DEVELOPMENT OF RURAL SUSTAINABILITY FINAL REPORT

John DuMontelle • Jessie McKay • Shannon Monahan • Nick Reimers • Doug Richards

Northern Arizona University

Development for Rural Sustainability Capstone
Tanzania: Waste and Power
Doug Richards, Jessie McKay, John DuMontelle, Nicholas Reimers, Shannon Monahan
Northern Arizona University
2112 S Huffer Ln
Building #69
Flagstaff AZ, 86001

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Bryan Cooperrider
D4P Capstone Professor
Northern Arizona University
2112 S Huffer Ln
Building #69
Flagstaff AZ, 86001

Professor Bryan Cooperrider,

Provided in the following pages is a proposal for the Development for Rural Sustainability (DRS) team's purpose and scope for the spring 2015 semester. It is the goal of DRS to provide a preliminary analysis of the effectiveness of bio-digesters and bio-batteries in rural settings, primarily in waste treatment and secondarily in usable power output. Additionally a compilation of the expanse of research that team DRS completed over the fall 2014 semester has also been provided. If there are any further questions regarding the information below, please feel free to contact any member of DRS via e-mail or phone.

Sincerely,

Development for Rural Sustainability Team

Jessie McKay
Shannon Monahan
Doug Richards
Nicholas Reimers
John DuMontelle

Abstract

Development for Rural Sustainability tested and prototyped two designs that help mitigate animal waste in a rural village. This document contains information about the location of the village and the people that live there. The team created testing procedures to build a bio-battery and a bio-digester. The battery produces electrical potential and the digester produces biogas (methane). Using the electrical potential produced by the batteries, a LED light bulb was powered for a short period of time. The digester produced a small amount of gas but the results of the prototypes will be further discussed in this document. The team also performed assessments to determine the impacts these designs would have on the village.

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1.0 Introduction

Both human and animal waste disposal is largely uncontrolled in rural areas throughout the world. This causes an increase in contamination to the community members resulting in widespread sickness and fatality. Developing a system to dispose of animal waste and converting it into usable material is the primary goal of the Development for Rural Sustainability (DRS) capstone group. Team DRS has designed two possible solutions to mitigate animal waste produce usable energy. The byproduct of these methods is a sterile fertilizer and either methane gas or a voltage gradient. In order to make these designs practical and accessible to rural communities, easy to build instructions and readily available materials are major design goals. These designs must also provide the ability to educate people in developing communities on topics such as of natural processes and resourcefulness.

During the spring 2015 semester team DRS compared the rural practicality of bio-batteries and bio-reactors. This was done in three stages consisting of an economic (cost/benefit) analysis, social assessment, and environmental assessment. Prototypes of these design concepts were built and tested to determine the feasibility of construction. Multiple bio-batteries were built and tested using different solutions and temperatures. A full scale bio-reactor was built as well. All of this information was recorded and organized into a catalog. The catalog is a reference that future groups can look back on and assess what was accomplished and how to improve the current designs, while also adding their own designs and alternatives. The framework of the catalog is set so that an individual without technical knowledge can understand and reproduce the same product.

Dr. Dianne McDonnell agreed to be a faculty advisor for the Development for Rural Sustainability team. Dr. Dianne McDonnell is an engineer with over 30 years of experience implementing projects in both developing countries and for low-income communities in the United States. She has supported and worked with a variety of stakeholders ranging from communities and nonprofits to government organizations. Her technical proficiencies range from ecosystem modeling and management to the design and construction of water and sanitation systems, catchment protection, drainage systems, and small scale energy systems. While Dr. McDonnell has a broad design and construction background, her focus is in on building capacity and helping stakeholders solve complex problems based on data, socio-economic issues, and the physical environment.

The project is supported by Gerjen Slim, CENE lab manager, village leaders, and an NAU student who is also a member of the village. Mr. Slim. is a graduate student that has assisted DRS in testing and building of the waste management designs. The village elders have assisted DRS with questions about the village of Lesoit and about the Maasai culture.

1.1 Location and Client

The Maasai people are a predominantly patriarchal society where older men tend to decide major matters in the village. The traditional Maasai village is centered around a collection of cattle. The cattle are their main source of food and capital. They have mostly cows but also tend to sheep and goats. The livestock is used mostly as a food source but is also used during ceremony. A man's wealth and social status are shown by the amount of cattle he possesses and the number of children he has.

Traditionally, they are also a nomadic group but have recently become more confined as farm lands surround them on all sides. This has caused the population of livestock to decrease and the dependence on crops to increase. Outside influences have affected traditional culture in many villages. The introduction of Christianity made education more available. Many elders have been able to retain their traditions even with the changing culture of the younger generations [1].

Lesoit is a village of about 2,500 people in Tanzania. They have 12,000 to 15,000 head of cattle. This particular village is more progressive compared to other villages. They are in a forested area but have some encroachment of farmland in their location. From interactions from outside influences, the many of the residences of the village have cell phones. The village does not have electricity but one man in the village has solar panels to charge phones and other devices. The main mode of transportation is on motorbike and the use of donkeys for the transport of other goods.

The culture in the village is active with ceremony and dances once or twice a week. The men still tend to be the major providers in the village with women tending to say and tend to the household tasks. Being a more progressive village there is a greater presence of outside interaction. Relationships are being developed and are trying to help solve some of the problems that are occurring in the village [2].

2.0 Specifications and Requirements

Team DRS built and tested bio-battery designs and a biogas digester in spring 2015. These designs represent options for waste management and energy production at the village level. The long-term goals are to apply these technologies to rural communities in developing countries. The bio-battery would be used to established small enterprises that would charge cell phones in areas without electricity. Gas from the biogas digester would be used for cooking or powering generators.

The bio-battery and digester both use animal waste to fuel the reactions that take place within either system. Each design converts this waste into a sterile fertilizer as a by-product with the resulting in the production of usable energy. The biogas-digester produces methane gas, while the bio-battery creates electrical energy. Both designs require water to mix with the waste in order to produce a waste slurry. Therefore, DRS recommends rainwater catchment system is incorporated within each design. During the rainy season water can be collected and stored to create the waste slurry. The rainwater catchment design can be found in the appendix.

The designs are evaluated based on their financial viability and their potential economic, social, and environmental impacts. The goal was to provide a cost effective sustainable waste management system that could produce usable energy. The final goal of this project is to create a catalog that can act as a manual and educational tool in the village as well as at NAU for future students to continue the work. Table 1 below lists the specifications for the designs and the corresponding measure for testing these specifications.

Table 1: DRS Design Specifications and Evaluation

Specification	Method of Evaluation
Sustainable	Site assessment and environmental assessment
Positive Impact on Lesoit	Frank, Juma, and Evalyne (members of the village)
Mitigate Animal Waste	Pounds of manure used and compost produced (lbs)
Power Cell Phones	Test the power output (mV)
Life Span	Material strength and durability
Educational Tool	Frank, Juma, and Evalyne and the site assessment
Affordable	Cost-benefit analysis

Along with specifications, the team created quantitative requirements and goals for the project. The main goal was to create sustainable alternatives for waste management and energy production. Building prototypes of the bio-battery and bio-digester solutions that were achieved. It was also intended that one of the requirements for the bio-battery was to be able to charge a cell phone. Aside from the prototyping and waste management goals, the team established that a catalog would be needed in order for future groups to continue the research. The final goal of this project is to create a catalog that can act as a manual and educational tool in the village as well as at NAU for future students to continue the work.

