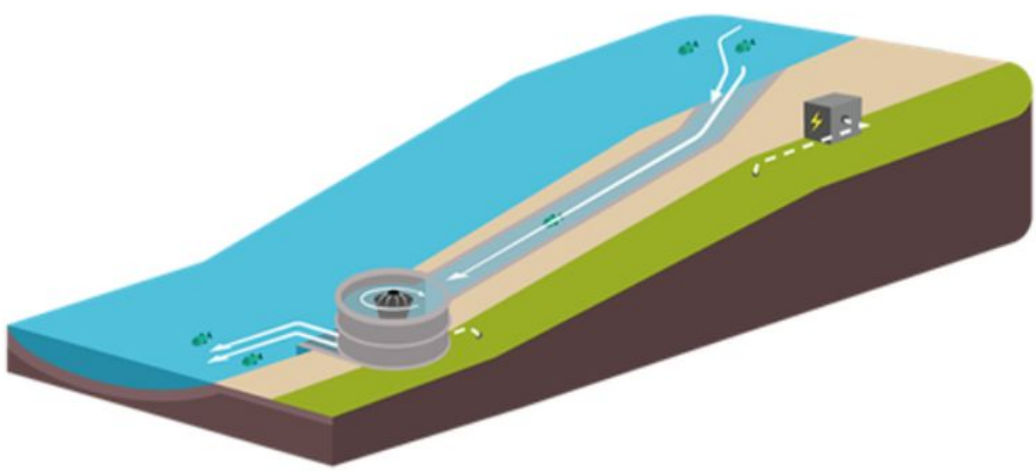


Figure 5: Mock diagram of Potential power station [9]

Where this solution is made unique is that Lake Bunyonyi is for the most part a standstill lake. Therefore, any head and flow will need to be artificially created. This can be done in one or two ways by creating a canal system or a dyke/levee system. The canal system would require us to dig out a waterway and line with concrete to protect from erosion. Over the course of the canal we will need to periodically create height differentials to create the head. We can then use a gate system to control the water flow. The problem will come in the form of returning the water to the lake which will require the use of a pump mechanism. If we go with the dyke/levee system, we will need to artificially raise the land in an area adjacent to the lake or find an area that is already raised. We would then pump water to the top and put the turbine and generator at the bottom to collect the water. Plant vegetation would be needed to be included in order to protect from erosion. Below are graphics of possible areas around the lake that could be used for this task.

The pros and cons of utilizing micro hydro power can be seen below in Table 5 below. Although the solution has high capital costs it would require minimum upkeep and maintenance following installment. This is also a large-scale option whereas the current option is used on a household to household basis. With that, it is possible to use this as a long-term solution in conjunction with the solar solution.

Table 5: Pros and cons of micro hydro system

Pros	Cons
Relatively long lasting solution that requires very little upkeep once implemented	Will require a microgrid to get electricity to the villages
Can be scaled to produce for one village or multipl (10 - 100 kW)	Higher capital costs
Very little environmental impact	Extensive manual labor
Easily generates enough electricity for villages' needs	Require new engineering techniques to build something that hasn't been attempted yet

A micro hydropower grid could possibly be a long-lasting sustainable energy source for the villages on lake Bunyonyi. However, pursuing this route will have significant upfront costs. The fixed cost of building a generator and turbine which combine make up around sixty percent of the total cost of the project. When you also take into account the cost of manual labor to dig out the ground to place either a canal system or a dyke/levee system, as well as the cost of the materials, would put this project above that of the capabilities of the villagers to pay for it themselves. With that, if we did choose to pursue this project, we would need to pursue financing from an external source. One that was found that looks to help fund projects such as these is the Green Climate Fund backed by the United Nations. Financing would have to be secured for this solution to be successful. With that, this project is also a long-term solution that can power the entire lake instead of a solution that would focus on individual households.

Final Deliverables

The load profile created to reflect the villagers' demands for lighting and phone charging was informed from personal accounts from villagers. Most of the accounts from villagers had to do with when they would have lights on at home/work and what other uses they would have for electricity. From this information, it was concluded that each home should have access to indoor lighting, outdoor security lighting, radio, and cell phone charging. TV in 25% of residential homes was also considered as part of the load.

