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R.I.S.E

Renewable and Integrated Systems of Energy

A technical model for the Energy, Water, Sanitation and Recycling needs for a sustainable community

25% Report

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This B.S. thesis is written in partial fulfillment of the requirements in EML 4905. The contents represent the opinion of the authors and not the Department of Mechanical and Materials Engineering.

Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Sergio Baltodano, Michael Enriquez, Babacar Cisse, Paola Davalos and Natalia Duque and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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Abstract

This project presents a technical model for the creation of a sustainable community, particularly for developing nations. The sustainable community model involves discrete but integrated subsystems including a small scale power plant, water and sanitation treatment plant and a recycling node. The integrated energy system encompasses solar, wind, hydro and biogas using a centralized energy approach that gathers converts and transmits the various energy forms as electricity. The water and sanitation system treats household waste in two ways. The first way is through bio-filters which biologically degrade greywater pollutants. The second way is through an anaerobic digester which produces biogas for cooking, heating and electricity, and a nutrient rich fertilizer for improving crop yield. The aim of this project is an initiative to join engineering technology with communities to impulse and assure the basic human rights of energy, water and sanitation to developing nations as part of the United Nations Millennium Development Goals for 2015.

1. Introduction

1.1 Overview

Energy is currently at the center of public concern due to rising oil prices, energy security and the need to address climate change. The use of non-renewable energy sources has brought about grave environmental, social, and political impacts. Worldwide energy demand is continually rising partly on account of the population and economic growth in developing nations. Energy is the key requirement for all development in our modern civilization. Although most industrialized nations are currently engaged in exploring new green alternatives in the fields of transportation, electricity and industrial processes, the world is still completely dependent on fossil fuels. The world's reliance on fossil fuels is not only environmentally unsustainable but also unviable in nations which are struck by poverty. Almost one third of humanity lives in the dark, having no electricity for their everyday needs. In addition, several billion people across the globe rely on solid biomass as their cooking fuel, causing large scale deforestation, smoke pollution and severe health impacts such as Acute Respiratory Disease.

This project introduces an interdisciplinary approach towards integrating renewable energy sources while exploring battery free energy storage options for the implementation in sustainable communities. This concept branches out from our recently award winning proposal, in the 2013 Odebrecht Award for Sustainability, titled " Education, Renewable Energy and Disaster Resistant Housing for Rural Haiti: An Integrated Design for Reconstruction." Through this proposal which was specifically aimed for Haiti, we have expanded the scope of our project to address the energy, sanitation and water needs for developing nations. By harvesting renewable energy and rainwater, recovering energy from waste, and creating a recycling based economy, existing communities can have a dramatic increase in their quality of life.

1.2 Problem Statement

Our reliance on fossil fuels as our main energy supply has brought about grave environmental, social, political and health impacts worldwide. Addressing these issues requires an interdisciplinary approach to provide a framework for a viable sustainable development model. There is a need for a global cooperative platform that adequately assesses technical solutions to some of mankind's most pressing issues: energy and water security, climate change and the development of a community focused expertise in sustainability.

1.3 Motivation

The way that aid has been performed over the last decades has been a patronizing system in which external entities enter communities and implement their versions of how to save the people. This form of aid has usually ended up harming the communities it sought to help, as can be seen in many failed aid projects in Haiti and Africa. The main reason why externally imposed aid seldom has a positive impact is because of its unwillingness to work alongside the people in a cooperative platform. In order to develop long-term solutions that improve a community's quality of life, a project must be implemented with respect, while providing communities who wish to be helped with the opportunity of becoming technical professionals.

Our ultimate goal is to create sustainable and integrated technical solutions that can address the energy, water, food, educational, and health issues faced by rural populations across the globe. Dealing with such a broad range of problems requires that the current project focus on a limited amount of technical components as an initial step in achieving our goal.

The technical components of the model sustainable community explore new areas of research: a plastics recycling system based on 3D printing technology and the design of an efficient pico-hydro low pressure head water wheel and an innovative horizontal axis wind turbine. In essence, our motivation is to address global issues from an interdisciplinary-technical standpoint that combines energy, water treatment and recycling into one technical-model for sustainable development.

1.3 Literature Survey

1.3.1 Sustainable communities

Masdar city is an example of an eco-friendly city that is currently being built in the United Arab Emirates. It is presented as an experimental model for ecologically sound urban planning and the integration of renewable energy sources, focused around the improvement of people's quality of life in urban settings. The community's master plan aims to provide housing to over 40,000 residents and access to 50,000 commuters. It addresses very specific efficiency requirements that significantly reduce the energy needs to 25% of what a normal city of this size requires. Masdar city's water consumption levels are reduced to less than 50% of a normal city, by use of smart water meters that detect leakages throughout the city and through usage of processed wastewater for irrigation. The eco-city's goal is to create a fossil free zone that utilizes 100% renewable energy, zero waste and zero net carbon (Lau). One limitation to the scope of this project is the isolation of this community in the middle of a desert with very little possibility that the community can expand beyond its initial plan. Another issue is the multi-billion dollar investment that it requires, accompanied by a planning strategy that does not take into account the inputs and desires of the local community.

Communities across the world are realizing the need for a sustainable model that is environmentally conscious, economically productive and socially just, thus assuring the entire population's right to food, energy and water. The world is entering a new period, a green revolution in which action is being taken on many scales: local, regional, national and international. The United Nations Sustainable Development Knowledge Platform aims to provide a simplification mechanism for the development, transfer and diffusion of clean and environmentally sound technologies. One of the outcomes of the Rio +20 United Nations Conference on Sustainable Development was the need to create Sustainable Development Goals (SDGs) which will replace the Millennium Development Goals (MGDs) in January 2016 (United Nations). Currently, there is a joint research conducted by the UN Department of Economic and Social Affairs/ Division for Sustainable Development and Duke University that explores national government capacity building for integrated water, energy and food security framework for developing nations. There is a crucial need for technical progress for an integrated management system that provides solutions to the water, energy and food needs of underdeveloped regions.

Sustainable development is defined as a type of development that meets the needs of the present, without compromising the ability of future generations to meet their own needs. The interdisciplinary and dynamic nature of sustainable development provides a basis for socio-economic development while addressing the finite concept of natural resources. Sustainable community development involves environmental protection by avoiding the depletion or contamination of natural resources, while promoting progress, growth and economic prosperity. The importance of sustainable community development can specially be seen in developing nations that are caught in a vicious cycle of environmental degradation, increased poverty and illness. There exists a technological gap between poor and rich nations, perpetuated by the erroneous thought that technology is too advanced and cannot be managed and maintained by people in developing nations. One of the most critical ways to promote sustainable community development in emergent nations is by facilitating the appropriate transfer of technology that preserves the environment and improves the quality of life (Hope).

1.3.2 Water and Sanitation

Despite global efforts to improve access to clean drinking water for all humanity, water and sanitation continue to be major issues, particularly in regions of extreme poverty.

1.3.2.1 The Uganda Case Study

The lack of access to clean drinking water and adequate sanitation negatively impacts the health, productivity and socio-economic growth of communities in developing nations. In Uganda, only one third of rural populations have access to adequate sanitation. Although governments are increasing their allocated budget for the water sector, one of the main obstacles is water quality. Waterborne illnesses contribute to increased morbidity rates, accounting for over 2 million deaths (World Health Organization) per year worldwide. Bacterial, viral and parasitic pathogens affect water via different mechanisms: contaminated water distribution, inadequate rain catching systems, pollution during collection processes, sewage leakage into drinking water, environmental pollutant infiltration into pipes and poor drainage. Another major contribution to water-related illness is the lack of information diffusion for rural households regarding how to improve their water and sanitation conditions. This information inadequacy is also directly linked to the lack of rural electrification in order to access information sources (Baguma, Aljunid and Hashim)

Water supply, water management, an effective sanitation plan and access to information sources are key components in the fight to improve water access and quality for rural communities. A capacity-building component with emphasis on rain harvesting usage instructions, information on waterborne illness prevention and promotion of active communal participation improve rural domestic water management (Baguma, Aljunid and Hashim). Although Uganda is well on its way to the MDG target for clean water **Figure 1** it has been unable to meet the MDG target for basic sanitation. A focus on the shortage of local technical personnel and information dissemination are key components for sanitation and hygiene improvement.

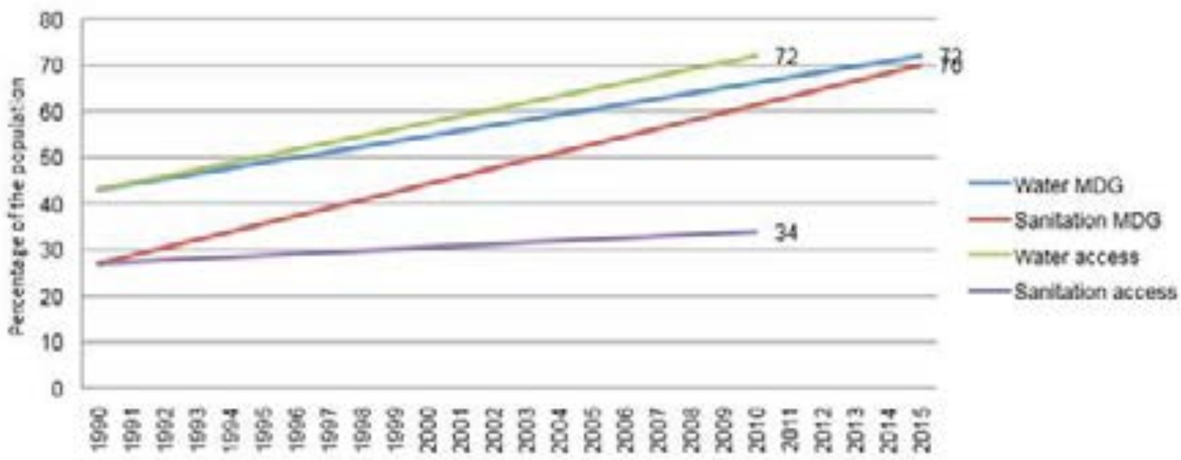


Figure 1: Water and Sanitation Improvements in Uganda. Source: WHO/UNICEF Joint Monitoring Programme 2012

1.3.3 Renewable Energy in Developing Nations

Renewable energy is one of the most potentially effective solutions for sustainable development. These green energy technologies can provide an alternative to fossil fuels and establish the basis for electrification systems in rural areas. Solar, wind, hydro and biogas units are already being studied and implemented.

1.3.3.1 Solar

As of now, 5000 MW PV power is produced by Photovoltaic Cells (PV) technology around the globe. The sector registered a 31% increase over the last 10 years with multi-crystalline silicon as the major PV material. With the mass production of thin film solar cells, the costs are predicted to markedly drop by 2020, making solar panels much more affordable. Their efficiency is in order of 40% as opposed to multicrystalline silicon, where the maximum efficiency obtained was 15% (Lior). In China, agriculture represents an integral part of society, with more than half a billion farmers relying on fossil fuels as an energy source. This degrades their natural environment but also presents a threat to the economic sector, as it will be impossible in the future to keep up with fossil-fuel energy production and demand. In rural China, PV systems increased by close to 300% (to 20 MW capacity) between 2004 and 2011. A research conducted in those areas reveals that more than half of the farmer's households surveyed agreed to convert their traditional houses to solar houses (Li, Li and Wang).

1.3.3.2 Hydro

One third of Bolivia's population, located in rural areas, lacks electricity. At the same time, Bolivia possesses the ability to generate Micro Hydro Power (MHP) due to its geography. The energy produced by a MHP installation would be a continuously available resource, since the Andes region contains rivers with head elevations between 1800-2900 meters. As a result, MHP provides a lower cost (US 7–20¢ per kWh) as compared to a small wind turbine (15–35¢) or a solar house (40–60¢). Many of the MHP systems are stand-alone and are financed by local and international organizations (Drinkwaard, Kirkels and Romijn).

Nuristan, a city located in the northern part of Afghanistan closely resembles Bolivia's rural areas. The availability of various streams and rivers make it suitable for MHP. In 2007, the implementation of a 7kW system helped in the generation of electricity and the sustainability of wheat production. Also, each home possesses one or more sources of lighting as a direct result of the MHP system. Prior to this, energy was scarce (Hallett).

1.3.3.3 Wind

Ghana possesses the ability to harness wind power with monthly wind speed readings of 4.8-5.5 m/s at an altitude of 12m. This diagnosis originates from an official report of the Solar and Wind Energy Resource Assessment Programme (SWERA) which collected reliable data at 11 coastal sites East and West of the Meridian near the Accra region. The research also proposes the ideal turbine which would be the most suited for this type of environment: the FuturEnergy Turbine. This turbine produced a reasonable amount of power (1 kW), compared to similar designs, but presented the most cost effective option. In ideal conditions, this turbine would also desalinate and provide water for nearly 100 individuals (Parkam, Schaferb and Richardsa).

1.3.3.4 Biogas

Biogas constitutes an abundant and cheap energy source. It is easily obtainable from animal, human, vegetable, agricultural and industrial waste. This form of energy can be used in a number of processes that positively impact the local economy, not only through energy generation but also through the production of high quality organic fertilizer. The biogas plant is appropriate for the technical conditions and economic possibilities of developing nations. The largest quantity of reported biogas installations is in Asia. India has successfully installed over two million household biogas facilities and dozens of community plants where gas reaches each home through gas pipes. Biogas production by means of anaerobic fermentation produces several benefits for rural populations and for the environment. A biogas plant produces the following benefits: green energy production, bio-fertilizer generation, hygienic condition improvement by managing black waters and manure, environmentally beneficial, easily scalable, and requires minimum maintenance and minimal technical training for operation. Across the world there are several examples of untreated wastewater contaminating surface waters, producing dead zones in the ocean, polluting recreational water bodies and destroying aquatic life. Anaerobic digestion eliminates bad odors caused by decomposition of organic matter and prevents untreated organic matter from reaching nearby water bodies (Sener).

1.3.4 Energy Storage Options

Currently there is a global challenge to provide energy storage options for off-grid and grid energy technologies that do not require the use of batteries.

1.3.4.1 Storing off-grid renewable energy using batteries

The use of batteries to store energy has been one of the eldest forms to accumulate electricity by the process of electrochemical cells. Although batteries possess some benefits in the application of energy storage from renewable sources, they negatively impact the environment as they contain toxic materials and a short cycle life. Lead acid batteries, which are among one of the most widely used for their power quality, suffer from a short life cycle in the range of 500 – 1000 charge cycles (Chen, Cong and Yang). This leads to additional environmental pollution when batteries are not properly disposed of. Aside from the high cost of batteries, they are not ideal for energy storage for a community based scale because of their low energy densities, small power capacities and high maintenance costs. Hence, the biggest challenge for the evolution of renewable energy lies in procuring effective energy storage solutions that do not rely on batteries.

1.3.4.2 Alternate Energy Storage methods

Pumped Hydro Storage (PHS), Compressed Air Energy Storage (CAES) and Electrolysis are examples of alternate methods for storing energy.

1.3.4.2.1 Pumped Hydro Storage

PHS is one the most mature energy storage technologies and is widely used around the world. There are currently 270 pumped storage plants that account for a combined generating capacity of over 127,000 megawatts (Manwaring, Mursch and Tilford). The PHS system consists of two reservoirs that store water at different elevations creating a potential energy difference. Initially, water at the lower reservoir is raised by using off-peak electricity to run a pump. Once water is stored in the elevated reservoir, it can be discharged as required to drive a water turbine similar to the ones in hydro-electric dams. Accounting for the evaporation and conversion losses, roughly about 71% -81% of the electrical energy used to pump the water can be regained (Chen, Cong and Yang). **Figure 2** shows a typical pumped hydro storage plant arrangement.