3.0 Assessments

In order to determine the benefit of implementing these designs in rural communities, the team performed three assessments. This section of the report will discuss the results and research surrounding a social, environmental, and cost assessment for the bio-battery and bio-digester. The team used assumptions and research to support these assessments.

3.1 Social Assessment

A preliminary social assessment was done to determine the viability of the both the bio-battery and the bio-digester. A decision matrix was used to consider how the designs would affect the village the results were separated into the categories pertaining to political, educational and other social impact of the prototypes. The village elders were then consulted to further understand the effect of the designs [1].

3.1.1 Educational Impact

These projects in conjunction with the school's cattle population can show other resources that a cow can provide. Both the bio-battery and bio-digester can be implemented at a school as a kinesthetic learning process to teach about energy and electricity. The bio-digester process can be used as an educational tool to teach children about the chemical processes that occurs as the manure breaks down. Seeing the expansion of the gas can also provide a visual way to educate the village as well as burning and using the gas. The school can also have a small garden to teach farming techniques and the benefits of using compost. The bio-battery can also teach about chemical processes but would focus electricity [1].

3.1.2 Cultural Impact

These designs have the potential to change the community of Lesoit. With more access to electricity with a bio-battery the village can become less dependent on the use of a single solar panel and contact between members can become easier. Both designs have the opportunity to create jobs by teaching how to create and maintain the designs over their lifespan. The designs also can help build relations with outside organizations and lead to further development of education and other projects that the village believes would be beneficial to the community [2]. The bio-battery will have a slightly larger impact on the social impact of the village because they will be able to eventually charge cell phones which will then increase their connection to the social media and each other.

3.1.3 Political Impact

The bio-battery and bio-digester may be used as political tools within the village and to create connections with communities surrounding the area. The degree for which each design will affect the political atmosphere is not completely known. The Bio-battery is a smaller unit made for individual application, and is easier to build with local materials. The plans and training for building a battery is relatively simple and easy to use as a bartering tool. The bio-digester is on a larger scale and requires more material and technical training. Since the main income of the villages surrounding Lesoit is farming these villages would need to come to the village of Lesoit to gather cow manure to operate the reactor.

A majority of the population owns or have access to a cell phone making it easier to keep in contact with each other. For a person of responsibility in the village this can be a crucial tool to solve everyday problems that rise up. On a smaller scale having a working phone is extremely useful ability if members of the village need to organize a meeting or event with a large population of the village within a short amount of time. If the bio-battery were able to maintain the production of energy needed to run a battery for a year, then the amount of people who have a cell phone would most likely increase. With a rise in people on their phones they are better kept up-to-date on events in the area and what transpires. Organizations and individuals trying to get into contact with the village with plans of providing assistance could better understand the realistic constraints of the area and the need of the villagers if able to stay in constant contact [2].

The bio-digesters themselves do not serve much political use to the village. The plans and training could be used as a way to improve relations with surrounding people in the area by providing the knowledge to implement a new technology to remove waste and provide a gas fuel. If a large percent of people in the area adopt this idea then the cow manure of the village could be used as a valuable resource to sell as well, allowing for the village to grow as a whole. With more resources and income the village will undergo change in the daily structure of life.

3.2 Environmental Assessment

The purpose of this assessment is to compare the impacts that the bio-battery and bio-digester will have on the environment in Lesoit, Tanzania. The following categories will be considered during this assessment: health, soil, water, air, and waste. The team made assumptions based on research and completion of both of the prototypes. The village has about 12,000 cows and therefore large amounts of unused manure. Cow manure can increase the amount of bacteria, methane and ammonia in the environment which can affect the water, air, soil, and health of the surroundings [1]. Using the bio-battery and bio-digester to decompose the cow manure could have a positive impact on the village. The methane can be collected and used as energy from the bio-digester while the ammonia and pathogens are decomposed through a microbial process in each design. Table 2 below is a design tree that compares the proposed designs to the current situation in Lesoit. The designs were rated on a scale of negative three (-3) to positive three (+3) and a score of zero indicates that there will be no impact on the current situation. This design tree is used to help the overall impacts that the bio-battery and bio-digester will have on the environment.

Table 2: Environmental Assessment Design Tree

Environmental Assessment		***Compared to Control***		***Score***		
		Bio-Battery	**Bio-Digester**	**BB Weighted**	**BD Weighted**	**Importance**
Health						
	Cow Health	0	0	0	0	high(x3)
	Human Health	0	0	0	0	
	Plant Health	2	3	6	9	
Soil						
	Soil	1	2	2	4	med(x2)
Water						
	Surface Water	1	2	3	6	high(x3)
	Ground Water	0	0	0	0	
Air						
	Air Quality	0	-1	0	-1	low(x1)
Waste						
	Solid Waste	-1	0	-2	0	med(x2)
	Cow Waste By-Product	1	3	2	6	
	Human Waste	0	0	0	0	
	Industrial (Toxic) Waste	-1	-1	-2	-2	
	Compostable (Bio-Degradable) Waste	1	2	2	4	
	TOTAL SCORE	4	9	11	26	

Based on the analysis, the bio-digester will have a larger positive impact on the environment than the bio-battery would (+24 versus +9). This is expected since the sizing and scale of each system is different. Even though some categories scored negative values, either system will benefit the environment by mitigating cow manure around the village.

It is important to consider the biological components of the environment. The main factors under consideration when analyzing the health ramifications of the design implementations are the health of the cows, humans and plant life. Because of the addition of ammonia, phosphorous, bacteria, methane and nitrogen to the environment, the health of the local ecosystem could be at risk. The anaerobic digestion of the cow manure primarily produces methane, carbon dioxide and a sterile biomass.

The bio-battery design uses manure to produce methane and energy through electrical potential. Ammonia naturally occurs in the environment and usually enters the environment through decaying manure. The Center for Disease Control says that humans can smell ammonia at a concentration of 50 ppm, which is much lower than the concentration it would take to harm cattle or humans via inhalation [3]. These designs decrease amount of methane and anaerobic facultative bacteria entering the environment. Because there is already great amounts of methane in the atmosphere, the only real risks for cows becoming ill, are if they eat the grass within 10 yards of the digester [3]. Bio-magnification will occur if cattle consume the grasses that are contaminated near the digester. This, in turn, could pose a threat to humans, who consume the beef. To minimize this risk, I suggest fencing off the digesters, so that cattle and children do not come in contact with the high levels of bacteria and methane.

Humans have very small health risk factors for the implementation of these designs. The only time a risk is posed to humans is the collection of methane or if a malfunction or leak occurs with the bio-battery. A study from Carnegie Tech had this to say about gaseous methane exposure: “Methane gas basically reduces the amount of oxygen that is present in the environment. Exposure to methane gas causes depression, agitation and eventual loss of consciousness in both humans and animals. Long term exposure causes convulsions and death. If the oxygen levels fall below twelve to sixteen percent, pulse and breathing increase, while muscle control decreases. As oxygen levels continue to deteriorate exposed individuals experience changes in behavior followed by fatigue, nausea, and shortness of breath. If the individual is not moved away or given oxygen immediately, death could occur” [3]. The bio-digester must be constructed in a well-ventilated or open-air area, and that the flow of methane must be well controlled. The bio-batteries must be well sealed and not allowed to be handled by children or uninformed individuals. The bacteria produced include lactobacillus, clostridium, bacillus and E. Coli. These bacteria can be found in human digestive tract and pose little harm to humans, especially in small concentrations. With proper use and attention to safety, the implementation of these designs will not only produce energy but make the overall health of Lesoit better [3].