From the villagers' accounts, indoor lighting was most popular in the evenings and was rarely used outside of businesses throughout the day. A Villager's use of electricity was modeled as any single villager being capable of turning that load on at any time about an average. For instance, because indoor lighting was typically turned on around 6-pm, each villager was modelled as turning on their indoor lights on average at 6-pm, with everyone having their loads on between five and 7-pm. The switching off of the load is modelled the same way, with the average villager turning off their lights and heading to bed by midnight, but everyone will have switched off indoor lights between 11-pm and 1-am. Figure 6 is the load profile developed from this kind modelling, with an additional 2-kW impressed for inefficiencies in distribution and inaccuracies in the size or use of loads.

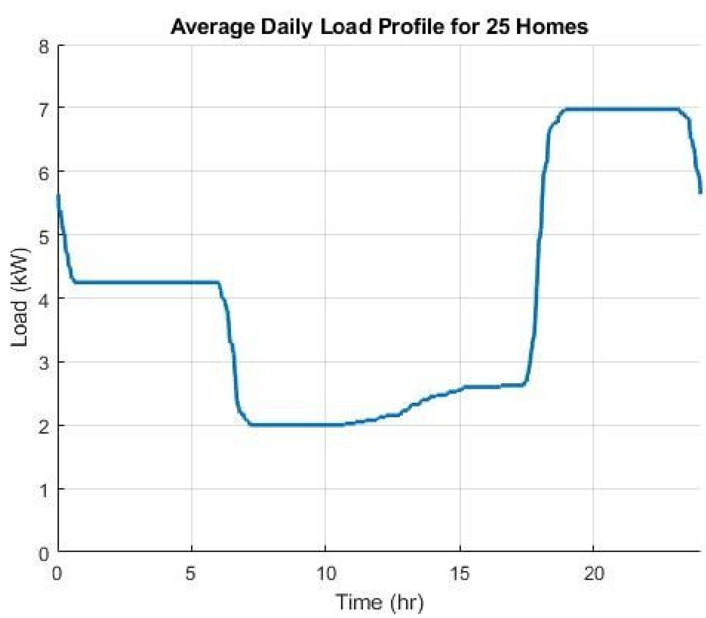


Figure 6: Average daily load for 25 residential homes

Note that load profiling is typically done after electric loads have already come into use and the fluctuations in demand are actually understood. Without any electric infrastructure connected to the majority of the loads that this project wants to serve, it is nearly impossible to say that this is the true demand from 25 residential homes. What this profile does allow for is the ability to study how feasible the proposed solution can be and it informs what size generating capacity is required to serve some of the basic loads in these villages. It is recommended that more detailed information regarding the load profile is gathered. Getting a more complete picture of what types of loads end up being used and at what times will go a long way to informing the design of a larger scale system that can serve more people from a central point.

<u>Hydro Generation and Code Discussion</u>

In the Intermediate Design Review, the team stepped through their process to justify how high a water tank will need to be placed to meet the stakeholders' night-time hourly load by leveraging research on flow through penstocks. The power water can generate from flow depends on several factors. The initial perceived most significant parameters that needed to be considered were the diameter of the pipe containing the flow and the height of the tank holding the standstill water. These two conditions dictate the quality of water flow, and the energy its motion contains. However, the most crucial equation that ended up halting the design specifies the amount of loss that the flow will experience as it moves through the penstock. The head losses for the flow are captured in Equation 1.

(Equation 1)

Head Loss Equation:

$$h_L := \frac{Q}{2 \cdot g \cdot {A_2}^2} \cdot \left(f \cdot \frac{L}{D_2} + k_{12} + k_N \cdot \left(\frac{A_2}{A_N} \right)^2 \right)$$

In the head loss equation, Q represents the flow rate through the penstock in m^3/s, g represents the acceleration due to gravity in m/s^2. The terms L, D_2, A_2 are all geometric properties of the penstock representing its length (m), diameter (m) and cross-sectional area (m^2), respectively. Further, A_n is the cross-sectional area (m^2) of the nozzle used to disperse the flow into the turbine. The 'k' values in the equation represent "local losses in [the] penstock" due to geometric flow impediments in the penstock and the head loss due to the nozzle (k_n) [10]. Walking through the steps detailed in the Intermediate Design Report, final power output can be calculated using the Power Equation (Equation 2).