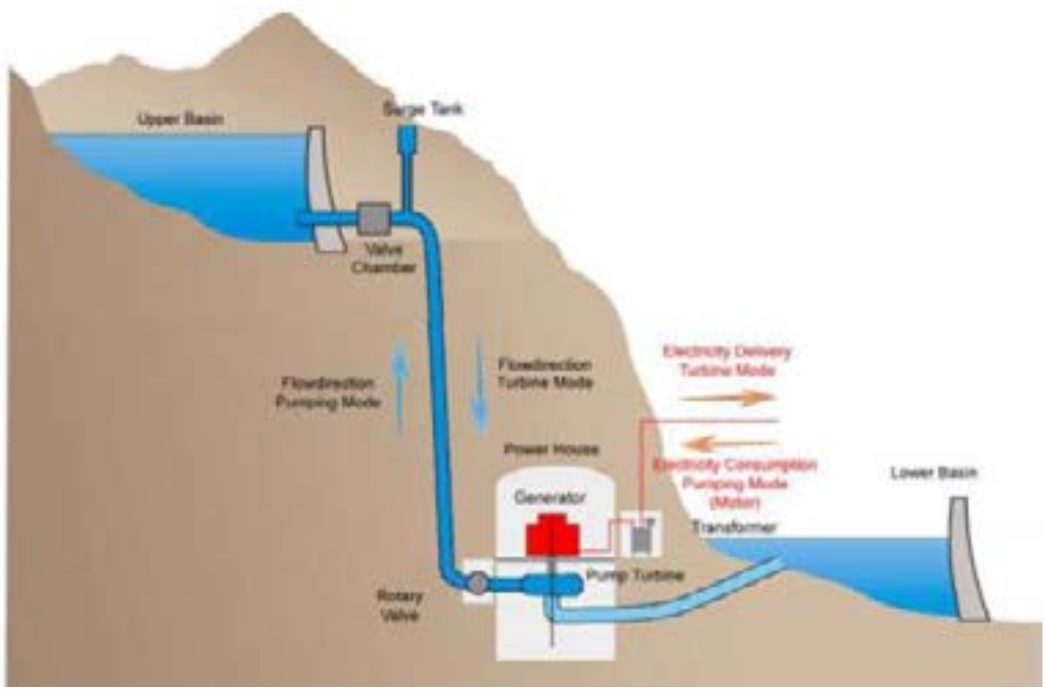


Figure 2: Pumped Hydro Storage Arrangement (Chen, Cong and Yang)

1.3.4.2.2 Compressed Air Energy Storage (CAES)

Compressed air energy systems are another viable option for the storage and distribution of electricity. The CAES can be separated into two groupings: large and small scale. Large scale CAES is a tested and proven technology that can have tremendous storage capacity of up to 100 MW (Chen, Cong and Yang). During off peak-electricity demands, the power is used to run a compressor which intakes atmospheric air, compresses it and stores it underground. Large scale CAES requires hard rock caverns, salt caverns or deep aquifers as air holding chambers (Zhang, Ahmari and Sternberg). Once there is an energy demand, the compressed air is then drawn and expanded through a high pressure turbine which captures a portion of the energy from the compressed air. Low pressure air is then mixed with fuel and combusted while the exhaust is expanded using a low pressure turbine. Both turbines produce electricity and maximize efficiency. **Figure 3** presents a diagram of a typical large-scale CAES system. In contrast, the small scale CAES utilizes reduced sized storage units which can be in the form of flexible bags underwater, steel tanks above or below ground surface and pipelines above or below ground surface, which are flexible and can be used at different locations (Zhang, Ahmari and Sternberg).

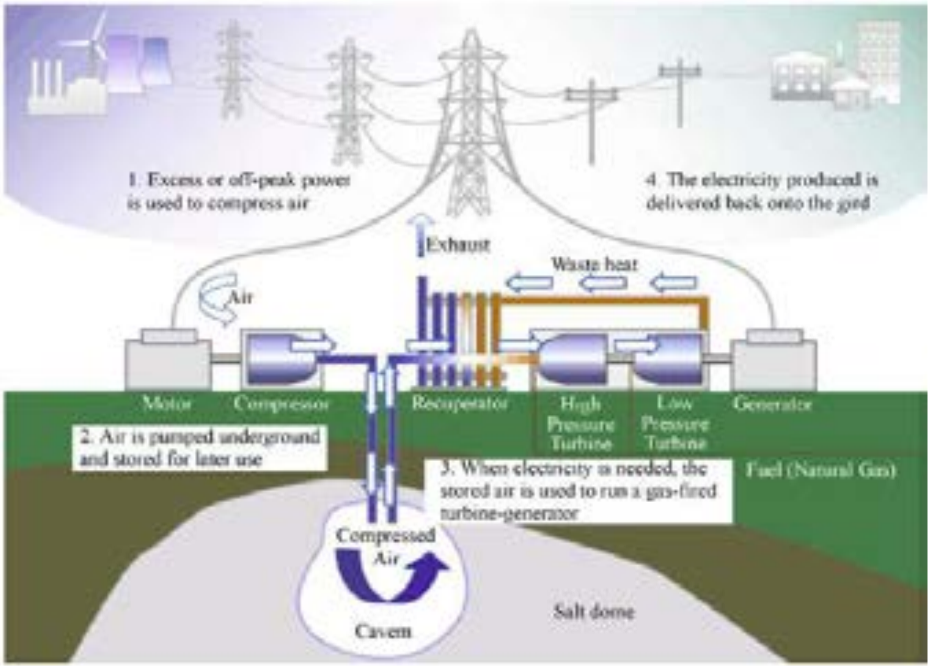


Figure 3: Large Scale CAES diagram (Chen, Cong and Yang)

1.3.5 Recycler Impact

Single use plastics are the greatest source of plastics pollution. Plastic bags, utensils, bottles, lids cups and others serve as a momentary convenience but do not biodegrade, therefore sticking around as trash and debris forever.

1.3.5.1 The plastics pollution problem

Plastics are one of the leading causes of pollution constituting 90% (Allsop, Walters and Santillo) of all trash floating in the ocean. Slow moving currents in the ocean carry away this plastic as they rotate in a clockwise direction forming massive heaps of plastic trash. Plastics are not biodegradable, rather, they are photodegradable, the sun breaks them down into smaller and smaller pieces, yet they never disappear completely. Plastic particles become so small that wildlife mistakes them for food; consequently causing negative effects not just for oceanic aquatic systems but also for the humans who consume the contaminated seafood.

In most of the world, people have adopted the mindset of single use plastics. That is, using plastics for initial purposes and either recycling them or disposing of them as miscellaneous polluting trash. We currently recover only 5% of the plastics we produce. Roughly 50% is buried in landfills, some is remade into durable goods, and much of it remains “unaccounted for”, lost in the environment where it ultimately washes out to sea (Derraik).

1.3.5.2 Mechanical properties and characteristics of thermoplastics

The mechanical properties of plastic material are extremely important because nearly all applications involve some amount of mechanical loading. It is necessary to understand the properties of the plastics that will be used on a given application, to ensure that failure will not occur which can potentially harm someone or cause a loss of life. Analyses on the mechanical properties of virgin thermoplastics such as High Density Polyethylene (HDPE) and Polyethylene Terephthalate (PET) have been tabulated and are available in material science books (Shah). The properties of these thermoplastics have been investigated by employed tests such as tensile tests, thermo tests, and variable loading tests. A problem arises when determining the mechanical properties of recycled plastics because the recycling industries are too young and detailed scientific studies have not been conducted in this field (Cornier-Rios). For this reason, it is vital to explore these mechanical properties of recycled plastic through proper testing guided by ASTM standards for thermoplastics. In doing these tests, we can confirm that material properties of recycled plastics remain unchanged and can be utilized in their intended applications.

1.3.5.3 A new concept in recycling plastics for 3D printing

At the moment there is a technological revolution unfolding and creating opportunities for people all over the world. 3D printing has been at the forefront of this revolution, by putting manufacturing and design into the hands of the consumer. With 3D printing people are able to design something on CAD software and immediately print it. This progress in technology stimulates people's imagination to find innovative solutions for local and global concerns. The integration of low cost 3D printers with portable plastic recycling machines may play a large role in the issue of plastic pollution.

The greatest obstacle is to design and manufacture a compact, user-friendly plastic recycler, which can be easily implemented in developing nations. The recycler must have the capacity to shred various types of plastics and process the shreds into a filament, which is then, the plastic supply necessary for 3D printing. This process enables communities to rid their environment of plastic trash while repurposing the trash into usable items, generating a recycling-based economy. One current example that has meaningfully impacted a community is ProtoPrint in India. Sidhant Pai, a fourth year Environmental Engineering student from MIT and the CEO of ProtoPrint has created affordable 3D printing services in Pune India by use of recycled plastic filament. This company is empowering wastepickers in urban India through the development of a low-cost method to convert plastic bottles and containers into 3D printing filament. This environmentally friendly and socially just solution is a great example of how 3D printing-recycling technological revolution can bring significant changes towards the economic development of emergent nations.

2. Project Formulation

The proposed project intends to integrate renewable energy, water and sanitation management and an innovative way to recycle plastics for reuse. By integrating all these aspects into a model community, the general scope of this report is to investigate the efficiency, costs and feasibility of this form of energy/water/recycling integration system. Through the analysis of the model community the next steps of impact of the project would be how to implement these technologies in developing nations who wish to improve their quality of life. This implementation can only be done through a cooperative partnership in which the community has input and authority in the decision making process. In this way, the appropriate technologies can be selected for implementation. Through an initial analysis on the topic of sustainable community development in emergent nations, our project aims to empower communities with technical aspects that can have a positive impact for economic growth, sustainable agriculture, energy, water and health security, as well as countless environmental benefits. This project also intends to meaningfully impact the technology gap between developed and developing countries.

2.1 Project goals

- Develop an innovative recycler to transform plastic bottles into 3D printing material
- Explore small scale alternative energy storage options as a viable means to store energy without the need of batteries
- Perform material testing on high density polyethylene (HDPE) and polyethylene terephthalate (PET)
- Design a low-head pico-hydro turbine using recycled material
- Develop a sizing chart for biofilters to treat greywater as a function of flowrate
- Create an easy-to-follow technical description of the biogas anaerobic digester

- Assess water filtration options for drinking water
- Construct an integrated rain water harvesting, pico hydro and water filtration system
- Incorporate Electrical Engineering assistance in combining solar, wind, hydro energy into one electricity supply line
- Perform field research in the Solar House at the FIU Engineering Center

3. Conceptual Design

We analyzed several options in the process of determining the best selection and design of each component of our sustainable community plan

3.1 Recycler Alternatives

At the moment there have been several individual "makers" who have designed and manufactured their own portable plastic recyclers. Their goals have been to create a plastic recycler, which has the ability to take ABS and PLA plastics of pellet form, and process it into a filament form, to then be used for 3d printing. Our present proposal for a recycler varies from others, in that the RISE recycler will be able to process two types of thermoplastics. The machine is designed to have variable heat settings, which can be then applied to each individual plastic. This allows for the intake of the most common plastics, which compose most of the world's plastic trash material, such as polyethylene. Currently, there are two basic types of recyclers in the market, simplified filament extruders and complex filament extruders.

The Filastruder, **Figure 4**, is a simplified filament extruder. This machine is designed to produce filament at a low extrusion rate and does not contain the ability to process multiple types of plastics. This is due primarily to the fact that in order for various types of plastics to be extruded, the drive shaft must rotate at variable speeds. The speed will vary based on the viscosity of the plastic when it reaches its melting temperature. Molten plastic, which is more viscous, will require the drive shaft to rotate at less of a rate than that of a less viscous plastic, simply because less pressure is required to extrude from the nozzle, where as a lightly viscous material will require more pressure in order for the resulting filament to be free of imperfections, such as air bubbles and exterior scaling. This particular design contains a constant speed motor, which will allow for an extrusion rate suitable only for one type of plastic, primarily ABS plastic, a highly used plastic for 3D printing.

Figure 4: The filastruder. A simplified filament extruder

The Recyclebot, **Figure 5**, is an example of a complex extruder. A complex extruder varies from simple extruders in that it is capable of processing multiple types of plastics. In this design a microcontroller is used to control the current received by the motor, which then allows for adjustable drive shaft speeds. As mentioned before, varying drive shaft speeds are necessary to process plastics which have different viscosities.

The design and main components of the two types of extruders are fundamentally the same, although the addition of a microcontroller gives the user more functionality out of the same components. Algorithms are written and implemented into the microcontroller in order to obtain variations in motor speeds as well as heating element temperatures. Both of these variables need to be optimized in order to produce a filament which may be considered usable for 3d printing.

Figure 5: Recyclebot: Complex Filament Extruder

3.2 Renewable Energy Alternatives

The main components we are analyzing in this section are solar, wind and hydro power in order to determine the best alternatives for each. The aim of this project is not to explore differences in existing photovoltaic panels but rather focus on wind and hydro systems.

3.2.1 Wind Power

Quantitative and qualitative variables must be taken into consideration when designing a system that harnesses wind energy. There are two basic types of wind turbines: horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT). From these two general classifications, several designs exist in the market in all ranges of sizes and shapes. In order to design a functional wind turbine for our purposes, we developed the design criteria detailed in **Table 1**.

Table 1: Wind Turbine Design Parameters

Design Parameters
Operates safely within wide range of wind speeds
Ability to be retrofitted to existing infrastructure
Low initial cost & low maintenance cost
Does not endanger wildlife
Withstands daily and rare extreme loads
Aesthetically appealing
Ability to be integrated into a gutter system
Economically feasible for developing nations
Long service life
Efficiency in capturing wind energy at low speeds
Quiet

Small, or mini, wind turbines are preferable for both residential and community-based renewable energy production. They have several benefits in terms of having a smaller operating footprint, and possessing the ability to operate at low wind speeds, below 10 miles per hour, as opposed to conventional wind turbines. Another convenience is the ability to install mini wind turbines on existing roofing systems, balconies or terraces. Small wind turbines utilize a generator that can work under any weather conditions to easily charge a 12 V battery or another type of energy storage mechanism.

A possible existing design for a wind turbine that fulfills most of our design parameters is the Savonius turbine. The Savonius turbine, initially invented in 1922 by Sigurd Johannes Savonius (McNiven), is a VAWT shaped like an S, **Figure 6**. Although this type of turbine has a very low rotational speed, it yields an impressively high torque, which makes it useful for mechanical energy production such as grinding grains or pumping water.

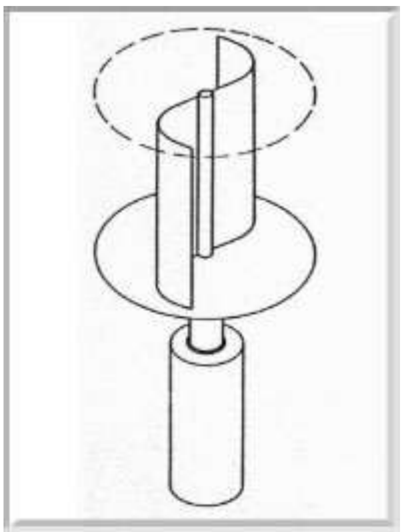


Figure 6: Savonius Wind Turbine Source: McNiven

The Helix wind turbine, produced by Sauer Energy Inc. is based on the Savonius design. It is a simple turbine design that harnesses small wind for residential and commercial settings. Benefits of this turbine include the ability to spin regardless of wind direction. This means that it can be mounted at lower heights, harnessing energy in turbulent flow conditions and also reducing associated installation costs.