Plant life is the cornerstone of economic and health success for the Maasai. Plants, especially grasses, have a very healthy relationship with cows. The plants use the manure as fertilizer, which enriches the soil and feeds the plants nitrogen to grow. However, large amounts of cow manure can be harmful to the soil and plant life. With both the bio-batteries and bio-digester controlling the amount of cow manure in Lesoit, the plant life will benefit. The used manure from the bio-digester and bio-batteries can be used as fertilizer to provide nitrogen and micro-organisms to the grasses in the area. In turn, this relationship will help the cows through a more abundant food source and therefore make the Maasai a richer sub nation.

Phosphorus levels in the soil can become too high due to excess amounts of raw cow manure. These high levels of phosphorus can cause an increase in algae growth and eventually lead to anaerobic water sources. An excess of ammonia in soil can also cause the pH to become more acidic than normal. This can inhibit the growth of many plants. Ammonia (NH_3) is broken down by bacteria into hydrogen and nitrogen, thus creating H^+ ions and an acidic environment [4]. The fertilizer bio-digester by-product, however, is much more beneficial for the environment. Plant life needs these macronutrients from the soil to grow. For humans and mammals water is especially vital, because the human body is made up of ninety percent water. In Lesoit, two major seasons exist: the monsoon season and the dry season. During the monsoon season the country receives eight hundred millimeters of water in five months, which comes in downpours. Once the dry season hits the area dries up and finding free flowing water can be difficult. Therefore water must be saved and stored for use in this season. This happens naturally within shallow and deep aquifers in the ground. The quality of this water can be contaminated by natural sources such as cow manure, and be unfit for human consumption.

Cows in Lesoit outnumber people by a five to one ratio. With over twelve thousand cows contained within a few square kilometers, cow manure is very abundant. On average, a cow produces about 65 kg of dung per day, with about 70% of that being water. Certain bacteria and pathogens can become trapped in the water as it flows into collection basins or aquifers. This is especially true for shallow aquifers and unlined boreholes where water is collected by the women for domestic uses. These pathogens and fecal bacteria then are transmitted into humans. There are no standards for water sanitation or treatment in Lesoit, and therefore, the population can then easily be affected and contract a variety of illnesses that can cause: minor discomfort, intestinal issues, fever, or death.

The Maasai rely on groundwater sources such as springs. The water is stored usually in shallow aquifers that can be found as shallow as a few meters below the surface or as deep as 300m. Depending on the size of these aquifers, all the water can be depleted before the rains return and replenish the aquifers. The bio-battery design uses small amounts of water, roughly less than half a gallon of water per unit replenished over every few weeks. Even with every resident creating a bio-battery there is a low chance of causing harm to the shallow aquifers. The bio-digester uses an extensive amount of water for both startup and continuous production [4]. Since the slurry mixture added into the bio-digester for startup is a one to one ratio a couple hundred gallons are needed. After startup, ten to twenty gallons are needed per day for a small unit to stay operational. This adds up especially when the dry season lasts for a majority of the year. However, the implementation of the rainwater catchment system can help supplement this water demand.

The air pollutants from manure can cause many health issues for both the people and the cattle. There is an increased risk of respiratory illness and diseases, asthma, and lung inflammation. Without the use of this manure, many of these health problems will continue. Toxic gases such as methane and sulfur dioxide are released from the undigested manure. This means that over time there will be an increase in greenhouse emissions from large quantities of undigested cow manure. These emissions of greenhouse gasses affects the health of humans and cattle [5].

Environmental wastes are substances and objects which are regarded as unwanted or unusable by the local community. Waste can come from the man-powered manufacturing of single-serve food containers and industrial chemical waste to left-over food and bodily discharge of unwanted nutrients and protein. Five categories of waste have been identified including: solid waste, cow waste, human waste, compostable waste, and toxic waste.

Plastic water bottles, discarded building supplies, and other solid material objects are examples of solid waste. Often times these materials are either recycled or sent to a landfill. In Lesoit, DRS assumes that these items end up in open pit landfills or on the landscape. In considering the possibility of the disposal of the bio-digester, it would have a larger impact on the solid waste within the village if it were to be discarded by the village. Because of this it received a -2 and the bio-battery received -1. Though not currently being used in either the bio-digester or the bio-battery, DRS has discussed the use of human waste. The hope is to have the future capstone groups analyze this problem. Mitigating the impacts of toxic human waste on the water quality as well as the soil quality within a community can have a large positive health effect.

Banana peels, apple rinds, and other food wastes are categorized under biodegradable compostable waste. Though not currently assessed as effecting either the bio-battery or the bio-digester, there is potential in both of these technologies for composting. More research needs to be done in this area to further analyze the impacts of biotechnology on compostable waste.

Toxic waste is considered to be chemicals that are harmful to the environment [5]. Chemicals used in the manufacture of the biotechnology, such as the carbon graphite paint, can have harmful effects on the environment. Because of these effects both the bio-battery and the bio-digester were given a -1 rating for the introduction of harmful chemicals through manufacturing. In order to mitigate this in the future research is being conducted using other substances than carbon graphite paint, etc.

According to the best assumption of team DRS, both bio-technologies will have a positive impact on the environment of Lesoit. Analysis is based on the prototypes currently in operation at Northern Arizona University. After more research and development, in the village of Lesoit, as well as on the prototypes, a more in depth and accurate analysis of the impacts of these technologies can be performed.

4.0 Bio-Digester

Bio-digesters have been in use for over 40 years as a way for rural homes/communities to dispose of waste while simultaneously creating energy. The bio-digester built was made with simple materials that could be found throughout the world. The chosen design is a continuous reactor which differs compared to most rural community units which are batch systems. A batch system means a certain amount of material is added to a bio-reactor and the reactor is sealed until it no longer creates any methane gas. A continuous system allows an individual to add and remove material on a weekly or daily basis, producing usable gas without interruption. Both types of system take up to a month to produce a usable quantity of biogas. The basic design is a sealed vessel that does not allow oxygen to enter or exit. This is filled with a ratio of water mixed with cow manure and sealed shut. The microbes and bacteria in the slurry break down the mix and produce methane gas in three stages. "In the first stage, hydrolysis, insoluble organic material and compounds like lipids, fats, proteins, and polysaccharides are broken down into soluble monomers, such as amino acids and monosaccharides, which can be used as a source of energy. The second step, which is called acid formation, involves the conversion of soluble monomers into volatile fatty acids. In this stage, another set of microorganisms ferment the breakdown products into hydrogen, acetic acid and carbon dioxide. The third stage, methane formation, entails the conversion of these products into biogas and a residual organic sludge. The mixture of methane and carbon dioxide that compromises biogas is produced by species of methanogenic bacteria that use acetate…" [4]. In areas with a large amount of cattle, it is hard to overlook the amount of animal waste that accumulates as time goes on. The average cow produces roughly 120 lbs of manure a day. This waste could offer individuals the ability to improve their quality of life with a material that is abundant to them.