(Equation 2)

Power Equation:

$$P := \eta \cdot \gamma \cdot Q \cdot (H_g - h_L)$$

The team used water's values at standard conditions, including specific weight (Ɣ, 9789 kg/m^2s^2). The efficiency of the system is represented with η and determined to be equal to 80%, while the tank's height (H_g, m) from the waterline was varied from 1 to 40 meters. The pipe diameters readily available in Kabale (Table 2) were iterated through the equations using MATLAB, eliminating any power values lower than the prescribed 8 kW peak demand shown in Figure 6. The pipe diameters and tank heights, along with their corresponding power outputs are shown in Figure 7 and tabulated in Appendix B.

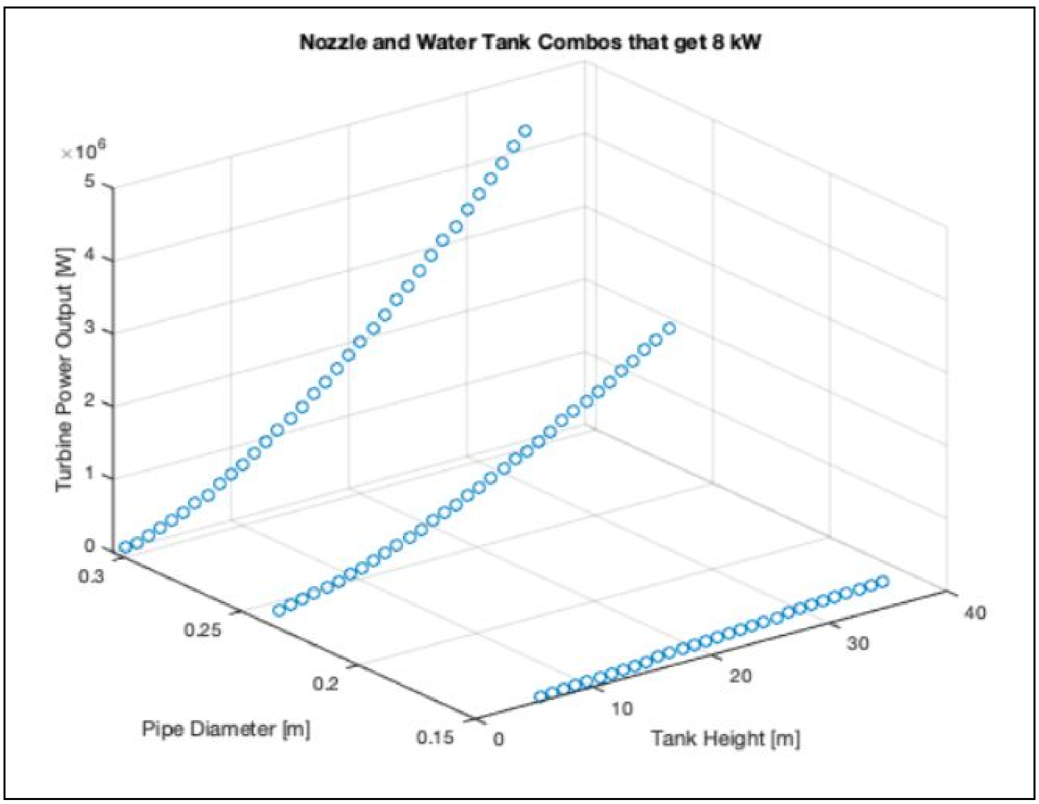


Figure 7: Power Outputs for ranging Pipe Diameters and Tank Heights

As one may notice, not every pipe diameter was able to generate a power output greater than the 8 kW threshold. Previously mentioned, the team learned the Head Loss Equation (Equation 1) held large authority in determining the possible power output. The head established by placing the tank on some of the surrounding terrain around and above Lake Bunyonyi is too small to overcome the viscous forces the water experiences in smaller pipe sizes. Therefore, the smallest pipe diameter to yield results was the 6 inch pipe (.1524 m in Figure 7).