Helical wind turbines are especially interesting for residential usage. The appearance of helical wind turbines varies from DNA looking structures, to drill bit shaped, to a variety of spiral designs that catch the wind while rotating and generating electricity. This type of wind turbine, aside from having the ability to be mounted lower to the ground on roofing structures for instance, can also harness a wide range of wind speeds. Another difference between traditional wind turbines and helical ones is that the latter do not possess serious risks for birds since they have a lower blade sweep area and are closer to the ground.

3.2.2 Hydro Turbine Alternatives

We aim to design a unique water wheel turbine able to produce electrical energy from flowing water. The design of this turbine relies heavily on two main characteristics of the water: pressure and flow rate. The pressure exerted on the turbine blades follows a linear relationship with the head elevation. The flow rate obtained at the outlet of the runner is a function of water volume, runner and nozzle diameters. As a matter of fact, the turbine selection process should start with an extensive study of the pressure and flow rate available at the water site. From there, three different types of turbines can be selected: impulse, reaction or impulse-reaction.

A high elevation water site provides the necessary water pressure to operate impulse turbines. An impulse turbine converts the momentum of the impacting jet of water into rotational kinetic energy. A high flow water site provides the necessary torque to operate reaction turbines. The blades of the turbine rotate due to the change in pressure in the water flow field. Here is an overview of some of the most commonly used turbines:

Impulse turbine

- Pelton/Turgo wheel: the design of the turbine's blades follows the same geometry as standard paddles. In this way, the maximum amount of energy is extracted by making use of the water jet, which impacts the blades at a high velocity.

Reaction turbines

- Kaplan propeller turbine: the design of the turbine's blades allows for power to be extracted from hydrostatic head and rotational energy of the water.
- Francis radial flow turbine: the design of this turbine is conceptually similar to the propeller turbine, however a wider range of head elevations is covered.

With a broader understanding of hydro turbines, the next step is to evaluate and compare their usefulness. In their research, Williamson, Stark and Booker drew a comparison between efficiency vs. head for diverse turbine configuration, **Figure 7**.

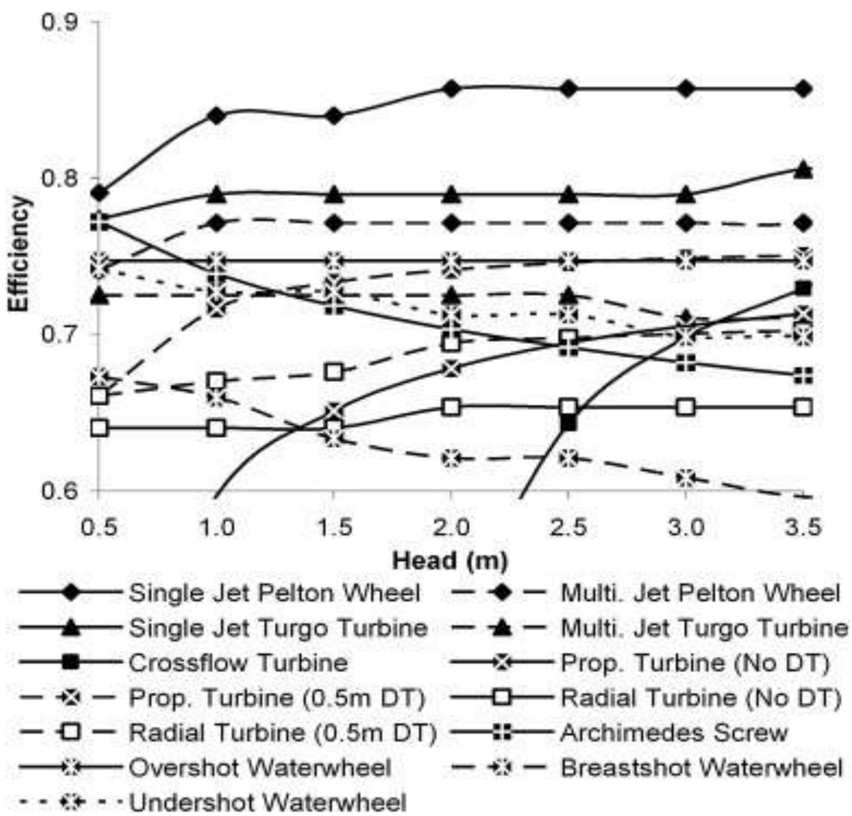


Figure 7: Efficiency vs. head for water wheel turbines (Williamson, Stark and Booker)

From **Figure 7**, the Pelton single jet wheel represents the most viable design for high head and low flow scenarios with an efficiency varying between 80-90%. Also, it is important to note that the multiple-jets arrangements for this design reduce the power density at low heads. For a smoother operation of the Pelton turbine, the designer needs to diffuse problems associated with low speeds and runner size. In fact, those two parameters have an impact on power density and portability. (Williamson, Stark and Booker).

3.3 Methane Digester Alternatives

Several types of existing methane biogas reactors, or anaerobic digesters, are currently in use throughout many parts of the world as a viable waste processing, energy recovering mechanism.

3.3.1 Anaerobic Digestion Overview

Bio-gas production in the form of methane by means of anaerobic digestion of human, animal, domestic and agricultural waste is a greatly viable tool in the puzzle to counter the existing worldwide energy crisis. Anaerobic digestion decomposes organic material biologically in an oxygen free environment and recovers valuable products in the form of energy and nutrients. Energy is recovered as biogas, typically containing 70% methane, 25% carbon dioxide and trace quantities of nitrogen, oxygen, hydrogen and hydrogen sulfide. The odorless, and colorless, nitrogen and phosphorous rich, liquid effluent recovered from the digester serves as fertilizer and is 99% free of pathogens (Rowse). Anaerobic treatment does not require aeration, which has the highest energy costs in wastewater treatment.

Anaerobic digestion is a microbial fermentation that occurs in the absence of oxygen. It evolves in a three step process in which different bacteria convert the organic material into a usable form for the next group of bacteria. The final stage is methanogenesis in which methane is produced by completing the decomposition process. Biogas is produced in a closed tank which can be constructed from various materials such as bricks, cement, plastic or metal. The bioreactor contains an entry port for organic waste and wastewater and an effluent port by which bacterially digested slurry exits.

3.3.2 Types of biogas plants

Biogas plants can be divided into batch, continuous and plug-flow reactors. The batch-type reactors are charged once and then emptied completely after a given retention time.

The incessant gas production of this type of digester can be accomplished by connecting several batch reactors in series.

Continuously stirred bioreactors, Figure 8, are charged and discharged periodically, usually on a daily basis. The influent and effluent in this case must remain uniform and this type of reactor is especially good for rural settings because of the constant organic waste produced by livestock.

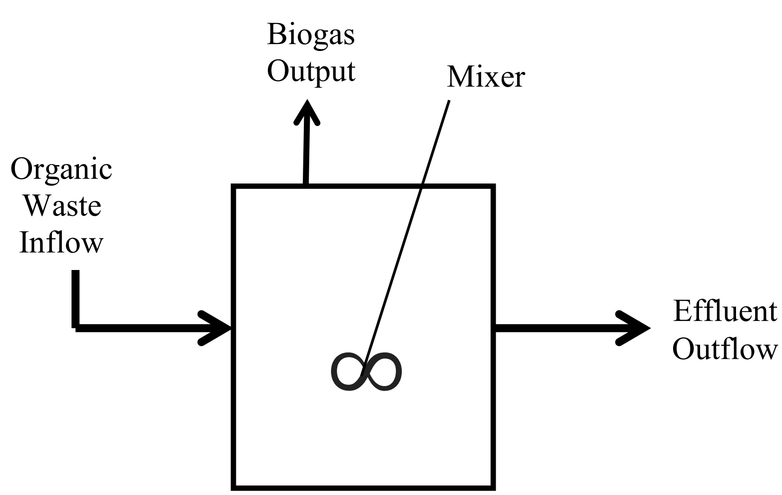


Figure 8: Continuously Stirred Methane Digester Schematic

Plug flow bio-reactors, **Figure 9**, have a typical length to width ratio of 5:1. This type of reactor is useful when organic waste is processed with low water quantities.

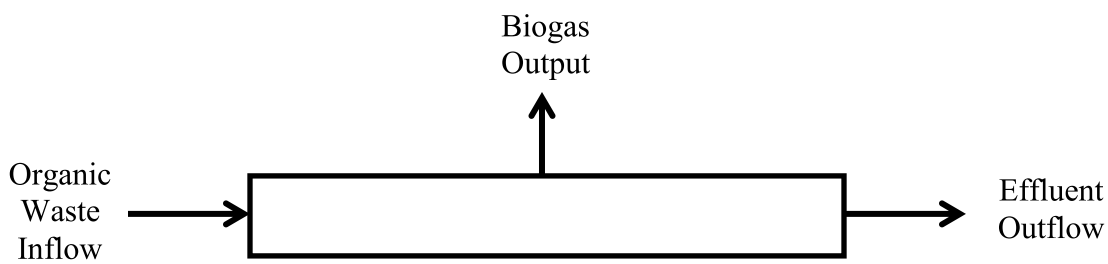


Figure 9: Plug Flow Reactor Schematic

3.4 Alternatives for Constructed Wetlands

There are two main types of constructed wetlands, subsurface-flow CW, and surface –flow CW.

3.4.1 Subsurface-flow constructed wetlands

Subsurface-flow constructed wetlands have no standing water; therefore they do not resemble natural wetlands. They contain a bed of graded stone media which has been planted with aquatic plants. Wastewater is introduced at one end of the bed of stone, wastewater stays beneath the surface of the media and it flows in contact with the roots and rhizomes of the plants. At the opposite end of the bed, a device collects and the treated effluent.

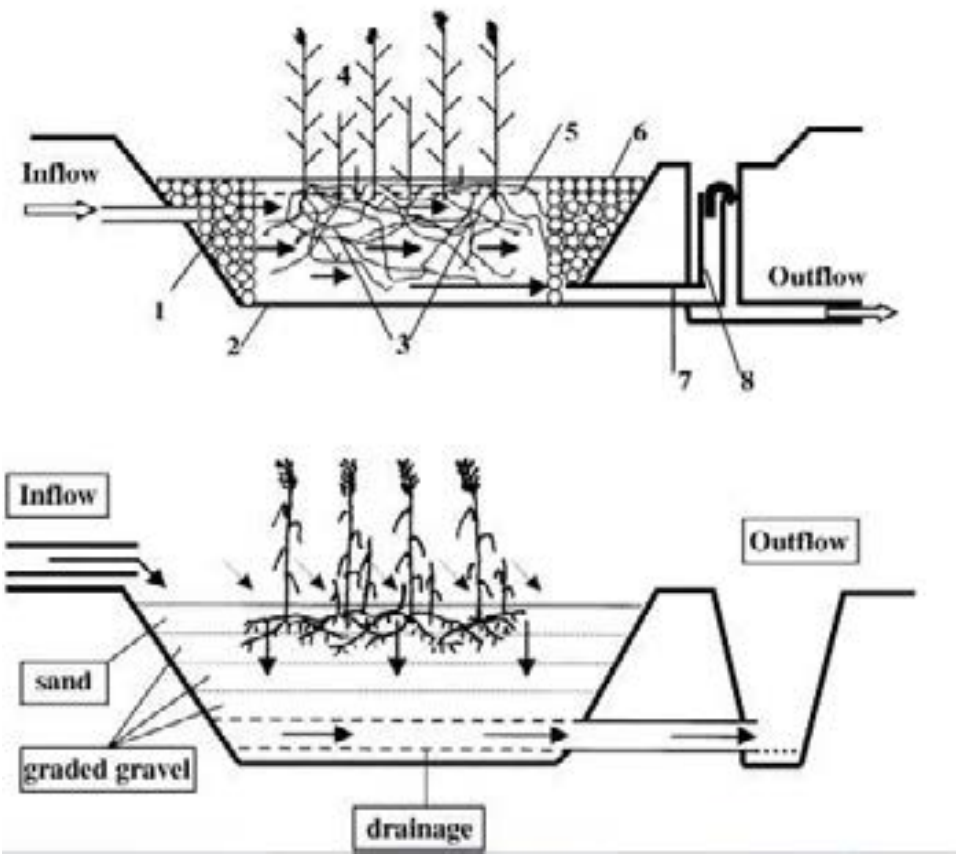


Figure 10: Subsurface-flow Constructed Wetland (Vymazal)

3.4.2 Surface-flow constructed wetlands

Surface-flow constructed wetlands consist of a shallow basin, soil or other medium to support the roots of vegetation, and a water control structure that maintains a shallow depth of water. The water surface is always above the substrate. In surface-flow CW the near-surface layer is aerobic, while the deeper waters are anaerobic. Surface-flow CW are very cost effective and easy to maintain

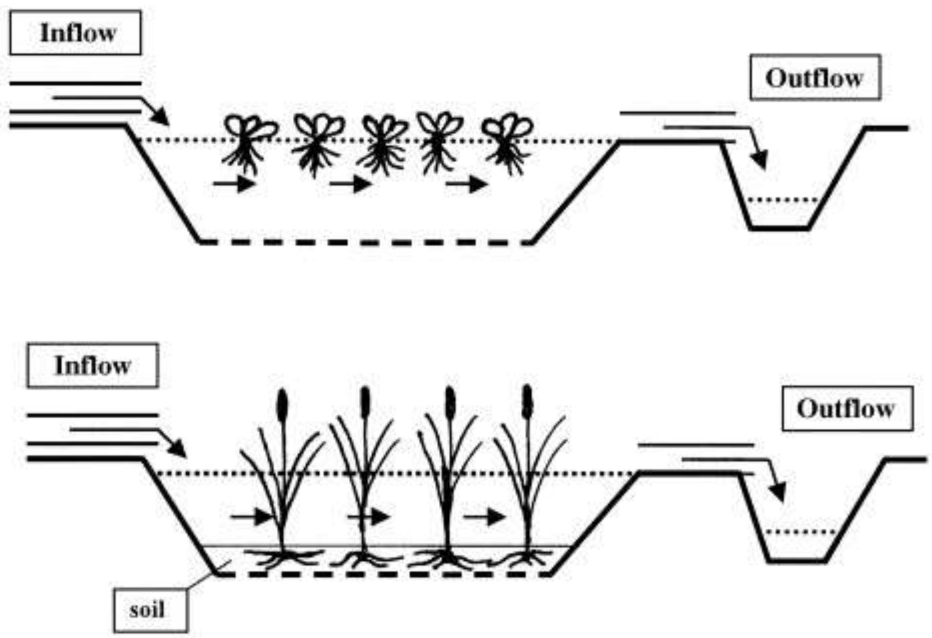


Figure 11: Surface-flow Constructed Wetland (Vymazal)

4. Proposed design

Our proposed design includes the integration of four renewable energy forms: biogas, hydro, wind and solar. The integrated energy system is combined with water and wastewater management as well as an innovative plastics recycling system. Our energy and water integration scheme relies heavily on the diagram reproduced in **Figure 12**.