4.1 Materials and Procedure

The bio-reactor consists of three component: reactor, stand, and swing arm. The reactor vessel used was constructed using three 55 gallon stainless steel drums that had the bottoms cut out. These were welded together and the inner seams were sealed with silicone/caulk. Both the top and bottom were welded with the lid side facing outward. This allows for the lids to be removed for easy access and for maintenance. Both top and bottom lids have a three inch screw cap; this allows for removal of solid fertilizer from bottom and the ability to add slurry into the top. Set on the opposite side of the top lid from the screw top is a globe valve. The globe valve is used to collect the methane gas once production starts. The stand has posts that allow the digester angle to be adjusted. This alters the surface area available on the inside of the digester, which in turn affects how the microbes react [6].

Both the stand and swing arm are made from 4" x 4" post. The stand is less than a foot high on one side and stands up to four feet on the opposite side. The taller side has holes drilled between the two posts which is where a 3' stake is fed through. The swing arm is hinged to the lower side, while the higher side is where the majority of the weight is supported by the stake. The swing arm is 8 feet long and supports the reactor along the outside edges. Procedures for constructing a bio-reactor and materials along with visual instruction are located in the appendix.

Once the bio-reactor is complete the bottom is sealed and the cap tightened as much as possible. The angle of the reactor is set using the stake. A bucket is then used to add the 1:1 ratio of cow manure and water. The top lid is closed and each day one five gallon bucket of slurry is added. Once every week 3-5 bucket of decomposed manure is taken from the bottom. After a month continuous gas accumulation should occur. Once gas is produced it should be collected from the reactor every 2-3 days.

4.2 Testing

There are six tests that should be conducted to determine the effectiveness of the bio-digester, as well as the bio-battery. These tests are conducted on the manure slurry that is added to both designs. Testing of the slurry helps to determine the potential amount of biogas that can be expected, expected electrical potential available, how fast the microbes digest the waste, amount of solids within the waste, pH of the slurry, and potential toxic inhibitors to the microbes. Testing should occur on at least a weekly basis.

1. BMP (biochemical methane potential)
    - Used to determine the amount of organics that can anaerobic digested and turned into biogas.
    - Open Environmental Engineering Journal, 2012,5,1-8 [7]
2. ATA (anaerobic toxicity assay)
    - "Predicts likely effect of potential toxicant on biogas and CH_4 production"
    - ISO 13641-2:2003
3. Total and Volatile Solids
    - Testing for Total and Volatile Solids gives the user the quantity of solids in the slurry.
    - HACH Method 8276
4. Alkalinity
    - The pH of the slurry is a key parameter that influences the ability of the microbes to create the biogas. If the pH falls outside of the ideal range then many of the organisms that break down the waste will perish and biogas production will become stagnant.
    - HACH Method 8221
5. COD (Chemical Oxygen Demand)
    - The COD test is used to determine the amount of organic compounds within the slurry.
    - HACH Method 8000
6. Temperature

- For ideal gas production the digester needs to remain between 84°F and 120°F
- A thermometer will be used to check the temperature of the waste on a daily basis.

4.3 Results

The bio-reactor did not generate any usable amount of gas. The reactor was set up outside without any insulation which greatly affected the performance. Due to the weather in Flagstaff, AZ there was too much of a temperature flux to produce gas. The microbes that turn the waste into methane need to operate above a temperature of 61°F, ideally maintaining a temperature between 84°F to 95°F [7]. The bio-reactor's temperature ranged from as high as 91°F to as low as 37°F. To raise the temperature and have less of a temperature flux the system should be insulated by either burying it or by covering it in an insulating material such as straw. If the reactor had produced gas, it would create roughly 75 cubic feet of gas every day. There is enough power in one day of gas collection to run a 100W light bulb for 6 hours. An individual would could also use this gas for cooking purposes, capable of running a burner for 4-5 hours a day.

The reactor did produce over 900 lb of sterile fertilizer as waste. This waste is full of nutrients and has been broken down by the microbes within the waste into simple compounds. The fertilizer is excellent for growing food, and the bio-reactor produce a steady supply. One reactor could produce a minimum of 60 lbs a week of fertilizer [6]. This fertilizer can also be sold for a profit in agricultural areas. Lab and field testing was limited. Many of the devices used for the testing were defective and needed replacing. There was not enough funds in the budget to replace the broken equipment. Due to this only one reading was taken. The results taken was omitted from this report because no comparison could be made to previous conditions.

5.0 Bio-Battery

A microbial fuel cell or bio-battery, is an energy storage device which utilizes microorganisms or enzymes to convert chemical energy into electrical energy. Like all batteries, a bio-battery consists of an anode, a cathode, electrolytes, and a connection. The unique feature of bio-batteries however, is of course that they exploit the features of electrically active bacteria or enzymes instead of metallic solutions. Batteries, particularly bio-batteries have a myriad of applications mainly involving energy storage. Because the bio-battery can be made out of accessible materials it is a plausible solution to energy needs in rural communities. Small electronics can be powered using cheap sustainable batteries. Other uses could be used as electricity for cooking and lighting. Development for Rural Sustainability created and tested two sets of prototypes. The purpose of the first prototype was to determine a baseline for which the team could improve on. The second set of prototypes focused on controlling and testing different variables in order to create a higher electric potential [8].

5.1 Materials and Procedure

The bio-battery was created using a terracotta pot that was coated with three layers of a conductive graphite paint [9]. The hole in the bottom of the pot was sealed with fiberglass to ensure that the water and manure mixture did not leak out. Once the pot was dry and a copper wire was taped to the graphite paint, a clear polyurethane coating was applied to the outside of the pot. To make the anode, a screw wrapped with aluminum wire was connected to a piece of carbon felt. Then the anode was coated with epoxy to prevent any corrosion from the manure mixture. The anode was placed in the pot and the free end of the aluminum wire was left sticking out of the pot. A mixture of 500 grams of manure and 500 mL of DI (deionized) water were added to the pot and covered with clear cellophane.

For the second round of prototyping, four terracotta pot batteries were created. The results from the first prototype were vague so determining which parameters to change or adjust was difficult. The polyurethane coating and electrolyte solution changed. Below is a grid showing the two different parameters being tested on the four different pots.

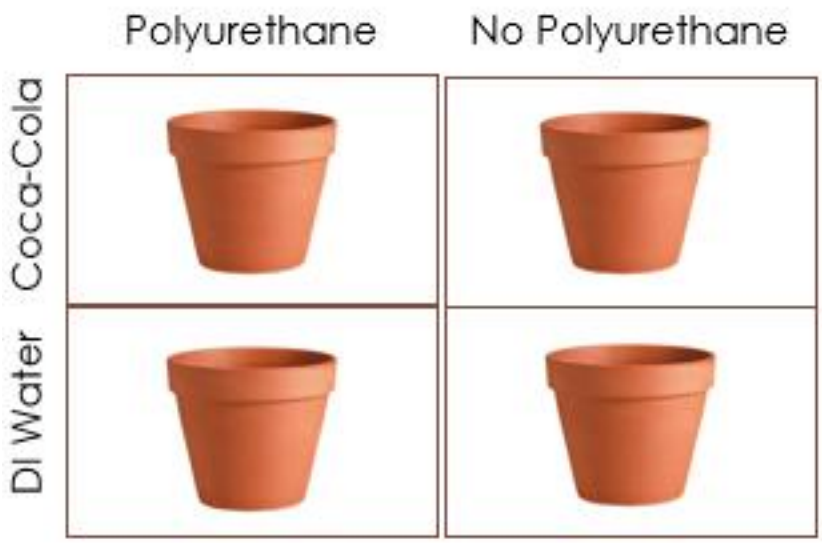

Figure 1: Prototype Design of Experimentation

Future testing will be conducted to determine what local materials work best to power a cell phone. The materials list is likely to change with continued testing. The supplemental DRS Catalog has a more in depth description of the set-up procedures along with step-by-step pictures. A list of materials and costs will be discussed later in the budget section of this report.