Nonetheless, the team tried to work with the results. The team iterated further in MATLAB to determine how the pipe's diameter can be altered, presumably through control mechanisms, to both lower the flow rate from the tank while still meeting the power needs of the stakeholder. Further referencing Figure 6, the load profile shows a power demand of 1800 W is needed for 3 hours after the peak hour of 8500 kW. Next, 700 W of power must be supplied over a 7.5 hour timespan. For these next iterations, the 32nd data point in Figure 7 was used specifying a tank height three meters and a pipe diameter of 10 inches (.254 m).

Based on the knowledge of pipe cost and the length of pipe that would be used in our design along the Lake, the team was able to conduct a rough cost analysis of the final design with regards to the varying pipe diameters being examined (Table 6).

Table 6: Cost Analysis of Piping

Pipe Diameter	Length of Pipe (m)	Cost ($)
0.1524m (6in)	1m - 40m	$8.20 - $328.09
0.254m (10in)	1m - 40m	$16.90 - $675.86

While the tank height stayed constant, the ten inch pipe diameter was divided into quarters to simulate covering the pipe diameter by 25, 50, and 75 percent. Equations 1 and 2 were again utilized to determine what sizes of pipe diameter can be used to meet the 1800 and 700 W power load requirements. For both values, the tank at the three meters with a pipe diameter of 10 inches was the smallest combination that resulted in the lowest flow rate. The losses in the pipe were too great to reduce the six inch pipe any further while still meeting the latter power demands.

Using the calculated flow rates and time desired to meet the load requirements, a value for the total amount of water needed to be pumped into the tank and released was found. All setup combinations and corresponding outputs are shown in Table 7 below.

Table 7: Load Demand and Hydro Generation Setup Combinations Used

Tank Height (m - ft)	Pipe Diameter (m - in)	Power Output (W)	Duration (Hrs)	Flow Rate (m^3/s)	Volume of Water Needed (Liters)
3 - ~10	.254 - 10	26,480	1	0.3693	1,329,516

3 - ~10	~.19 - 7.5	5914	3	0.1641	1,772,688
3 - ~10	~.19 - 7.5	5914	7.5	0.1641	4,431,720
Total:	N/A	N/A	11.5	N/A	7,533,924

After calculating the values above, given they are the minimal combinations possible, the team realized the amount of water needed in this design was unfeasible to hold. The largest tanks found in Kabale were 10,000 L. If these tanks were used, the team would need to purchase and place approximately 754 of them somewhere along the hilltops around Lake Bunyonyi. Unfortunately, this put the team at a crossroads where a whole new design approach needed to be conducted to find a feasible solution. Given the time constraint following our final calculations and the unprecedented nature of global events, we were unable to bring these new designs to fruition. The full documentation of the MATLAB code used for this project is pictured in Appendix B.

Project Management

The team's roles and work breakdown schedule were successful for the duration of the project. The team was able to successfully fundraise funds to visit Uganda. The breakdown of fundraising, which was put together with the help of GoldMines, and the money spent on the trip is displayed in Table 8 below.

Table 8: Cost itemization of Capstone funding

Line Item	**Funds Raised**	**Funds Spent**
Gold Mine Campaign	$3,500	
Independent Grant	$1,500	
Airfare (3 people)		$3,600
Entusi Resort (3 people)		$1,250
East African Visas		$300
Total	**$5,000**	**$5,150**

Clearly, the numbers do not quit balance in the table. Independent of the funds raised, the capstone team also had a $1,000 budget to use, and $150 was utilized from that budget for the few outstanding travel expenses. The team had planned to use the rest of that budget to create a prototype for the capstone design showcase, however, in light of recent events, the funds were not used.

Regarding success from the workflow standpoint, the team performed very well. The updated work breakdown schedule is contained in Figure 8 below. Because of the nature of the project, our design process was more fluid than concrete, and some of these deliverables were performed in a different order than may be ideal. This was as a result of not being able to visit the site until February. After the site visit, the team had the necessary information to make an appropriate decision in regards to a design solution. This greatly constrained the team's ability to produce a comprehensive solution at the end of the semester.