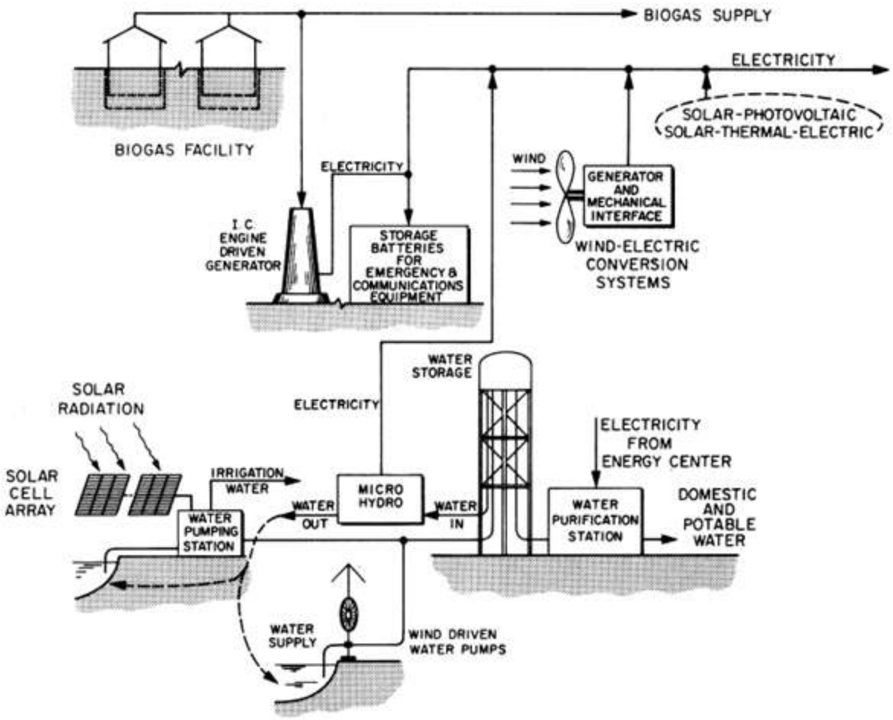


Figure 12: Proposed Design (Ramakumar and Hughes)

The proposed design involves discrete sub sections that require individual analysis and specific design components. These subsections are: recycler, pico-hydro turbine, helical wind turbine integrated with gutter system, water filtration, biofilter and the methane bioreactor.

4.1 Recycler design

The recycler is designed to extrude molten plastic at an average rate of 4 ft/min. It is also capable of processing multiple types of plastics. It achieves a 4ft/min extrusion rate by optimizing the algorithm used to control both heating element temperatures and drive shaft speeds. The recycler contains the ability for the user to select heating and motor speed settings by a press of a button. There are 3 buttons, which are programmed to activate the proper combination of motor and temperature settings for the extrusion of three types of plastics.

In order for the plastic waste to process through the recycler, the plastic particles entering the recycler must be no larger than ¼” in every direction. In order to obtain plastic particles of this size it is necessary to shred the particle until it reaches the required dimensional range. A custom-made tool steel shredder is used to reduce the size of the particles. The shredder is integrated onto the foundation of the recycler, and contains a bin placed beneath it in order to collect the shredded particles of plastic. These plastic bits will then be processed through the shredder again until the required dimensions are met, or it is dumped into the hopper, where the particles are driven through a shaft and into the heating chamber, where the bits of plastic then melt to the desired temperature and extruded through a nozzle of 1.75mm in diameter

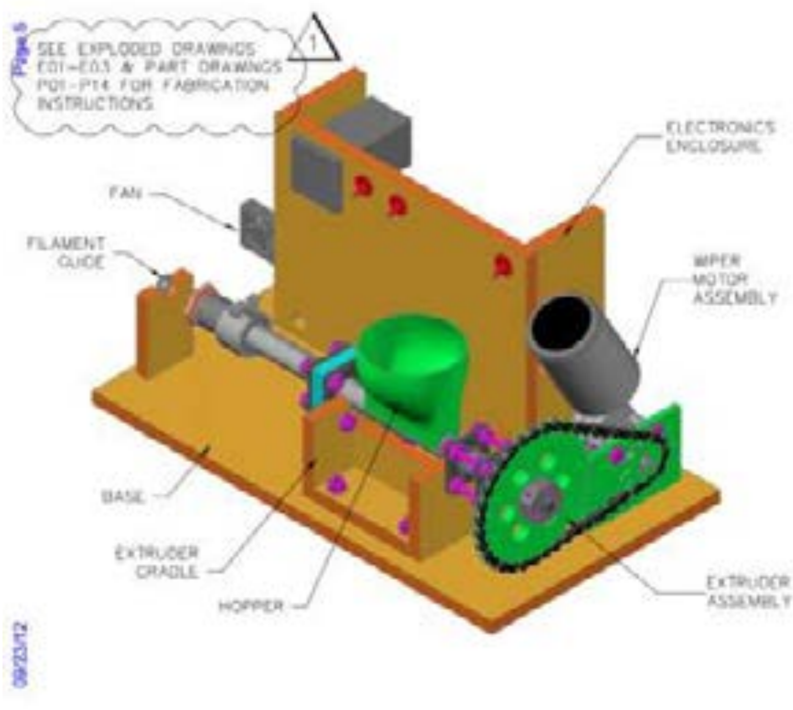


Figure 13 Lyman Recycler Source: Lyman

4.2 Pico Hydro Turbine

The Pelton turbine represents the basis of design for our Pico Hydro system. This turbine would be installed inside the downspout of a rain collection system. The double buckets of the runner allow for the incoming jet of water within the pipe to be split in half: in this way, the water imparts a higher impulse to the runners before escaping at a lower velocity. Here are two different illustrations which highlight the basic working principles for the turbine:

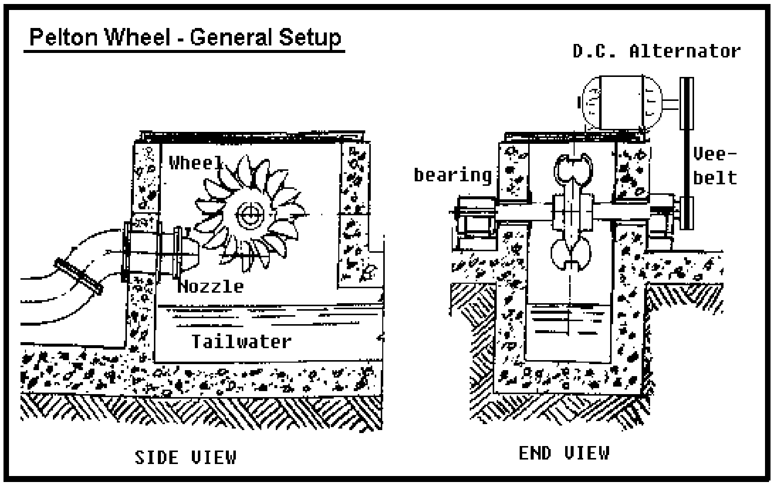


Figure 14: Overview of a Pelton Wheel system (Shannon)

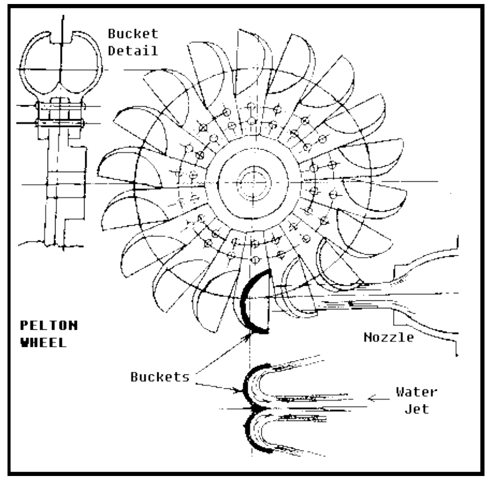


Figure 15: Detailed view of a Pelton turbine (Shannon)

4.3 Helical Wind turbine integrated with gutter system Design

Reusing rainwater helps preserve one of the planet's most valuable resources, water. Urban and rural runoff flows into bodies of water, picking up debris and contaminants in its path and threatening aquatic ecosystems and even our own water supply. Rain catchment begins with systems to keep rain as clean as possible through gutters, downspouts and filters. Rain can be collected for household use in rain barrels or diverted through bioswales (swaled drainage courses that remove pollutants from surface runoff) into a communal reservoir.

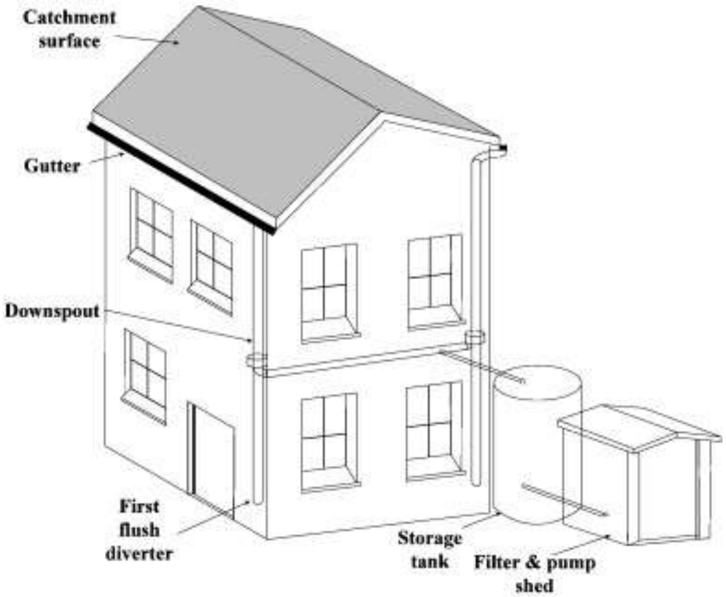


Figure 16: Rain Harvesting Diagram Source: (Zhe)

Figure 17 is a rendering of how the wind/hydro/gutter system can be integrated in a low rise building.

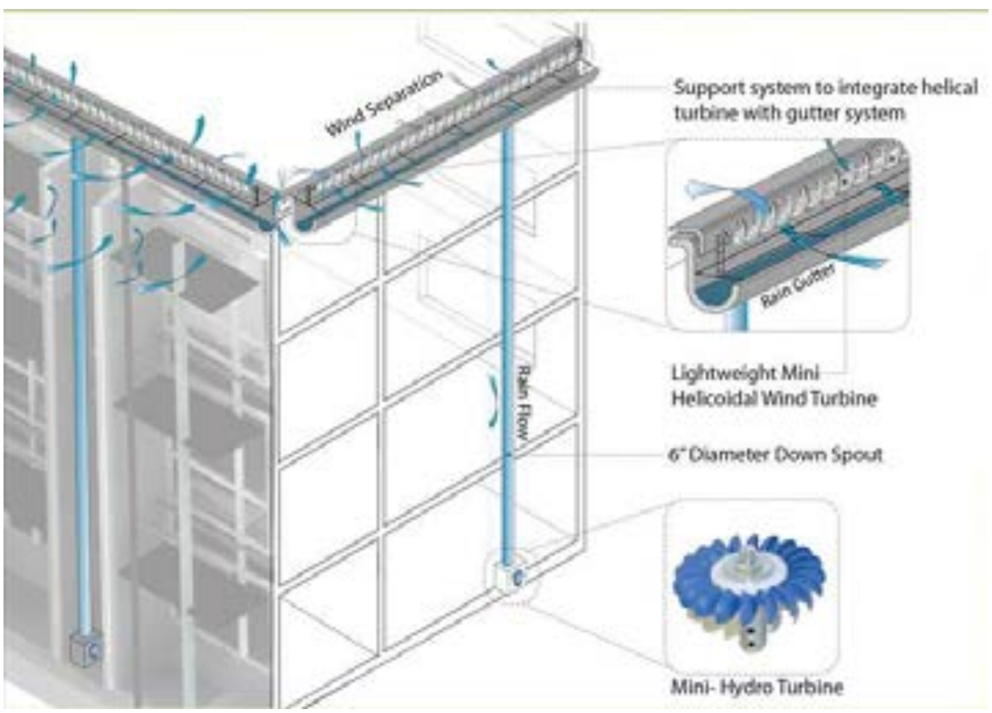


Figure 17: Integrated Wind turbine gutter system with pico-hydro turbine Source: Dr. Arindam Chowdhury, FIU

4.4 Water Filtration Design

The water filtration design utilizes pressure to purify the rainwater for drinking purposes. The gutter captures the water collected from the roof, or catchment surface. Coarse screens are placed at the gutter downspout to prevent leaves or large debris from entering collected water. First flush diverters prevent initial contamination to occur. The final steps are a pressure pump and a treatment system before delivering water into the home as seen in **Figure 18**.

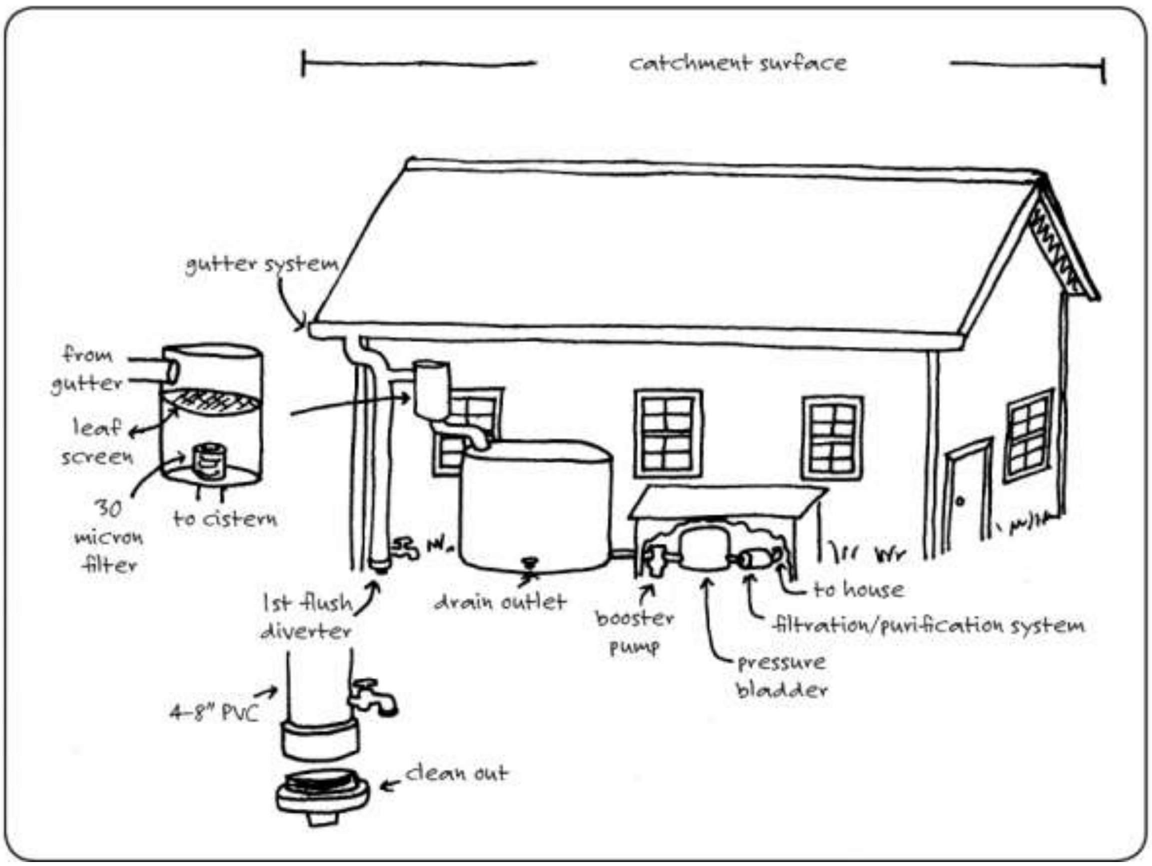


Figure 18: Water catchment and filtration (Biller)

The proposed design for the drinking water filtration system involves a slow-sand filter followed by a drip carbon filter and a UV or chlorination disinfection stage.