5.2 Testing

The testing for the bio-battery was conducted in a laboratory environment that allowed different variables to be controlled. The first prototype was tested at room temperature and sealed with cellophane. The air-tight seal did not perform as expected. The temperature and voltage were measured almost daily and recorded. After the potential of the pot dropped significantly from the initial voltage, the pH was measured and determined to be too high for the microbes. The second round of prototyping was designed to test two different variables, the electrolyte solution and the air-cathode. Four pots with alternating variables, polyurethane coating and coke/DI water, were used to identify fallacies in the first prototype. The pots were placed in a cooler with a heat lamp on them in order to maintain a temperature of 28°C. Pots were filled with additional coke or DI Water to account for evaporation as needed. Recordings of how much water, coke, and manure for each prototype can be found in the appendix.

5.3 Results

Data for potential, temperature, and pH were recorded over a number of day starting with day one for both prototypes. Bacteria activation requires 14 days which is hypothetically when the microbial fuel cells would begin to increase in potential [10]. As can be seen in the figures below, potential (voltage) decreased over the course of testing. All data for both prototype tests can be found in the appendix. Future testing, over a longer period of time is required for a better analysis of the processes of the biological battery.

Prototype one was tested over a 21 day period. A graph showing the potential of the pot versus the days of incubation is shown in Figure 2 and 3. Potential voltage between the anode and the cathode was lost over the total time. DRS hypothesized that this is due to too low a temperature during incubation and too high a pH for (such and such) bacteria.

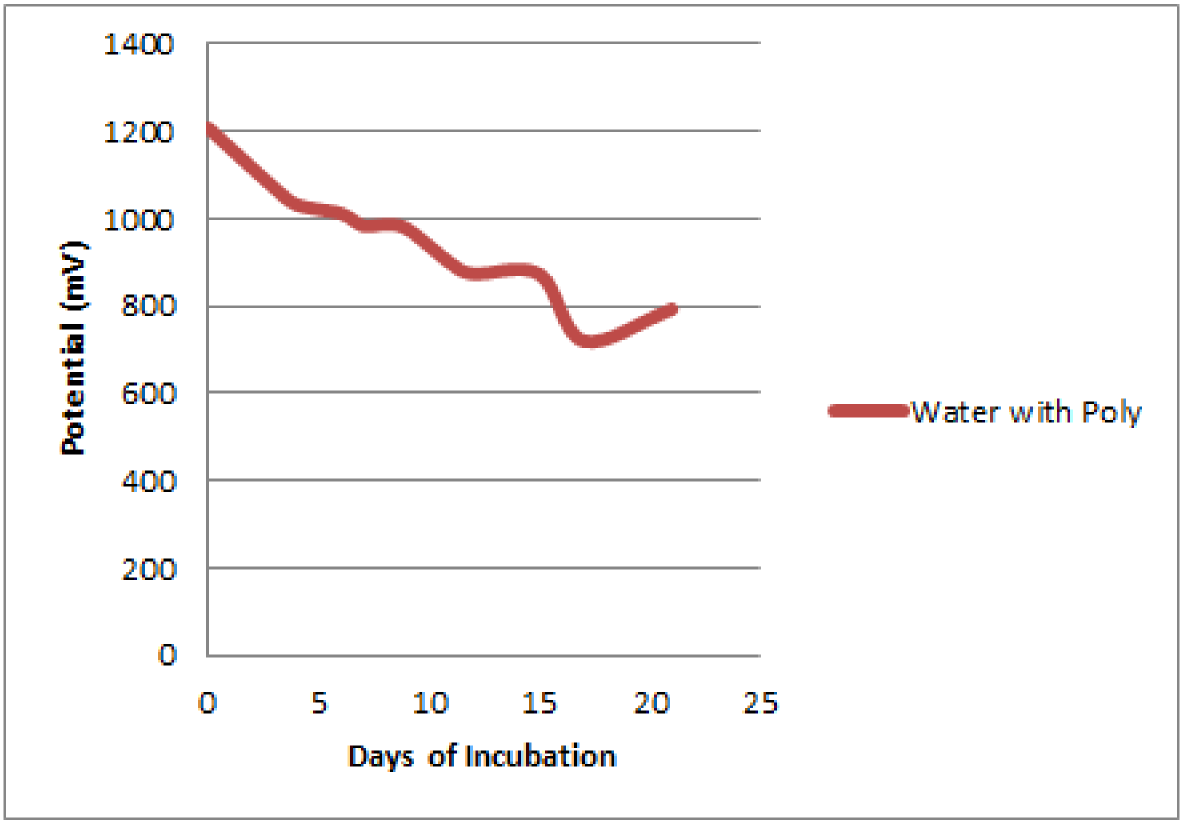

Figure 2: Prototype 1 Results - Water with Polyurethane Coating

In order to identify the issues with the first bio-battery, a second round of prototyping was implemented with two alternating variables and a constant temperature 6°C higher than the first prototype. Prototype Two was tested over a course of 14 days. As shown in the figures, all pots continued to lose potential over the course of evaluation. It was determined that the polyurethane coating still allowed for the air-cathode process and only provides a protective coating to prevent tarnishing of the carbon graphite paint. The DI water provided the largest potential in the beginning of testing, however it was found that the coke provided a more consistent potential.