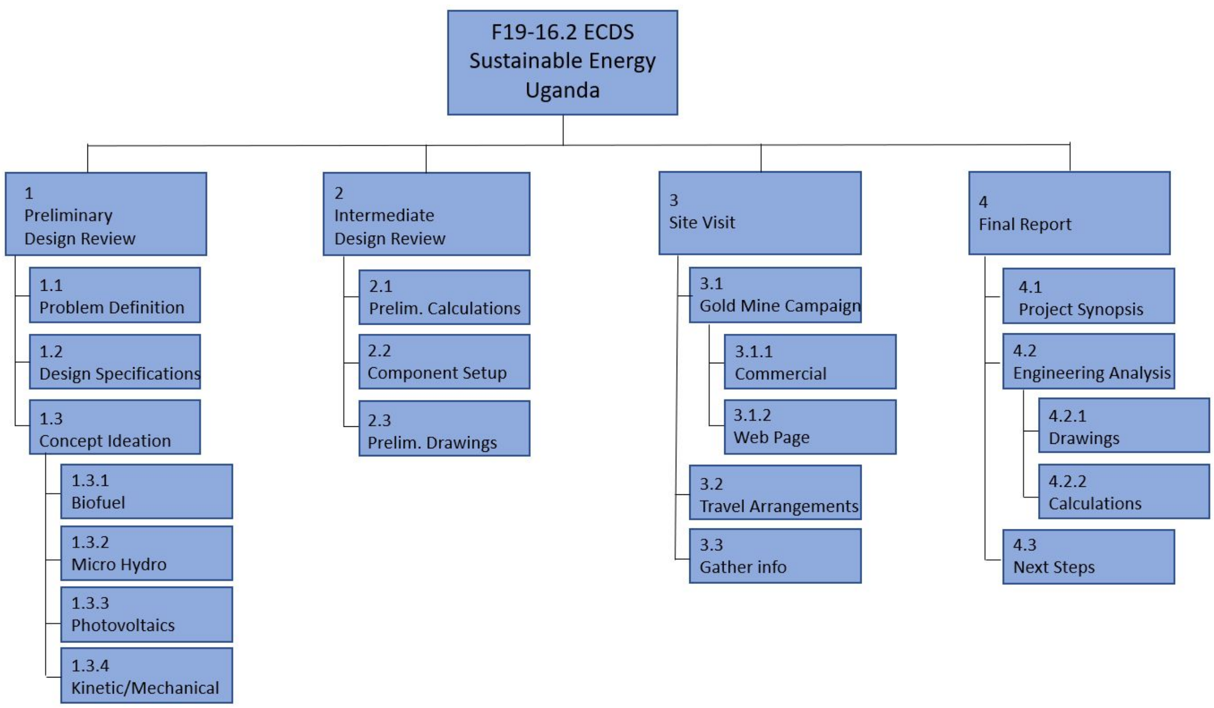


Figure 8: Workflow diagram for Capstone

Moving forward, ensuring that this project continues is the most pertinent action item. After visiting Entusi and meeting with community members, the team recognizes the need for this project, and a passion for finding a solution. There are several methods that can be deployed to meet our goals: assigning the project to another senior design team, creating a campus club/organization, or giving the project to a club already on campus. Assigning this project to another senior design team will ensure one more year of work. Realistically, the project may not be complete in one more year. Alternatively, we could begin a voluntary club/organization on campus and recruit students to help continue the project. We believe that with the proper marketing, many students would be interested in getting involved. Finally, passing it on to another organization on campus such as Mines Without Borders or the Humanitarian Engineering department is an alternative option. We wish we could have created a solution in one year, but the nature of this project, which requires an enormous amount of community buy in and integration, is best suited to a long term time table.