4.5 Biofilter design

Biofilters as depicted in **Figure 19** are constructed wetlands, in other words, they are biological systems that provide an interaction between media, plants, microorganisms and wastewater to biodegrade pollutants from household greywater.

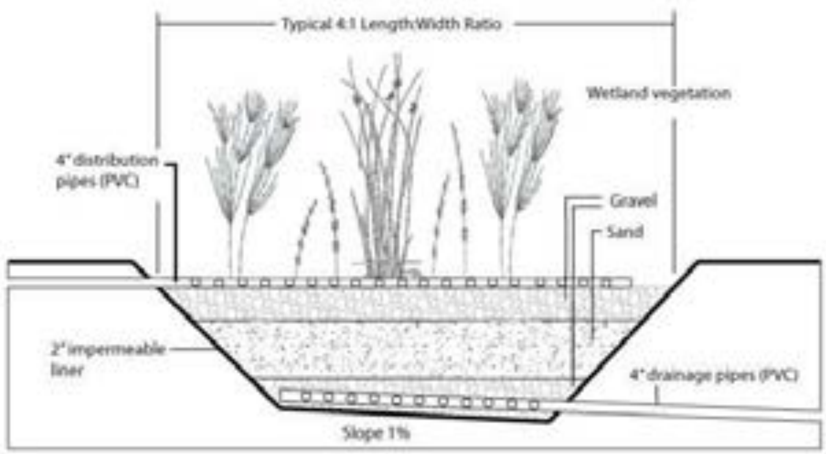


Figure 19: Biofilter design

4.6 Methane Bioreactor

The anaerobic design choice is a continuous flow underground reactor **Figure 20**.

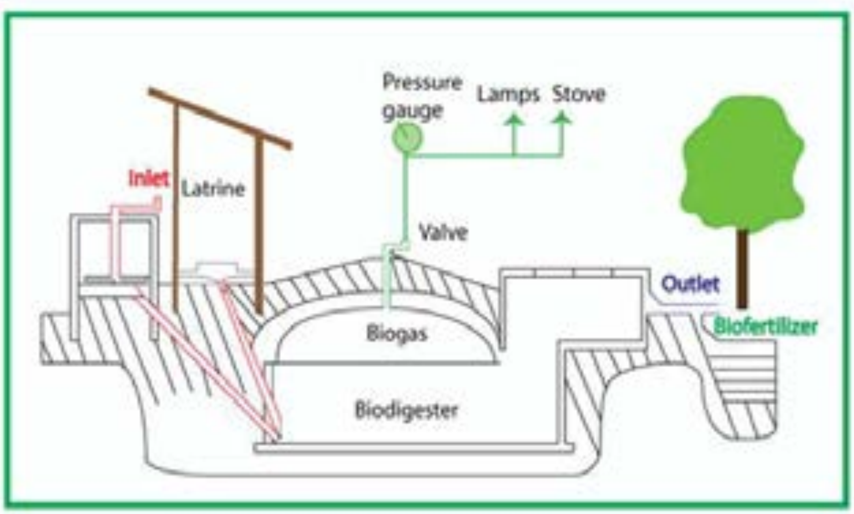


Figure 20: Methane Bioreactor design

5. Timeline

Figure 21 depicts our proposed timeline for project completion

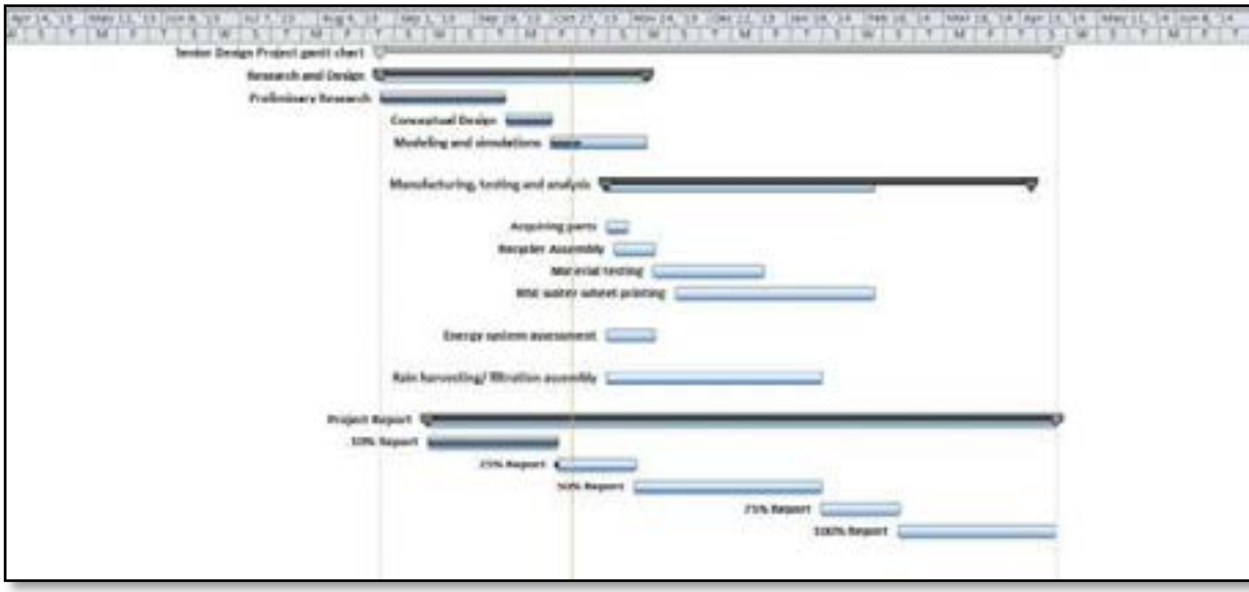


Figure 21: Timeline

6. Investigative Analysis of Components

6.1 Analysis of Recycler & Plastics testing

6.1.1 Thermoplastics Analysis

A proper investigation of the mechanical properties of (HDPE) High Density Polyethylene and Polyethylene Terephthalate (PET) was performed to ensure these thermoplastics do not weaken after the recycling process. The high density polyethylene plastics and polyethylene terephthalate are mainly utilized in milk jugs, water bottles, caps, detergent containers etc. Once processed, the material properties of the (HDPE) and (PET) can possibly be altered. In order to successfully and safely use the recycled printed products, we performed a series of laboratory tests to ensure that a satisfactory material property was attained. The test sample was fabricated through the 3-D printer and was sized according to the ASTM standard D638 Type 1 for plastic testing. **Figure 22** shows the test specimen used based on the ASTM standard for plastic testing.

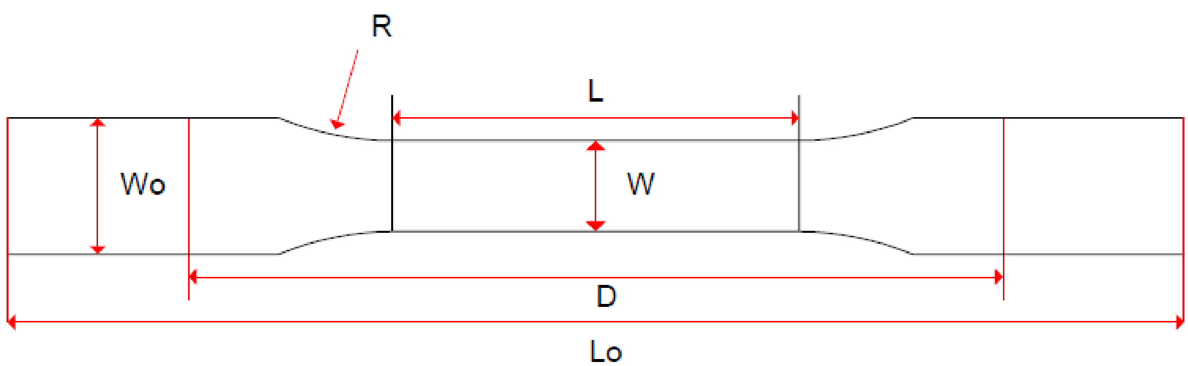


Figure 22: Test sample

The test sample was dimensioned according to ASTM standard D638 for plastic testing for a type 1 configuration as denoted in **Table 2**.

Table 2: ASTM Standard dimensions for test sample Type 1

Description	ASTM (in)	ASTM (mm)
W_o	.75	19
R	3	76
L	2.25	57
W	.5	13
D	4.5	115
L_o	6.5	165

With this test sample and the tensile testing apparatus, we calculated the following properties of the recycled plastic: strain, elongation, yield strength, modulus of elasticity, and ultimate strength. For the tensile strength testing, we calculated the yielding point of the specimen and at break (ultimate strength). Yield strength is the stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain which occurs at the yield point (Shah) as shown in **Figure 23**.

$$Tensile\ Strength\ at\ Yield = \frac{Maximum\ load\ recorded}{Cross - section\ area}$$

The ultimate strength can be noted as the point where the test specimen breaks, and is expressed in the following equation:

$$Tensile\ Strength\ at\ break = \frac{Load\ recorded\ at\ break}{Cross - section\ area}$$

Along with tensile strength, other important mechanical properties that we evaluated are tensile modulus and elongation. Tensile modulus or modulus of elasticity is the ratio of stress to corresponding strain below the proportional limit of a material (Shah).

$$Tensile\ modulus = \frac{Difference\ in\ stress}{Difference\ in\ corresponding\ strain}$$

Furthermore, were able to calculate the strain for the test sample which is the change in length per unit of the original length.

$$strain = \frac{Change\ in\ length\ (elongation)}{Original\ length\ (gauge\ length)}$$

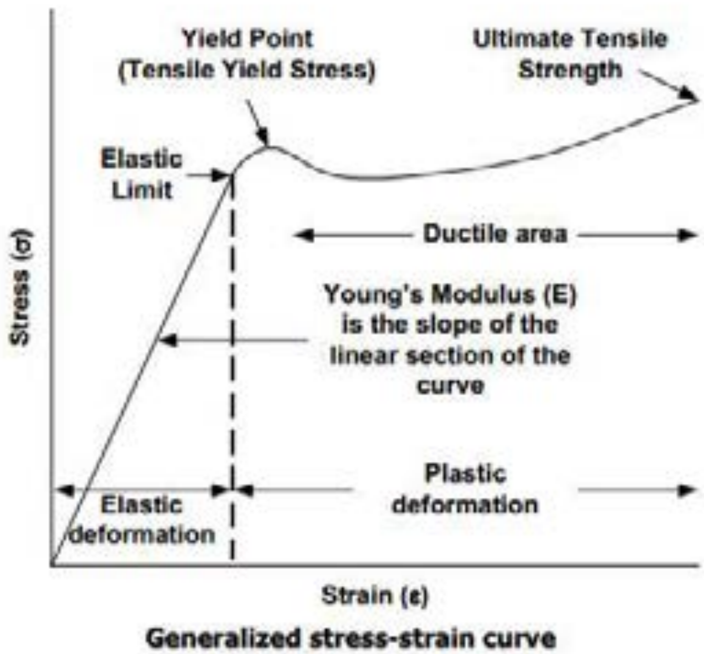


Figure 23: Stress-Strain Curve Source: (Zeus Industrial Products, Inc)

Following ASTM standards for tensile testing for plastics, it is obligatory to test the sample a minimum 5 times to achieve accurate results. With a series of tests we compiled an average value of modulus of elasticity, yield strength, ultimate strength, and strain to properly analyze products, specifically the pico-hydro turbine.

6.2 Modular Solar Unit Data Acquisition

In order to obtain practical information regarding photovoltaic energy production potential in tropical regions, we set up a modular solar unit in the outsides of the FIU Engineering Center by the outdoor recreational gazebos. The purpose of this set up is to gather continuous remote data via Wi-Fi to analyze the daily electricity production under different weather conditions. Furthermore, we intend to provide an additional benefit to students by setting up a cell phone charging station at this location, to promote usage of these gazebos and provide functionality for the solar panels.

6.3 Integration of Rain Harvesting, Wind-gutter turbine, pico-hydro turbine and water filtration Analysis

The final design for a renewable-energy powered home includes a rain harvesting component in which a helical wind turbine can be installed. The water collected in the gutters will first pour through the pico-hydro turbine and then collect and filter in rain barrels.

6.3.1 Rain Harvesting Analysis

The amount of water that can be harvested from roof tops depends on the area of the roof, the rainfall depth, and the runoff coefficient that depends on the material of the roof. The volume of rainwater that can be harvested per household per month is determined by the following equation:

$$V = \frac{H \times A_R \times C}{1000}$$

Where:

V monthly volume of rainwater per household (in cubic meters)

H monthly rainfall depth (in millimeters)

A_R household roof area (in square meters)

C runoff coefficient (unitless)

This information is used to design the storage capacity, and the overflow discharge if necessary.

6.3.1.2 Rain Harvesting system components

A typical domestic rainwater harvesting systems consists of three components: a catchment (roofs), a runoff delivery system and a storage tank.

6.3.1.2.1 Catchment

The catchment has to be impermeable and cannot seriously contaminate the water. Roofs of houses are the most common and effective type of catchment used for harvesting rainwater. The most important factors for a roof to be effective are the area, the slope and the material. The roof has to have sufficient surface area and slope to direct water to the runoff delivery system. It is preferable if the material used in construction is smooth, clean and impervious.

6.3.1.2.2 Runoff delivery system

The runoff delivery system usually consists of gutters and downpipes that deliver rainwater from the catchment area to the storage tank. When designing the piping system, the amount of runoff available plays a most important role, the system has to be able to satisfactorily deliver the harvested water.

6.3.1.2.3 Storage tank

The harvested rainwater is ultimately stored in a storage tank. It is essential to design and construct the storage tank effectively. The tank can be built into the house, or it can be built as an individual component located away from the house. The most common materials used in the construction are cement-brick, metal, plain-cement concrete, and reinforced-cement concrete.

6.3.2 Helical Wind Turbine power Analysis

The power of wind turbines is mainly dependent on three factors: the amount of air (volume), the speed of air (velocity), and the mass of air (density) flowing through an area which can be referred to as "flux". The following formulas are used to assess power generation capability of a wind turbine:

From the definition of kinetic energy we have:

$$KE = \frac{1}{2} m v^2$$

Also, taking the energy per unit time gives power:

$$P = \frac{1}{2} \dot{m} v^2$$

Noting that the flux is the amount of mass per unit time flowing through an area,

$$\dot{m} = \frac{dm}{dt}$$

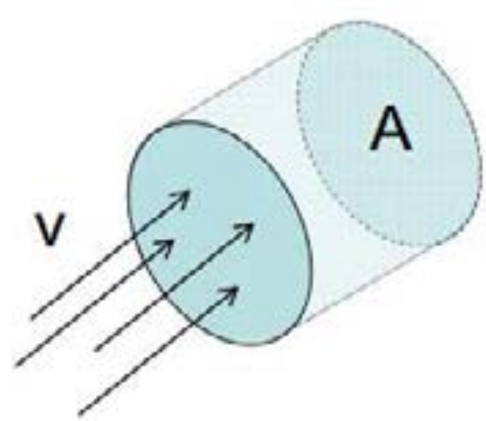


Figure 24: Mass flux through an Area Source: MIT, Wind Energy

From fluid dynamics we know that the mass rate is the product of density, area, and velocity.

$$\dot{m} = \rho A v$$

Combining the power equation with the mass flow rate given by fluid dynamics, we attain the following power equation:

$$P = \frac{1}{2} \rho A v^3$$

Where A is the cross-sectional area perpendicular to the flow of air

This equation shows that the power generated by a wind turbine is directly proportionate to the cube of velocity, air density, and the swept area.