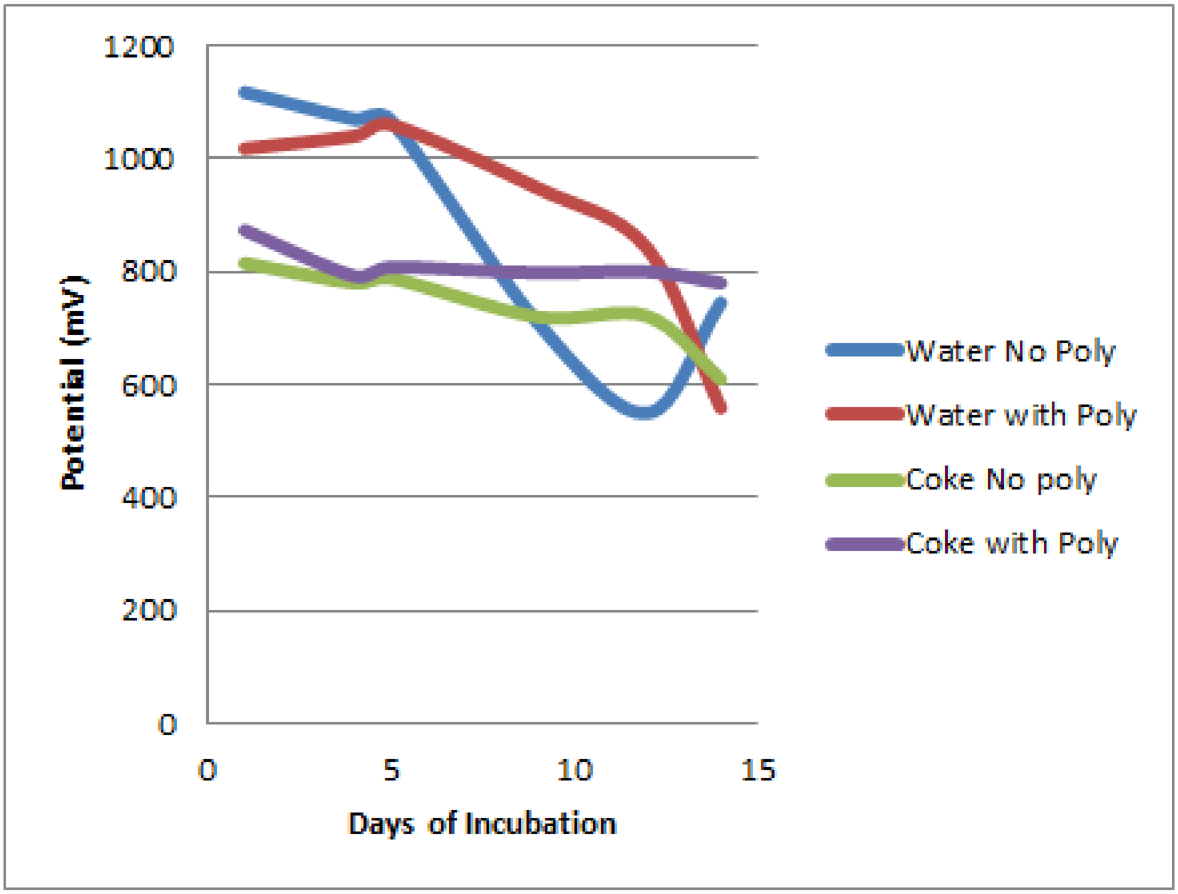

Figure 3: Prototype 2 Results - Four Pots with Two Alternating Variables

The goal of this design was to be able to charge cell phones in rural communities. The results of this year's DRS capstone team did not have the potential to power a cell phone, an LED was lit up at the end of the second prototype with all 4 pots in series. Further testing and analysis is required to improve the potential of the terracotta pot microbial fuel cell design. See the attached appendix for information about how to harness the energy from the batteries.

6.0 Cost-Benefit Analysis

An excess of cow manure exists within Lesoit. The design and implementation of bio-batteries and bio-digesters, as a source for waste management and energy production, will be analyzed using the cost-benefit analysis in the following report. Little to no sources of electricity exist within the community. There is a school within Lesoit, and based on conversations with village leaders, Frank and Juma, there is an interest from the people in learning new technologies. A cost-benefit analysis has been developed to analyze the benefit and cost of implementing bio-technology within rural communities, specifically in this analysis Lesoit.

The basic layout consists of four parts. Part one is the investment costs for the design phase. This mainly consists of the amount of time spent by the DRS team on designing and researching both designs. Part two is focused on the implementation costs. This includes the cost of bringing in a consultant and local engineers to teach the methods used and the construction process. Included as well is the cost of materials for each design. The bio-digester costs are for the construction of one reactor. The bio-battery expenses are based off the construction of 50 individual units. The costs included are based off prices found in Flagstaff and would need to be adjusted to deal with cost found in different regions. Each design will break down as time goes on; therefore, replacement cost for parts is considered in part three. The replacement of parts is based on a five year life expectancy. The final portion concentrates on the annual costs and income.

6.1 Bio-Digester Analysis

The funding needed to implement and design a bio-digester does not come at a small price. The engineers need funding so that they can be compensated for the design process. The design process includes background research, creation of design alternatives, analysis, and trial and error. During this phase the overall focus of the project changed on multiple occasions creating the need for more time spent adjusting the designs. After computing the total hours that each member spent on this phase the cost equaled 15,000 US dollars. The breakdown of each member can be seen in the table below.

Table 3: Bio-Digester Investment Cost for the Design Phase

	Quantity	Unit	Unit Cost	Total
Consulting Services	-	-	-	-
International Project Manager	200	hours	50.00	10000.00
International Engineer	20	hours	30.00	600.00
International Engineer	30	hours	30.00	900.00
Traveling Engineer	70	hours	35.00	2450.00
Traveling Engineer	100	hours	35.00	3500.00
		Total Cost ($)		**15000.00**

The implementation phase is the amount of man hours spent on building the reactor and is adjusted to include time that would be spent teaching locals the essentials of the design. The amount spent on materials to build one reactor is 418.70 US dollars. The total for manpower at this phase came out to 13590 US dollars.

Table 4: Bio-Digester Investment Cost for the Implementation Phase

	Quantity	Unit	Unit Cost	Total
Engineering Services				
International Project Manager	160	Hours	50.00	8000.00
Field Technician	130	Hours	25.00	3250.00
Local Engineer	130	Hours	18.00	2340.00
Constructions				
55 gallon drums	3	Barrels	20.00	60.00
4"x4" 8' pole	8	Pole	9.27	74.16
4-5" screws	1	lb	9.33	9.33
wood glue	1	bottle	3.83	3.83
marine epoxy	2	unit	5.64	11.28
3' steel stake	1	stake	5.41	5.41
2" x4" mending plate	10	plate	0.76	7.56
3.5" tee hinge zinc	2	hinge	5.40	10.80
3" ABS cleanout adapter	2	unit	5.29	10.58
1/2" Flp gas ball valve	1	valve	9.30	9.30
Local Villager	10	hr	5.00	50.00
Local Villager	10	hr	5.00	50.00
	Total Cost ($)			**13892.25**

The maintenance and operation of such a design can be costly too, but the design actually will produce more income than the cost. After the bio-reactor is functional, the only consistent cost is an operator. The operator will be in charge of collecting cow manure to be added to the reactor. This person will also be mixing the slurry and adding it into the reactor, along with removing fertilizer from the bottom. The reactor produces two kinds of income. The first being flammable methane gas which is used either as a fuel source for cooking, or paired with a generator would be able to create electrical energy. If a tank can be constructed to store this gas at high pressures then the gas can be transported and purchased by interested individuals. The waste product, fertilizer, removed is also a valuable source which can bring in capital. The amount listed below is based on adding the manure slurry in every day. The compost and methane production will outweigh the operation costs and eventually cover the price of construction and design after a period of three years.

Table 5: Bio-Digester Annual Cost and Income

Operation and Maintenance	**Quantity**	**Unit**	**Unit Cost USD**	**Total USD**
Maintenance	10	LS	6.00	-60.00
Operator	1,560	Hours	5.00	-7800.00
Staffing (list)		Hours		
			Subtotal Annual Cost ($)	**-7860.00**
Income				
Compost	15,000	lb	0.50	7500.00
Methane	9,627	ft^3	0.50	4813.50
			Total Annual Income($)	**12313.50**

6.2 Bio-Battery Analysis

This portion of the analysis will focus on the costs and benefits of the bio-battery. The design of the bio-battery proved to be costly, because the design phase must include research trial, analysis, error and redesign. The design underwent changes that focused on altering the slurry, and regulating the temperature. The output of the bio-battery was much less than that of the bio-digester. The minimum amount of output is due partially to the size of the battery, and the difficulty in regulating specific parameters including: temperature and pH. The total hours spent designing and choosing a final design for the bio-battery equaled 448 hours. Based on the assumed hourly wage of the different group members the total cost for design was 16,840 US dollars.