Lessons Learned

The team learned a lot from this project. The most important takeaway is that community center sustainable designs, such as this project, takes years to complete. Entering this semester with the intention of creating a complete solution by the end of the school year was completely misguided. There are a lot of reasons for this: the importance of community buy-in and direct community feedback, time-zone differences, communication barriers, and the complexity of this solution. Nonetheless, the rewards are fruitful. Having the opportunity to work to better lives around the world is nerve wracking, yet humbling. Sustainable development work consists of numerous iterations while maintaining countless contact with the key stakeholders. The people of Lake Bunyonyi are amiable and kind-hearted. They are similar to every other person around the world - trying to make the most of their means and wishing the best for their children. It is the team's ultimate hope that GLI and their supporters can continue to help evolve the communities around the lake and work toward establishing a reliable energy generating system for them.

Another learning experience came with the fundraising process and the gold mine campaign. Overall, we were more successful fundraising than we expected, but there's a lot of requirements for such fundraising to happen. We had to meet with the Gold Mine campaign representatives, create a website and commercial, and put a lot of time into disseminating the information--on the phone, sending emails, and writing thank yous. Crowdfunding was very successful for us, but if we were to go through this process again, we would start fundraising much earlier; it takes a lot of time and a lot of work.

As far as the process of establishing a design and determining feasibility goes, we were also able to take away many lessons from those experiences as well. Although we had been through the design process many times before, working on a system this large for a real client, and a real community definitely made things more challenging. We found that there were so many aspects of our final design to consider; feasibility, materials, cost, the layout of the land, community buy-in, and several others were among the most important considerations involved. We also found that when the team ran into problems, the process to fix or mitigate those complications was time consuming and difficult. This has a lot to do with time management and the involvement with other priorities in our lives. Finally, we learned that a design of this magnitude takes a lot of planning, consideration, and reiteration to get to a presentable, final solution. We quickly found that we did not have the time for this amount of reiteration, testing, and design change that was needed for the solution we wanted to implement. So, the biggest lesson learned through the design preparation was the need for time management and cohesiveness to get to a solution.

Appendix

Appendix A: Resources pictured in Kabale, Uganda including tanks, various pipe sizes, connectors, and solar panels


PPR TEE
3/4
PPR FEMALE
TEE
PPR TEE
1"

Appendix B: MATLAB code for energy equation calculations

Getting It Done

Table of Contents

Properties

```
%Variables and other Constants
const.rho = 997;          % Density [kg/m^3]
const.sw = 9789;          %Specific Weight [kg/m^2*s^2]
const.eff = 0.8;          %Efficiency [percent]
const.g = 9.81;           %gravity [m/s^2]
const.k_12 = 0.5+1.0;     %loss coeff [m]
const.C_v = 0.98;         %Nozzle velocity coeff.
const.tankdia = 5;
const.mu = 0.0010016;     %Dynamic Viscosity [Pa*s]
```

Geometric Parameters

Create arrays to loop through different physical attributes

```
% theta = theta.*(pi/180); %Convert degrees to radians
% Lets keep thetha at a 45deg angle -> common for pipes
% Mainly try to eliminate all of these changing paramters

const.thetha = 45 * pi/180;
y = [1:35];     % Height from bottom of tank to turbine [m]
H_g = [1:40];   % Gross Head from waterline to turbine; 200
D_2 = [.0381, .0508, .1017, .1524, .24384, 0.3048];  % Nozzle Diameter
 [m]
i_Dpipe = length(D_2);
i_y = length(y);
D_N = zeros(1,i_Dpipe);

Head_Loss = zeros(i_Dpipe,i_y); %Allocating space for Head_loss combo
 values

k = 1;
```

Power and Time

```
Power = zeros(i_Dpipe,i_y);
P_want = zeros(i_Dpipe,i_y);
```

```
% Following values retrieved from Tyler's Load Profile
% The community uses 8,500 W at max peak for one hour, 1800 W for 3
 hours
% after that, etc.
P_needed = [8500, 1800, 700];   % Watts
T_span = [1, 3, 7.5];           % Hours
T_span = 3600*T_span;           % Seconds
```

Calculate Initial Power, Diameter, Height, Velocity, etc.