Further analytical investigation for the helical wind turbine is the assessment of the efficiency. This can be done by obtaining the power coefficient, which measures how efficiently the wind turbine converts wind energy into electricity. The power coefficient by definition is the ratio of electricity produced by the wind turbine to the total energy available in the wind.

$$C_p = \frac{P_T}{P_W}$$

With the power coefficient, the power equation for the wind turbine changes to the following:

$$P = C_p \frac{1}{2} \rho A v^3$$

Now the power equation for the wind turbine is an actual representation of the energy it can harness for the production of electricity.

6.3.3 Hydro turbine analysis

The following subsections describe the design analysis process for the pico-hydro component.

6.3.3.1 Nomenclature

Table 3: Nomenclature for hydro turbine

Description	Symbols	Units
Absolute velocity of water jet	c_1	$m*s^{-1}$
Approximate number of buckets	z	null
Bucket depth	t	m
Bucket height	Hn	m
Bucket width	b	m
Coefficient	ku	null
Density of water	ρ	$kg*m^{-3}$
Efficiency	η	%
Gravitational constant	g	$m*s^{-2}$
Net head	Hn	m
Nozzle coefficient	kc	null
Offset of bucket	k	null
Optimal jet diameter	d	m
Optimal peripheral velocity (at the pitch circle diameter)	$u1$	$m*s^{-1}$

Outside diameter of runner	Da	m
Power output	P	kW
Rotational Speed of driven machine	n_0	min^{-1}
Transmission ratio (RPM of driven/ RPM of turbine)	i	null
Water discharge	Q	m^3*s-1
Width of bucket opening	a	m

6.3.3.2 Design Process

The Pelton turbine needs to be designed and integrated within a specific rain collection system. This design section will cover all the aspects necessary for the implementation of the turbine in this system. As such a systematic and detailed approach will be used starting with the flow rate derivation, then power estimation before concluding with the computation of the nozzle and turbine parameters. For this exercise, the various assumptions, formulas and analytical tools were derived from Micro Pelton Turbines by Markus Eisenring, MHPG Series Volume 9, published by SKAT, 1997. To ensure consistency, the unit system of use would be metric, unless otherwise specified.

Flow rate derivation

The rain water flows from the rooftop to the turbine unit through a combination of gutter and downspout system. For our purpose, the flow rate of water available within the downspout pipe needs to be ascertained. The average rain fall precipitation in Miami for an hour period equals to 114.3 mm. (Florida Building Code Plumbing). From there, the flow rate will be determined by multiplying this number with the effective area of the house. The flow rate computation is as follow: $Flow\ rate\ \left(\frac{m^3}{s}\right) = rainfall\ \left(\frac{m}{s}\right) * effective\ area\ (m^2)$

To find the effective area for the catchment bay which will be installed on the roof, the same concept outlined in the figure below will be applied. Once this is done, the flow rate through the pipe could be derived by selecting a pipe suitable for this application. At the same time, the velocity of the flowing water will be derived.

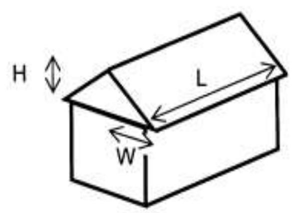


Figure 25: Conventional building effective area (More Complex Gutter Design)

Description	Symbol	Unit
Roof length	L	m
Eaves to ridge width	W	m
Eaves to ridge height	H	m

Basic Power Estimation

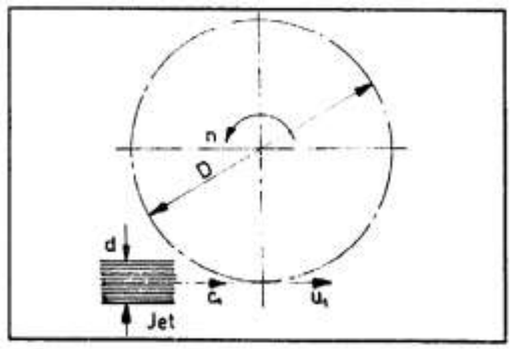
Two parameters are required to determine the output power from the Pelton turbine: head elevation and flow rate. Once the flow rate has been established from the previous exercise, the output power can be derived using the following formula:

$$P = Q * H_n * g * \eta * \rho$$

Generator sizing

From the power output equation, above, the suitable generator can be selected. Setting this value of the power as the lower limit of our generator rating avoids future issues related to overheating. For an application of this size, the team explores cheap options for the generator; one option being to reconvert a DC motor to function as a generator. (William Bolon et al.)

Nozzle parameters



Description	Symbols	Units
Absolute velocity of water jet	*c1*	m*s^-1
Optimal jet diameter	*d*	m
Optimal peripheral velocity (at the pitch circle diameter)	*u1*	m*s^-1
Pitch circle diameter	*D*	m

Figure 26: Design of the nozzle (Eisenring)

This marks the beginning of our hydro system dimensioning. The optimal diameter of the jet of water needs to be derived from the section. For that, the absolute velocity of the water jet needs to be specified using:

$$c_1 = kc\sqrt{2 * g * H_n},$$

where kc depends on the pipe's Reynolds number and the diameter ratio between the nozzle and the pipe (typically between 0.95 – 0.98).

Then, the optimal diameter can be computed from:

$$d = \sqrt{\frac{4Q}{\pi c_1}}$$

The peripheral velocity of the Pelton turbine can be derived. This corresponds to the velocity of the water after the water escapes the buckets

$$u_1 = ku\sqrt{2 * g * H_n},$$

where ku depends on the rotational speed of the turbine and the power output (typically between 0.45 and 0.49 for standard turbines).

As such, the pitch circle diameter (PCD) can be derived. This corresponds to a theoretical circle, drawn along the bucket, which is tangent to the jet of water. PCD is the diameter of the rotor.

$$D = \frac{60}{\pi n}$$

Where n depends on the expected rotational speed from the generator. For the purpose of this exercise $i = 1$, which means a 1:1 transmission ratio exists between the turbine and the generator.

Turbine parameters

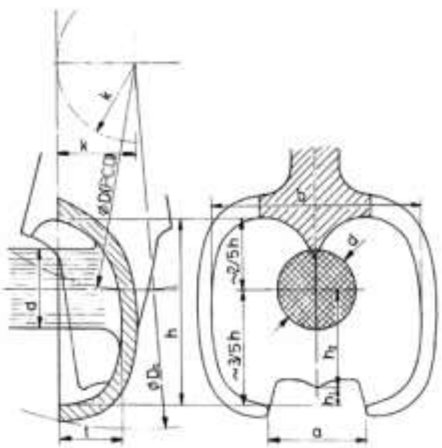


Figure 27: Design of the runners (Eisenring)

Description	**Symbol**	**Unit**
Bucket width	b	m
Bucket height	h_n	m
Bucket cavity length	h_1	m
Bucket center distance from tip	h_2	m
Bucket depth	t	m
Width of bucket opening	a	m
Outside diameter of runner	D_a	m
Optimal jet diameter	d	m
Offset of bucket	k	null
Approximate number of buckets	z	null

Once the nozzle parameters have been defined, the turbine specifications become relatively easy to derive. Below is a list of formulas needed to obtain the geometry of the turbine:

- Approximate number of buckets:$z = \frac{D\pi}{2*d}$
- Bucket Depth: $t = 0.9 * d$
- Width of Bucket opening: $a = 1.2 * d$
- Outside diameter of the runner: $D_a = D + 1.2 * h$

The parameters below depend upon the value of the jet diameter:

- Bucket Width: $b = (2.5\ to\ 3.2) * d$

- Example: if d= 17.9 mm, then $b = 2.85 * d$

- Bucket Height: $h = (2.1\ to\ 2.7) * d$
- Bucket Cavity Length: $h_1 = (2.1\ to\ 2.7) * d$
- Bucket Center distance from tip: $h_2 = (0.85\ to\ 1.5) * d$
- Offset of Bucket: $k = (0.1\ to\ 0.17) * D$

More

The final design of this system needs to include several additional parts which are not considered as of now. As the project moves forward, the team should have a better understanding of the requirements and calculations necessary to integrate those parts in the system:

- Housing: hosts the turbine runners, provides the inlet for the nozzle and outputs the collected water (after impact) towards the next component of the rain collection system.
- Shafts, support, bearings, nuts and bolts: represent the basis for the rotational motion of the turbine and the generator. They would be specified accordingly, to provide a smooth operation of the overall system.
- Voltage regulator: Rectifies the variable incoming voltage from the generator to a steady voltage which could be used for charging a battery or powering a load (device).

6.3.4 Water filtration analysis

Slow sand filtration improves the chemical, physical and bacteriologic quality of water. Another word for a slow sand filter is a bio-sand filter because it removes bacteria, viruses and parasites by adsorption mechanisms onto the sand. Biological activity develops on the top layer of the sand filter, therefore the cleansing of the sand filter involves scraping this top sand layer to remove bacterial populations.

6.3.4.1 Flow Rate

The flowrate of water through the sand filter is directly proportional to the cross sectional area of the sand and the hydraulic loading, or pressure head, above the sand. Other properties that affect flowrate include the length of the sand column, and the properties of the fluid such as density, viscosity as well as the sand's characteristics such as porosity and specific yield. These sand characteristics have a direct effect on the sand's hydraulic conductivity, or the capacity of water to pass through a cross-sectional area of the sand as a function of time.

Henry Darcy formulated a macroscopic, phenomenologic law (Darcy's Law) that mathematically describes the one-dimensional flow of fluids through porous media. It derives an expression for direct proportionality between the volumetric flow rate of water and the hydraulic gradient. The constant of proportionality is the hydraulic conductivity which is a soil property that indicates its degree of permeability and depends on the type of soil, porosity and the configuration of its voids.

$$Q = -kA\frac{dh}{dL}$$

Where:

Q: flow rate $[L^2]/[T]$

k: hydraulic conductivity [L]/[T]

A: cross sectional area perpendicular to flow $[L^2]$

(dh/dL): The hydraulic gradient

An experimental expression of the hydraulic gradient as a function of permeability through values of porosity, tortuosity, and grain size of the media was developed as the Kozeny-Carmen equation:

$$\frac{dh}{dL} = \frac{5\mu v_a}{\rho g} \frac{(1-\eta)}{\eta^3} \left(\frac{d}{6}\right)^2$$

Where:

μ: dynamic viscosity of fluid

η: porosity

d: diameter of grains constituting porous media

Flow rates through bio-sand filters should be maintained in the range of 0.1-0.4 m/hour. Bio-sand filters have been noted to operate as plug-flow reactors (Elliott, Stauber and Koksal), in other words all the water parcels moving through the sand travel at the same speed, therefore their residence time is uniform. Factors such as pretreatment and post-disinfection stage also allow for an increased operation flow rate through the bio-sand filter with no effect on bacteriological quality of treated water.

Virus removal is significantly improved utilizing finer sand and lower hydraulic loading. The best combination has been determined to be 0.17 mm sand with 10 cm head combined with a long residence time (Jenkins, Tiwari and Darby). Therefore slower flow rates are preferable and particular attention must be placed in selecting sand size and hydraulic loading. The slower flow rate provides an increase in pathogen removal capability so that the bacteria are maintained in the upper portion of the filter and pathogens do not get carried deeper into the filter.

6.4 Energy Integration Analysis

The design team is presently collaborating with IEEE to identify the electrical components needed to transform the various renewable energy forms into one main electrical supply line.

6.5 Waste Treatment Analysis

Household waste water will be separated in two forms: Water from sinks, and laundry washing will be treated by bio-filtration whereas sewage water will be directed into the anaerobic digester for volume reduction, treatment and energy production.

6.5.1 Greywater treatment: Bio-filters

6.5.1.1 Introduction of Wetlands

Wetlands are land areas that are partially or completely saturated with water most of the time. They are intermediate between aquatic and terrestrial ecosystems, and support both plant and animal communities adapted to these environments. The soil is usually a hydric soil that has been under saturated conditions long enough to develop anaerobic conditions in the upper part. The vegetation is one adapted to saturated conditions.

Wetland systems reduce or remove contaminants including organic matter, inorganic matter, trace organics and pathogens from the water. They accomplish this reduction through a combination of physical, chemical, and biological processes including sedimentation, precipitation, adsorption to soil particles, assimilation by the plant tissue, and microbial transformation (Moshiri).

Macrophytes are aquatic plants that are usually found on wetlands. They are emergent, submerged, or floating. They have several properties and characteristics that make them ideal for water treatment. Some of these characteristics are: light attenuation, wind velocity reduction, nutrient storage, excretion of photosynthetic oxygen, among others. **Table 4** summarizes the role of macrophytes in wetland water treatment according to the parts of the plant.

Table 4: Macrophyte properties (Kröpfelová)

Macrophyte property	Role in treatment process
Aerial plant tissue	Light attenuation → reduced growth of phutoplankton
	Influence of microclimate → insulation during winter
	Reduced wind velocity → reduced risk of resuspension
	Aesthetic pleasing appearance of the system
	Storage of nutrients
Plant tissue in water	Filtering effect → filter out large debris
	Reduced current velocity → increased rate of sedimentation, reduced risk of resuspension
	Provides surface area for attached biofilms
	Excretion of photosynthetic oxygen → increases aerobic degradation
	Uptake of nutrients
Roots and rhizomes in the sediment	Stabilizing the sediment surface → less erosion
	Prevent the medium from clogging in vertical flow systems
	release of oxygen increase degradation (and nitrification)
	Uptake of nutrients
	Release of antibiotics

Macrophytes are especially efficient at removing nutrients, namely nitrogen and phosphorus. Depending on the type of macrophyte, they can have nutrient uptake capabilities of up to 2500 kg/ha-yr of nitrogen, and up to 350 kg/ha-yr of phosphorus. **Table 5** summarizes the nutrient uptake capacities of commonly used macrophytes in wetlands.

Table 5: Nutrient Uptake of Different Macrophyte Plants (Kivaisi)

Nutrient Uptake of Different Macrophyte Plants		
Macrophyte	**Nutrient Uptake (kg/ha-yr)**	
	Nitrogen	**Phosphorous**
Cyperus papyrus	1100	50
Phragmites australis	2500	120
Typha latifolia	1000	180
Eichhornia crassipes	2400	350
Pistia stratiodes	900	40

Potamogeton pectinatus	500	40
Ceratophylum demersum	100	10

6.5.1.2 Constructed Wetlands

Constructed wetlands, as the name implies, are engineered systems that mimic the natural conditions of wetlands. They are created with the purpose of treating wastewater. Constructed wetlands have great advantages when treating wastewater, they have low construction cost, require very low maintenance, and have low energy requirements. They are able, through different mechanisms, to remove suspended solids, BOD, nitrogen, phosphorus, and pathogens from influent wastewater.

The macrophytes in the constructed wetlands remove pollutants by directly assimilating them into their tissue, and providing surfaces and a suitable environment for microorganisms to transform pollutants and reduce their concentration (Moshiri). The bacteria attached to the plants remove soluble organic compounds aerobically. The oxygen needed to support this process is supplied by the atmosphere, by photosynthetic oxygen production, and by oxygen leakage from macrophyte roots.

6.5.1.3 Efficiency of Constructed Wetlands

Table 6 presents a tabulation of the contaminant removal efficiencies obtained by constructed wetlands.