Table 6: Bio-Battery Investment Cost for the Design Phase

	Quantity	Unit	Unit Cost	Total
Consulting Services	-	-	-	-
International Project Manager	180	hours	50.00	9,000.00
International Mechanical Engineer	150	hours	30.00	4,500.00
International Civil Engineer	78	hours	30.00	2,340.00
International Social Scientist	20	hours	25.00	500.00
National Social Scientist	20	hours	25.00	500.00
		Total Cost ($)		**16,840.00**

Below, the investment cost for fifty bio-batteries is categorized into parts including cost of labor and materials. The total cost equaled 14,490 US dollars which can be found at the bottom of the table. Fifty bio-batteries is what can be built using the entire pint of graphite paint. The graphite paint was considered the limiting factor due to the difficulty of acquiring the paint in rural areas. This is what the DRS team decided to use as their standard purchase.

Table 7: Bio-Battery Investment Cost for the Implementation Phase

	Quantity	Unit	Unit Cost	Total
Engineering Services				
International Project Manager	160	Hours	50	8,000
Field Technician	120	Hours	25	3,000
Local Engineer	120	Hours	18	2,160
Constructions				
Graphite Paint	1	pint	31.28	31.28
Terracotta pot	50	unit	1.50	75.00
Polyurethane Coating	1	pint	11.73	11.73
Carbon Felt	3	ft^2	15.17	45.51
22 Gauge Insulated Copper Wire	1	50' roll	6.99	6.99
Epoxy	15	tube	5.64	84.60
3/8" zinc bolt	50	bolt	1.05	52.50
3/*' zinc nut	50	nut	0.85	42.50
Cow manure	30	lb.	none	
saran wrap	100	ft^2	0.01	0.50
22 Gauge Copper wire	1	50' roll	7	6.99
Energy Harvesting Module (EH301)	10	unit	53.15	531.50
		Total Cost ($)		**14,049.10**

The table below shows the salvage value for the bio-battery. This is the monetary value that the bio-battery would have after the end of its intended use. According to the table, the bio-battery materials do not have any salvage value. Since, none of the materials could be salvaged there is a predicted cost per year for replacement parts only. The saran wrap is replaced every time the slurry is replenished in the battery, because of this the saran wrap is the highest replacement cost.

Table 8: Bio-Battery Replacement and Salvage Values

	Quantity per Facility	Unit	Life Expectancy (Years)	Units Replaced over the Project Life	Units for Salvage over the Project Life	Unit Cost	Replacement Costs	Salvage Value
saran wrap	2	ft^2	5	45.0	0	0.05	-2.25	0.00
Manure	250	grams	5	60.0	0	0.00	0.00	0.00
bolt	1	unit	5	1.0	0	1.05	-1.05	
nut	1	unit	5	1	0	0.85	-0.85	0.00
copper wire	3	ft.	5	1	0	0.14	-0.42	0.00
						Total Cost ($)	-5	0.00

The next table below shows the annual cost it takes to maintain and operate the bio-battery. The majority of work is replacing the slurry whenever the potential in the battery reaches a minimum voltage. For the reason maintenance cost is minimum, and usually falls upon the owner of the battery.

Table 9: Bio-Battery Annual Costs and Income

	Quantity	Unit	Unit Cost USD	Total USD
Operation and Maintenance				
Maintenance	20	Hours	1.50	-30.00
Manure	7	lbs.	0.00	0.00
			Subtotal Annual Cost ($)	-30.00
Income				0.00
			Total Annual Income ($)	-30.00

6.3 Overall Cost Analysis

The overall cost of the bio-battery and bio-digester is shown in the tables below. The cost for the bio-digester is less than that of the bio-battery. This is due to the recoverable costs associated with the bio-digester. The bio-battery's production of electrical potential is not included as an income because such a low potential was achieved. As seen below the bio-reactor should expect a payback of roughly 7,000 US dollars a year. If the potential in the bio-batteries could be improved then the income needs to be reassessed.

Table 10: Bio-Battery and Bio-Digester Cost-Benefit Analysis

Project Location: Lesiot, Tanzania

Subject:	Describe your Program			**Alternative 1**		**Biodigester**		**Bio-Battery**	
Description:	Life Cycle Cost			**Description:**		**Description:**		**Description:**	
Project Life Cycle =	**5 Years**			Do Nothing		Produces usable methane gas and composting material		Reflects value of 50 units, used to produce electrical potential	
Discount Rate (Real Rate w/ Constant $'s) =			**3.00%**						
Present Time (Year of Const) =	**%**								
INITIAL COSTS/FIRST PHASE									
	Description			**Est.**	**PW**	**Est.**	**PW**	**Est.**	**PW**
A.	Design Costs				0.00	541.00	541.00	75.27	75.27
B.	Construction			______	0.00	302.00	302.00	889.10	889.10
C.	Employment			______	0.00	28590.00	28590.00	30000.00	30000.00
D.	____________			______	0.00	______	0.00	______	0.00
E.	____________			______	0.00	______	0.00	______	0.00
F.	____________			______	0.00	______	0.00	______	0.00
G.	____________			______	0.00	______	0.00	______	0.00
Total Initial Cost					**0.00**		**29433.00**		**30964.37**
Initial Cost PW Savings (Compared to Alt. 1)							**-29433.00**		**-30964.37**
REPLACEMENT COST/ SALVAGE VALUE/OUTYEAR INVESTMENTS/FUTURE PHASES									
	Description	**Year**	**PW Factor**						
A.	Beams	10.00	0.74	______	0.00	37/46.25	-9.25	______	0.00
B.	Hinges	20.00	0.55	______	0.00	0/10.80	-10.80	______	0.00
	ball gas valve			______	0.00	0/9.30	-9.30	______	0.00
	barrels			______	0.00	2.00	20.00	______	0.00
	inlet outlet piple			______	0.00		11.00	______	0.00
	22 gauage copper wire			______	0.00			0.42/0	0.42
	nut			______	0.00			0.85/0	0.85
	cover			______	0.00			2.25/0	2.25
C.	bolt	25.00	0.48	______	0.00			1.05/0	1.05
Total Replacement/Salvage Costs (Total)					**0.00**		**1.65**		**4.57**
ANNUAL COSTS/INCOME									
	Description	**Diff. Escl. %**	**PWA**						
A.	Maintenance	0.00	4.58			5.00	22.90	20.00	91.59
B.	Operations	0.00	4.58	______	0.00	1560.00	7144.34	______	0.00
C.	Staffing	0.00	4.58	______	0.00	______	0.00	______	0.00
D.	Rent	0.00	4.58	______	0.00	______	0.00	______	0.00
E.	Income (negative sign)	0.00	4.58	______	0.00	-12314.00	-56394.51	______	0.00
F.	____________	0.00	4.58	______	0.00	______	0.00	______	0.00
Total Annual Costs (Present Worth)					0.00		-49227.27		91.59
Total Life Cycle Costs (Present Worth)					0.00		-19792.62		31060.53
Life Cycle Savings (Compared to Alt. 1)							19792.62		-31060.53
*********PRESENT WORTH DOLLARS: USE FOR COMPARISON ONLY. DO NOT USE FOR BUDGETING.*********									
Discounted Payback (Compared to Alt. 1)			**PP Factor**			Never	Years	-1474.64	Years
Total Life Cycle Costs (Annualized)			0.22	0.00	Per Year	-4321.81	Per Year	6782.21	Per Year

6.4 Lifecycle Cost Analysis

The graph below provides a graphical representation of the recoverable costs for the bio-digester versus no recoverable costs from the bio-battery.