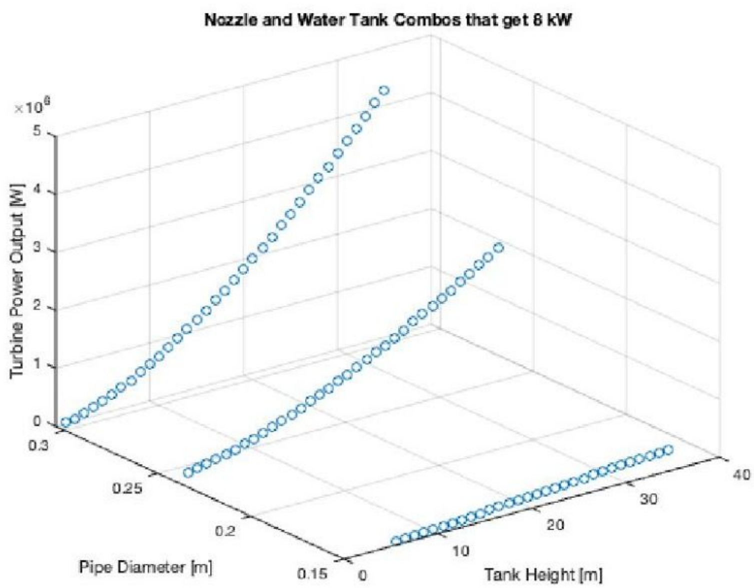
Run through each paramter combination and calculate Power value Iterate through each of the tank height values for a given nozzle diameter, then change diameter and go again

```
        for i = 1:i_Dpipe
            for j = 1:i_y

            L = y(j)/cos(const.thetha);              %Length of pipe
 [m]
            V_N = 0.95*sqrt(2*const.g*y(j));   %Velocity through pipe
 - Changed H_g to y (Discuss)[m/s]
            D_N(i) = D_2(i);                       %Diameter of pipe [m^2]
 -> Put in function

            Re = (const.rho*V_N*D_N(i))/const.mu; %Reynolds Number

            if Re >= 2300
                f = colebrook(Re,0.002);
            else
                f = 64./Re;
            end


            A_N = (pi/4)*(D_N(i)^2);         %Area of nozzle [m^2]
            A_2 = (pi/4)*(D_2(i)^2);         %Area of pipe [m^2]
            Q_N = A_N*V_N;                   %Flow rate through pipe
 [m^3/s]
            k_N = (1/const.C_v^2) - 1;       %Nozzle headloss coeff

            Head_Loss(i,j) = HL(const,Q_N,D_N(i),f,L,k_N);

            %Power Equation
            %First element in Power matrix corresponds to the element
 combo
            %from head loss
            Power(i,j) = Pow(const,Q_N,y(j),Head_Loss(i,j));


                if (Power(i,j) >= P_needed(1))
```

```
                P_want(i,j) = Power(i,j);
                Y_want(k) = y(j);
                D_want(k) = D_2(i);
                P_want2(k) = Power(i,j);
                Q_want(k) = Q_N;
                k = k+1;

            end
        end
    end
```

Initial Power Plot P(diameter,tank height)

```
plot3(Y_want,D_want,P_want2,'o')
title('Nozzle and Water Tank Combos that get 8 kW')
xlabel('Tank Height [m]')
ylabel('Pipe Diameter [m]')
zlabel('Turbine Power Output [W]');
grid on
```