Table 6: Removal Efficiencies of Constructed Wetlands (Friedlich)

Contaminant Removal Efficiencies	
Total nitrogen	68% - 80%
Total phosphorus	70% - 83%
Suspended solids	90%
BOD	60% - 80%

Lead	93% - 98%
Zinc	93% - 98%
Hydrocarbons	90%

Table 7: Removal Efficiencies of Constructed Wetlands (Friedlich)

6.5.2 Blackwater treatment: Anaerobic digester

The Environmental Engineering team is currently investigating the chemical and microbiologic aspects of anaerobic digestion. The following variables influence the digestion process greatly:

- pH
- Temperature
- Acidity
- Solids content
- Nutrients
- Toxins

7. Major Components Schematic

Figure 28 presents a diagrammatical representation of the complete integration of the components we are analyzing for the implementation in a sustainable community.

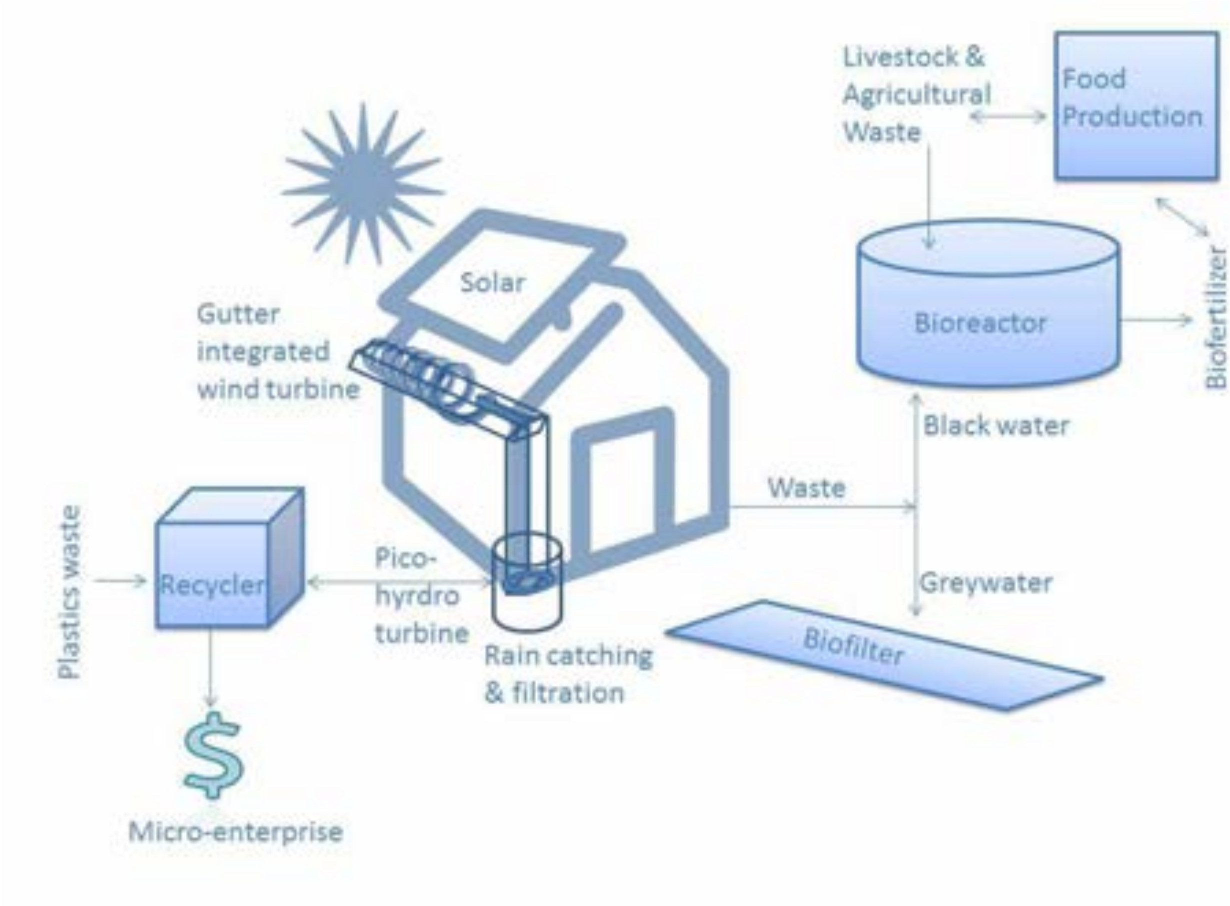


Figure 28: Integrated Components Schematic

8. Field testing

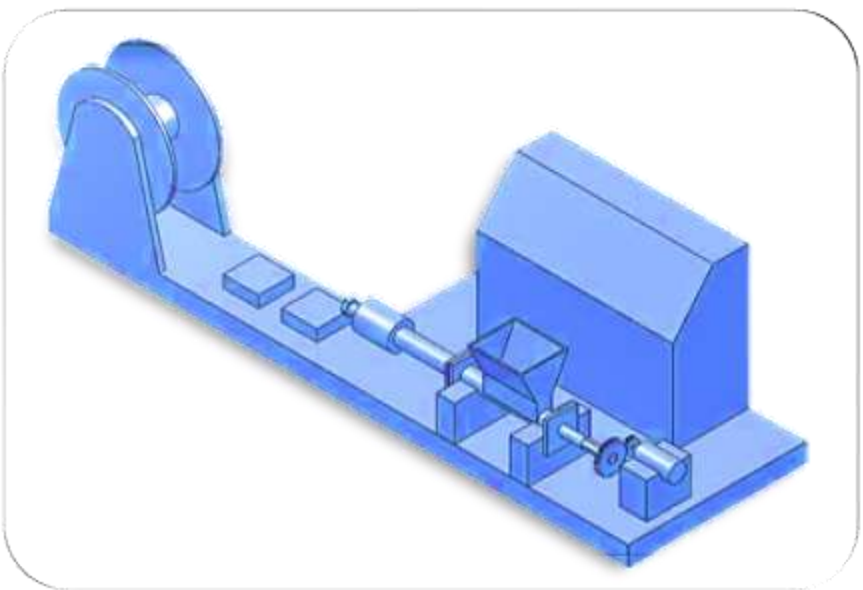
Further experimental analysis will be conducted at the FIU Engineering Center Solar House **Figure 29** beginning of December. The Global Student Engagement Student Advisory Board grant obtained for this project covers the acquisition of a gutter system to install on the Solar House eaves edge. Once installed, the next step is the addition of the bio-sand filtration system from which we will obtain valuable water quality testing samples to assess validity of our design. Moreover, once our recycling unit is assembled we will test the printed pico-hydro turbine to obtain experimental data in terms of energy production and component resistance to water flow.

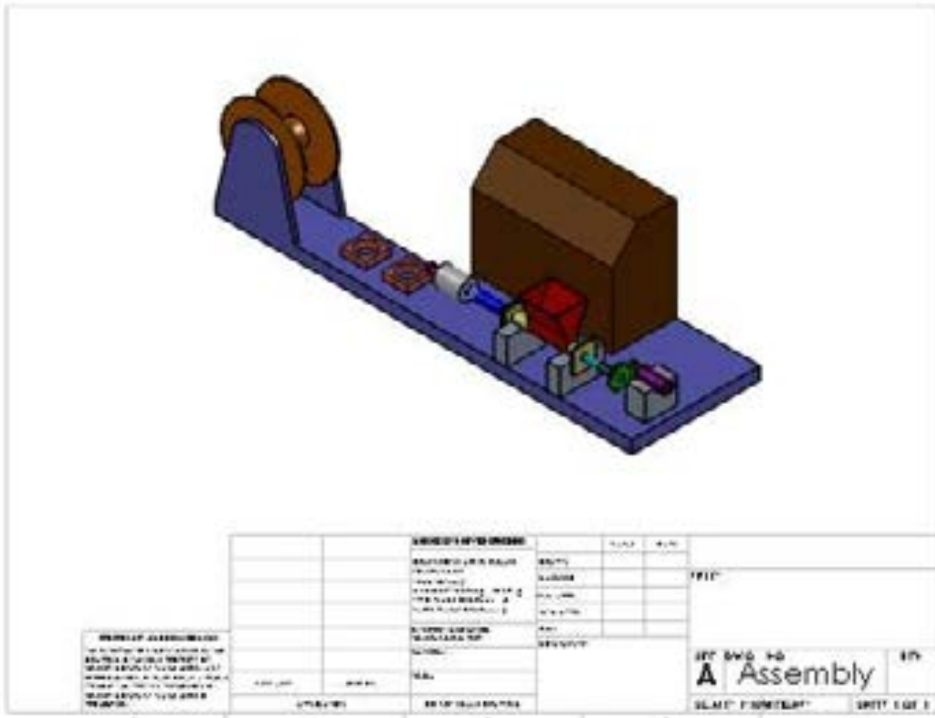
Figure 29: FIU Engineering Center Solar House

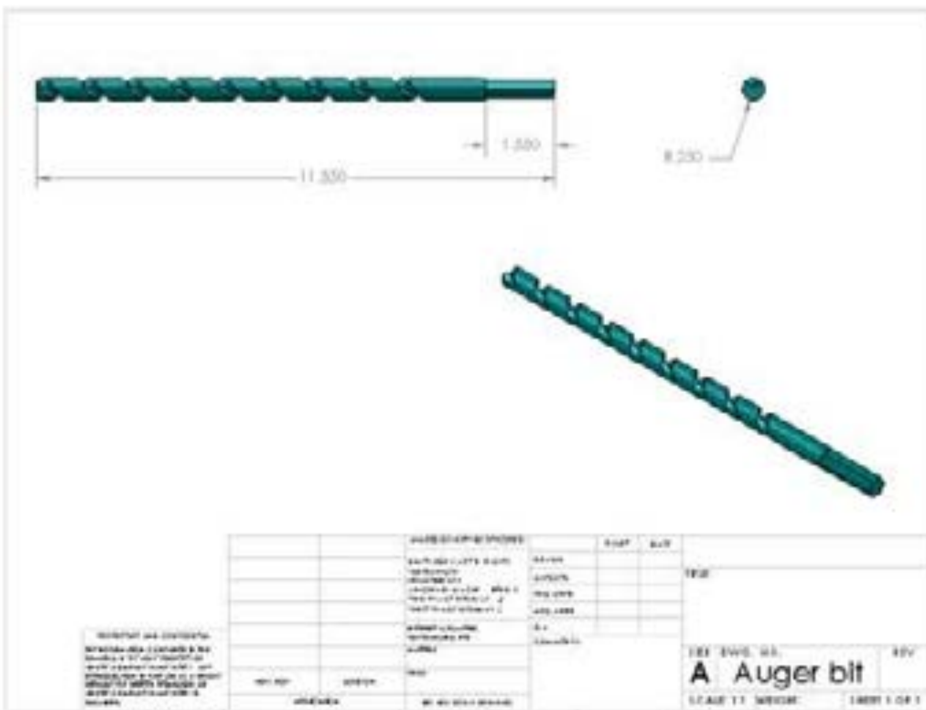
9. Laboratory testing

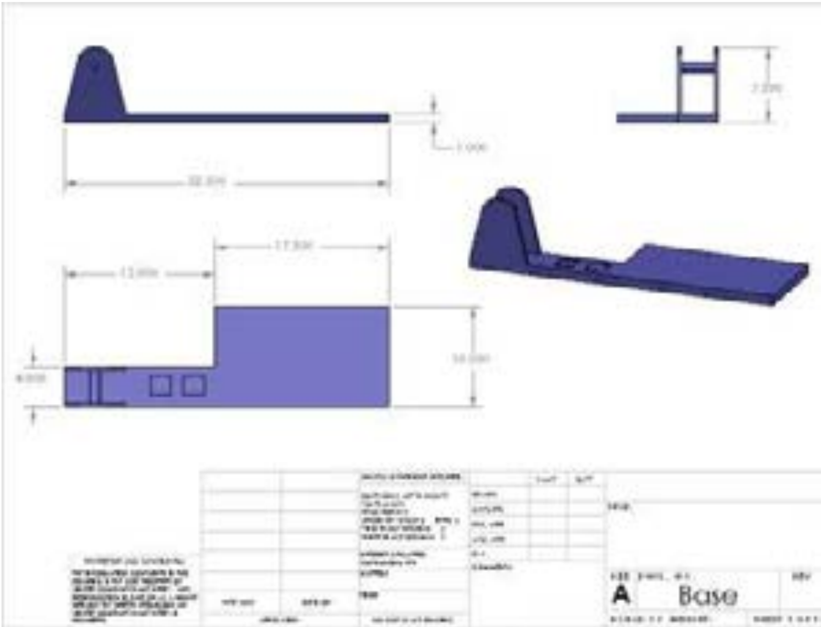
The recycled plastic test samples will be analyzed in the laboratory for material consistency.