Covering the other loads

Now that we have our parameters that meet our max power desired, we can extrapolate those heights and diameters to see how we can change things to use as little water as possible. We will keep the height values constant, but vary the diameters to play with the flow rate.

```
% Get pipe diameter and height combos first
Combos = zeros(length(D_want),2); %Two columns for diameter and tank
height
N = 4; %Want four diameters per full diameter to see if we should
cover
       %og dia up by 25%, 50%, 75%

D_new = zeros(length(D_want),N); % Matrix of new broken down
diameters
Power_combos2 = zeros(length(D_want),N); %Get Power Values for all
new dia's
Power_combos3 = zeros(length(D_want),N); %Get Power Values for all
new dia's

FlowRates2 = zeros(length(D_want),N); %Preallocate for flow rates
FlowRates3 = zeros(length(D_want),N); %Preallocate for flow rates



for temp = 1:length(D_want)

    %Place in matrix for ease of comparison
    %Combos is the initial combinations that get at least P_needed(1)
    Combos(temp,1) = D_want(temp);
    Combos(temp,2) = Y_want(temp);
    D_new(temp,:) = linspace(0,Combos(temp,1),N);
    % Break down the diameters into quarter slices to account %
coverages

    %Calculate new power values for each new diameter
       for i_d = 1:N


    % Gets the power output, if there is one that is over the SECOND
Power
    % Needed index and its corresponding flow rate
    [Power_combos2(temp,i_d),FlowRates2(temp,i_d)] = DHP(const,...
        Combos(temp,2),D_new(temp,i_d),P_needed(2));

    % Gets the power output, if there is one that is over the THIRD
Power
    % Needed index and its corresponding flow rate
    [Power_combos3(temp,i_d),FlowRates3(temp,i_d)] = DHP(const,...
        Combos(temp,2),D_new(temp,i_d),P_needed(3));


       end
end
```

Calculate Amount of water needed

```
%Volume of water for first set of diameters, times, heights, and
power
```

```
Cubic_m1 = zeros(length(D_want),3);
Liters1 = zeros(length(D_want),3);
Gallons1 = zeros(length(D_want),3);

for t = 1:length(D_want)

    [Cubic_m1(t,1),Liters1(t,1),Gallons1(t,1)] =
Flow(T_span(1),Q_want(t));

end

 for t2 = 1:length(D_want)

    [Cubic_m1(t2,2),Liters1(t2,2),Gallons1(t2,2)] =
Flow(T_span(2),FlowRates2(32,3));

 end

  for t3 = 1:length(D_want)

    [Cubic_m1(t3,3),Liters1(t3,3),Gallons1(t3,3)] =
Flow(T_span(3),FlowRates3(32,3));

  end

 Cubic_tot = sum(Cubic_m1(1,:));
 Liters_tot = sum(Liters1(1,:));
 Gallons_tot = sum(Gallons1(1,:));

 Energy1 = P_want2(1)*T_span(1)/1000; %kJ of Energy for first power
value
 Energy2 = Power_combos2(32,3)*T_span(2)/1000;
 Energy3 = Power_combos3(32,3)*T_span(3)/1000;
 EnergyTot = (Energy1 + Energy2 + Energy3)/1000; %MJ of Energy

fprintf('Amount of water for first power is:\n%.2f m^3\n%.2f Liters\n
%.2f Gallons', Cubic_m1(1,1), Liters1(1,1), Gallons1(1,1));

fprintf('\n\nAmount of water for second power is:\n%.2f m^3\n%.2f
Liters\n%.2f Gallons', Cubic_m1(1,2), Liters1(1,2), Gallons1(1,2));

fprintf('\n\nAmount of water for third power is:\n%.2f m^3\n%.2f
Liters\n%.2f Gallons', Cubic_m1(1,3), Liters1(1,3), Gallons1(1,3));

fprintf('\n\nTotal Amount of water is:\n%.2f m^3\n%.2f Liters\n%.2f
Gallons', Cubic_tot, Liters_tot, Gallons_tot);

fprintf('\n\nTotal Energy in first power delivery is: %.2f kJ',
Energy1);
fprintf('\nTotal Energy in second power delivery is: %.2f kJ',
Energy2);
fprintf('\nTotal Energy in third power delivery is: %.2f kJ',
Energy3);
fprintf('\nTotal Energy harnessed/dispursed is: %.2f MJ', EnergyTot);
```

```
Amount of water for first power is:
676.88 m^3
676879.01 Liters
178696.06 Gallons

Amount of water for second power is:
1633.71 m^3
1633709.19 Liters
431299.23 Gallons

Amount of water for third power is:
4084.27 m^3
4084272.98 Liters
1078248.07 Gallons

Total Amount of water is:
6394.86 m^3
6394861.18 Liters
1688243.35 Gallons

Total Energy in first power delivery is: 48512.46 kJ
Total Energy in second power delivery is: 30097.20 kJ
Total Energy in third power delivery is: 75243.01 kJ
Total Energy harnessed/dispursed is: 153.85 MJ
```

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