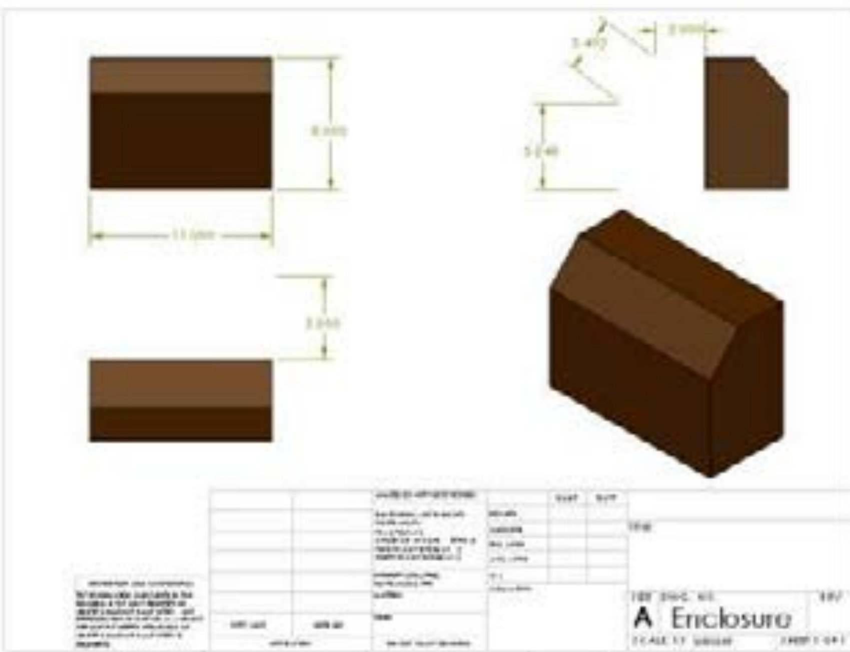
10. Structural Design

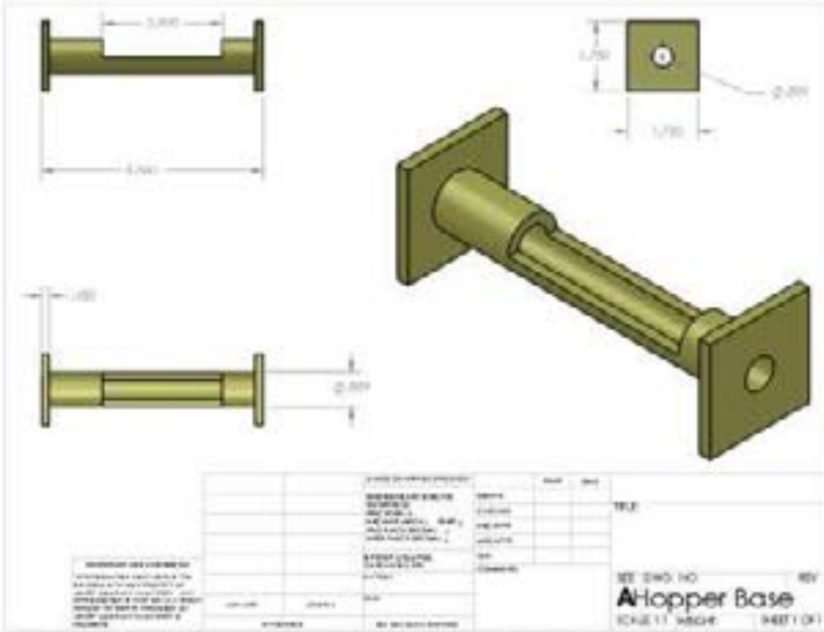


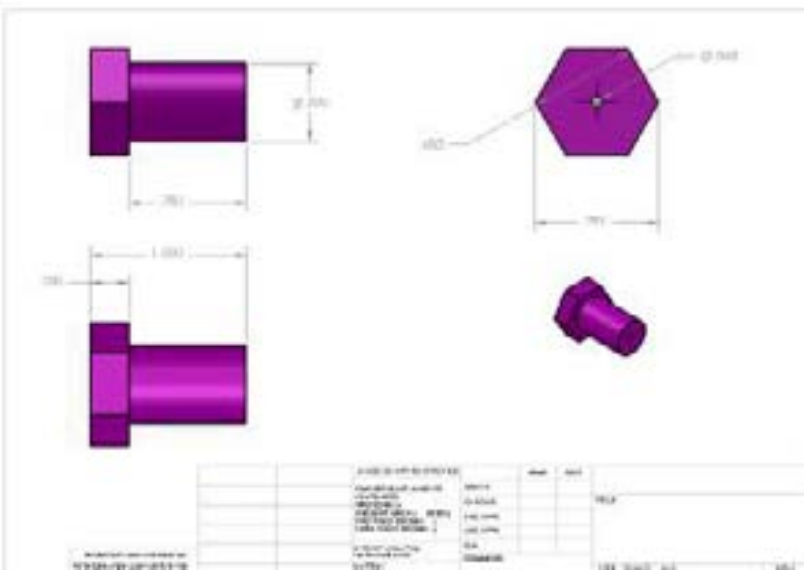

A Assembly

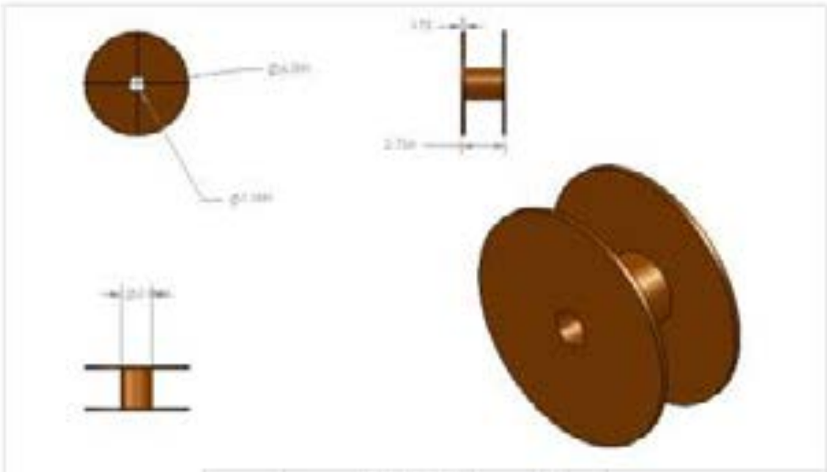

A Auger bit


A
Base


A
Enclosure


Hopper Base





11. Cost Analysis

11.1 Recycler Bill of Materials

LINE ITEM	DESCRIPTION	SIZE	QTY	COST PER UNIT	ACCUMULATED COST
1	TOOL STEEL SHREDDER	6.2X4.5"	1	$468.00	$468.00
2	1/2" BLACK IRON COUPLING	2" LONG	1	$2.44	$2.44
3	1/2" INSULATION BOARD	2"X2"	1	$12.00	$0.19
4	1/2" MDF BOARD	2'X2'	4	$1.25	$5.00
5	1/2" PIPE NIPPLE	10"	1	$6.27	$6.27
6	1/4" BOLT	1-2/4"	4	$0.21	$0.84
7	1/4" BOLT	2-1/4"	2	$0.28	$0.56
8	1/4" BOLT	1-1/4"	4	$0.15	$0.60
9	1/4" BOLT	1-1/2"	8	$0.17	$1.36
10	3/16" STL FLAT BAR	1-3/4"	9	$0.36	$3.24
11	ALUMINUM FLAT BAR	1/2X1-1/2X1-1/2	1.6	$0.43	$0.69
12	ALUMINUM FLAT BAR	1/8X1-1/4X1-1/4	1.35	$0.12	$0.16
13	ALUMINUM FLAT BAR	1/8X1/2X1"	6.6	$0.08	$0.53
14	AUGER DRILL BIT	5/8" DIA	1	$8.00	$8.00
15	BAND HEATER	1-1/2"	1	$21.46	$21.46
16	BICYCLE CHAIN	1/2"	0.5	$8.80	$4.40
17	BRONZE FLANGED BEARING	3/8'	1	$0.62	$0.62
18	BUMPER FEET	.62X.31	4	$0.25	$1.00
19	CABLE CLAMP	1/4"	1	$0.05	$0.05

20	CAP SCREW	M4-35	3	$0.25	$0.75
21	CAP SCREW	M3-14	3	$0.15	$0.45
22	COLLAR	10mm	1	$2.34	$2.34
23	FAN 24V	40X40X10mm	1	$4.28	$4.28
24	HOOKUP WIRE	VARIED	8	$0.12	$0.96
25	NUTS	1/4"	24	$0.06	$1.44
26	NUTS LOCK	M4-35	3	$0.11	$0.33
27	PHENOLIC LABEL	1/8X1+X1+	1.2	$0.12	$0.14
28	PID TEMPERATURE CONTROLLER	TA4	1	$24.99	$24.99
29	PLA FILAMENT	1.75 OR 3mm	0.5	$17.85	$8.93
30	POWER SUPPLY 24V OUT	120V IN	1	$23.99	$23.99
31	SCREWS #4	1/2" OR LESS	4	$0.02	$0.09
32	SCREWS #8	1/2" OR LESS	3	$0.05	$0.15
33	SET SCREW	M5X15	1	$0.28	$0.28
34	SOLID BRASS PLUG	1/2"	1	$2.36	$2.36
35	SOLID STATE RELAY	24V-120V	1	$4.96	$4.96
36	SWITCHES	SPST	3	$0.75	$2.25
37	THERMOCOUPLER	TYPE K	1	$1.00	$1.00
38	THRUST BEARING	7/16"	1	$2.72	$2.72
39	VOLTAGE REGULATOR	24V IN	1	$9.99	$9.99
40	WASHER	5/16"	1	$0.06	$0.06
41	WASHER	1/4"	20	$0.03	$0.64
42	WASHER	M4	6	$0.08	$0.48
43	WASHER	M3	3	$0.02	$0.06
44	WIPER MOTOR	12V	1	$16.99	$16.99
				SUBTOTAL:	$636.04
				ESTIMATED SHIPPING:	$70.01
				TOTAL COST:	$706.05

11.2 Engineering Hours

Table 8 itemizes an estimated quantification of each individual's time spent working on the project.

Table 8: Engineering hours

Hours for Fall	Projected Hours for

						Spring				
Task	**SB**	**BC**	**ME**	**PD**	**ND**	**SB**	**BC**	**ME**	**PD**	**ND**
Meeting	32	32	32	32	32	36	36	36	36	36
Research	12	6	4	16	7	3	5	5	3	3
Presentation	10	4	4	10	2	5	5	5	3	3
Design	3	5	6	3	2	2	8	8	4	2
Writing	10	8	2	17	4	10	10	10	10	10
Building	5	0	0	5	0	12	12	14	12	12
Field Testing	0	0	0	0	0	10	10	10	10	10
Troubleshooting	0	0	0	0	0	8	8	8	8	8
Total per member	72	55	48	83	47	86	94	96	86	84
Total per semester					258					446

SB: Sergio Baltodano

BC: Babacar Cisse

ME: Michael Enriquez

PD: Paola Davalos

ND: Natalia Duque

12.Conclusion

R.I.S.E. "Renewable & Integrated Systems of Energy" is the first step in assessing the efficiency of the technological components that make up an off the grid sustainable community. After the preliminary designs and energy calculations are completed, the next steps are to perform CAD models, prototypes and an economic analysis of the entire system. Upon completion of initial estimates, our goal is to continue working in a multi-disciplinary environment to create user-friendly manuals and guides on how to build, maintain and operate these systems. The last step is creating a network of collaborators from various sectors to generate awareness and cooperation for the actual implementation of these systems in participating rural communities.

13. Works Cited

Aladenola, Olanike Olowoiya. *Assessing the Potential for Rain Water Harvesting*. Research. Montreal: Springer Science, 2010. Document.

Allsop, Michelle, et al. *Plastic Debris in The World's Oceans*. Scientific report. Amsterdam: Greenpeace, 2005. Document.

Baguma, David, et al. "Rainwater and Health in Developing Countries: A Case Study on Uganda." 11 October 2012. *United Nations University.* 20 October 2013. <http://unu.edu/publications/articles/rainwater-and-health-in-developing-countries-a-case-study-on-uganda.html>.

Biller, Scott. *Integrated Dwelling Design*. 17 July 2010. Document. 23 November 2013.

Chen, Haisheng, et al. "Progress in electrical energy storage system: A critical review." *Elsevier* (2008): 219-312. Document.

Cornier-Rios, Harold. *Effect of Recycling on Material Properties of Polyethylene Terephthalate at Various Recycling Ratios and Recycling Generations*. Master's Thesis. Mayaguez: University of Puerto Rico, 2003. Document.

Derraik, Jose G.B. "The pollution of the marine environment by plastic debris: a review." *Marine Pollution Bulletin 44* (2002): 842-852. Document.

Drinkwaard, Wouter, Arjan Kirkels and Henry Romijn. "A learning-based approach to understanding success in rural electrification: Insights from Micro Hydro projects in Bolivia." 2010. document.

Eisenring, Markus. *Micro Pelton Turbines*. St Gallen: SKAT, Swiss center for Appropriate Technology, 1991.

Elliott, M.A., et al. "Reductions of E. coli, echovirus type 12 and bacteriophages in an intermittently operated household-scale slow sand filter." *Water Research Vol 42* (2008): 2662 – 2670. Document.

Florida Building Code Plumbing. *Florida Building Code Plumbing 2007*. Miami, 2008.

Friedlich, Brian. "Engineering Concepts for Bioretention Facilities: From Rain Gardens to Basins." *NJASLA 2011 Annual Meeting & Expo*. February 1, 2011.

Hallett, Michael. "Distributed Power in Afghanistan: The Padisaw micro-hydro project." 2009. document.

Hope, Kempe Ronald. "Promoting Sustainable Community Development in Developing Countries: The Role of Technology Transfer." *Community Development Journal* (1996): 193-200. Document.

Jenkins, M.W., et al. *The BioSand Filter for Improved Drinking Water Quality in High Risk Communities in the Njoro Watershed, Kenya*. Research Brief 09-06-SUMAWA. Davis: Global Livestock Collaborative Research Support Program. University of California, 2009. Document.

Khamis, Alias, et al. "Development of Mini Scale Compressed Air Energy Storage System." *IEEE First Conference on Clean Energy and Technology CET*. 2011. 151-156. Document.

Kivaisi, Amelia K. "The potential for constructed wetlands for wastewater treatment and reuse in developing countries: a review." *Ecological Engineering* (1 February 2001): 443-598.

Kröpfelová, Lenka. *Wastewater Treatment in Constructed Wetlands with Horizontal Sub-Surface Flow*. Czech Republic: Springer Science + Business Media B.V., 2008.

Lau, Arthur. "Masdar City: A model of urban environmental sustainability." *Stanford Undergraduate Research Journal* (2012): 77-82. document.

Li, Xuesong, Hao Li and Xingwu Wang. *Farmers' willingness to convert traditional houses to solar houses in rural areas: A survey of 465 households in Chongquing China*. Survey report. Chongquing, 2013. Document.

Lior, Noam. "Energy resources and use: The present situation and possible paths to the future." 2007. document.

Manwaring, Michael, Debbie Mursch and Kelly Tilford. *Challenges and Opportunities For New Pumped Storage Development*. NHA's Pumped Storage Development Council. Washington DC, 2012. Document.

McNiven, Neil. *REUK.co.uk*. 14 Juyl 2013. Document. 23 November 20133.

More Complex Gutter Design. n.d. 24 11 2013. <http://draincenter.co.uk/pdfs/flow%20calcs.pdf>.

Moshiri, Gerald A. *Constructed Wetlands for Water Quality Improvement*. Boca Raton: Lewis Publishers, 1993.

Parkam, G.L., A.I. Schaferb and B.S. Richardsa. *Potential of wind-powered renewable energy membrane systems for Ghana*. 2008. document.

Ramakumar, R. and William L. Hughes. "Renewable Energy Sources and Rural Development in Developing Countries." *IEEE Transactions on Education* (1981): 242-251. Document.

Rowse, Laurel E. "Design of Small Scale Anaerobic Digesters for Application in Rural Developing Countries." Graduate School Thesit. 2011. Document.

Sener, Rodrigo. *Obtencion de biogas mediante la fermentacion anaerobica de residuos alimenticios*. Madrid: Departamento de Calidad y Medio Ambiente, AINIA, 2005. Document.

Shah, Vishu. *Handbook of Plastic Testing and Failure Analysis*. New Jersey: John Wiley & Sons, 2007.

Shannon, Permaculture Association of Western Australia Inc. and Ron. *Conference Proceedings Chapter Eight - Technology Stream*. 01 01 1997. 24 11 2013. <http://permaculturewest.org.au/ipc6/ch08/shannon/index.html>.

United Nations. "The Future We Want: Resolution adopted by the General Assembly on 27 July 2012 ." *Rio + 20 United Nations Conference on Sustainable Development*. Rio de Janeiro, 2012. 8-53. document .

Vymazal, Jan. "Removal of nutrients in various types of constructed wetlands." *Science of The Total Environment* (15 July 2007): 48-65.

William Bolon et al. *GREEN MECHATRONICS PROJECT:*. Ottawa, 2010.

Williamson, S.J, B.H Stark and J.D. Booker. "Low Head Pico Hydro Turbine Selection using a Multi-Criteria Analysis." *World Renewable Energy Congress 2011*. Sweden: Linköping University Electronic Press, 2011. 1377-1385. Document.

World Health Organization. "Disease and injury country estimates." 2008. *Health statistics and health information systems* . Report. 25 October 2013. <http://www.who.int/healthinfo/global_burden_disease/estimates_country/en/index.html >.

Zeus Industrial Products, Inc. *Strength & Stiffness of Plastics*. Orangeburg, NC, 2010. document.

Zhang, Lianyang, et al. "Feasibility Study of Compressed Air Energy Storage Using Steel Pipe Piles." *GeoCongress 2012*. Oakland: American Society of Civil Engineer, 2012. 4272-4279. Document.

Zhe li, Fergal Boyle, Anthony Reynolds. "Rainwater Harvesting and Greywater treatment systems for domestic applications in Ireland." *Elsevier* (2010): 8. Document.