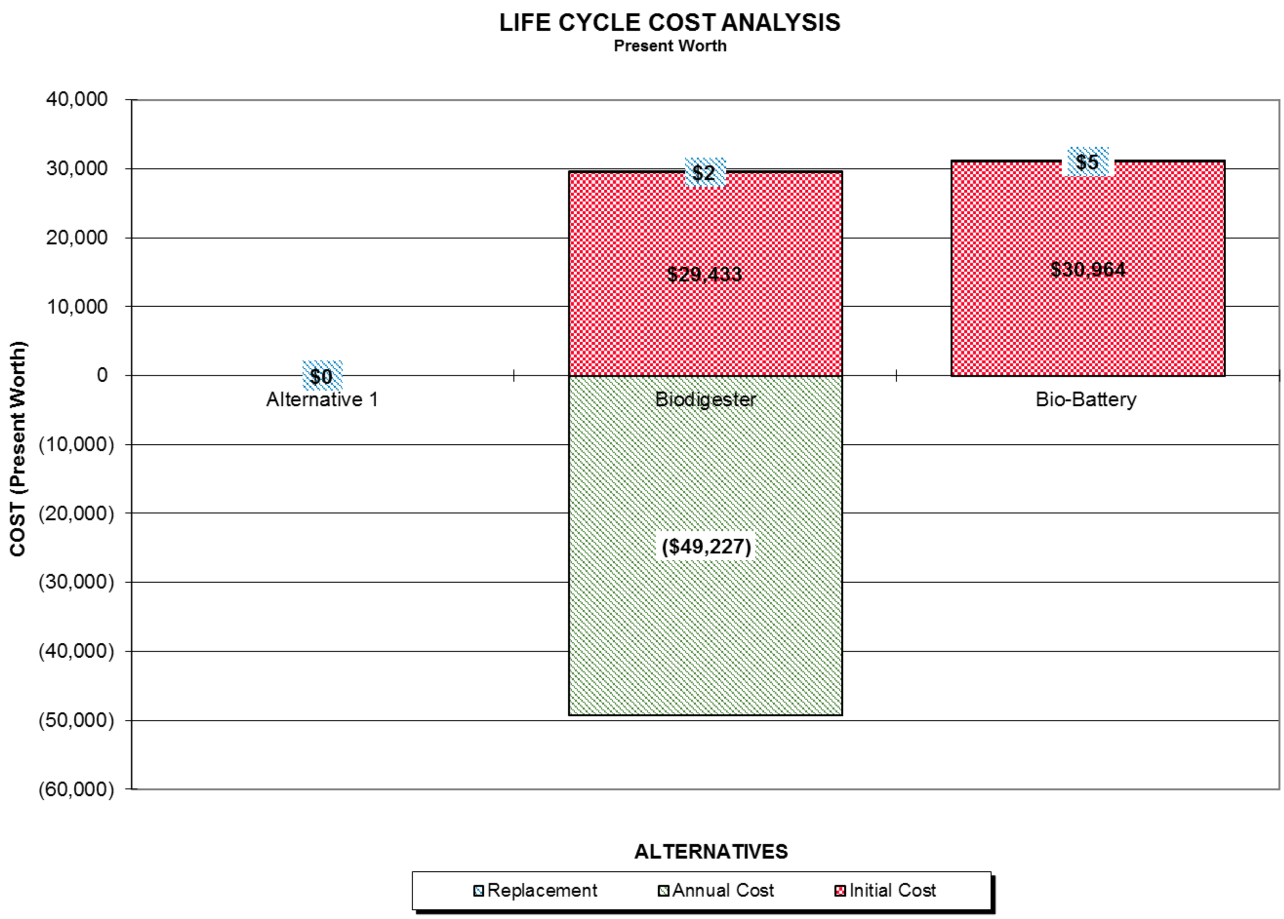

Figure 4: Life Cycle Analysis

Since the bio-digester is more large scale than the bio-battery, profits can be made on the supplies and by-product of the system. Both systems will cost money upfront but over time the amount of energy and usable by-product produced by each system will help pay off the initial costs.

7.0 Catalog

The catalog is a way to convey these designs to the people who would like to build these themselves. We have included the designs and instructions on how to construct the bio-digester, bio-battery and the rainwater catchment system. The purpose of this catalog is to increase the reproducibility of the designs. According to the village elders, they would like to grown the educational system in Lesoit [1]. Education is an important goal for this project. The village of Lesoit would use this catalog to educate their society. The instructions and designs can then be carried out to construct the biotechnologies. They are meant to guide the construction and be reproduced and shared with the cultures that have energy needs. Every culture could use energy to live a lifestyle with more comfort and protection. The catalog will provide stepping stones for future capstone groups to continue the work that has been completed thus far. Rural communities can also use the catalog as a design manual to build these designs themselves.

8.0 Conclusion

Throughout the semester Development for Rural Sustainability has created and tested two waste management systems. The goal of these designs were to mitigate cow manure in the village of Lesoit as well as produce usable energy. The team built a prototype of the bio-digester, however, due to the dramatic weather changes of Flagstaff, very limited results were collected. The bio-battery was tested and built in a laboratory environment which allowed the team to control more variables. After creating two rounds of prototypes, the team succeeded in powering an LED light with four of the terracotta batteries connected in series.

More testing and prototyping needs to be done in order to make these designs ideal for the village. A catalog will accompany this report as a manual and template for continuation of this project. In addition to testing these designs, a social, environmental, and cost assessment were performed for each prototype. This was done to determine the success of implementing alternative waste management systems in rural areas. Overall, these two designs would benefit the community. With a future assessment trip and more information is collected, further testing can be done to better each design.

9.0 References

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10.0 Appendix

Supplemental information for the above designs can be found in this section. More detailed design procedures are located in the DRS Design Catalog.

10.1 Chemical Processes

In the process of creating energy from a manure fueled bio-battery, a few processes need to take place to create a potential between the anode and the cathode. Before anything else is to take place the bio-battery must be anaerobic so it can produce the electrolyte, acetic acid, and create the potential. The flow of electrons from the carbon-felt anode through the manure and water electrolyte to the graphite paint coating cathode is the cause of the potential. Gabriel Bitton says "Consortia of microorganisms, mostly bacteria, are involved in the transformation of complex high-molecular weight organic compounds to methane" [3]. Team DRS has experimented using different cathodes, anodes, temperatures and electrolytes. The 2 electrolytes are mixtures of Coca-Cola and manure, and water and manure. The cathode used in the 2 designs is a graphite paint coating. Water is, in itself, an electrolyte because of the dissolved H_3O^+ and OH^- in balance. With the addition of cow manure, the electrolytic strength increases. This is because of the stronger concentrations of dissolved ions. Coca-Cola has more electrolytes than water (E.C. = 0.7 dS/m^3), but still depends on the cow manure to provide the nutrients for strong electrical current. According to Aguilera, the liquid manure characteristics have contents according to the table below. This shows the electrical conductivity when manure is added to water [11].

Table 11: Liquid Cow Manure Characteristics

DM (Dry Matter)	53 g/L
EC (Electrical Conductivity)	5.9 dS/m3
OM (Organic Matter)	71.1 mg/kg
DOC (Dissolved Organic Carbon)	2140 mg/L
pH	7.5
N (Nitrogen Content)	28.6 g/kg

In the bio-digester, the electrical conductivity does not contribute to the methane production. The constant mixing and constant temperature between 81°F and 95°F are the most important parameters for methane production, because the bacteria will not survive below 60°F. This produces a mixture of 60% methane and 40% carbon dioxide. The process of anaerobic digestion of manure is as follows.

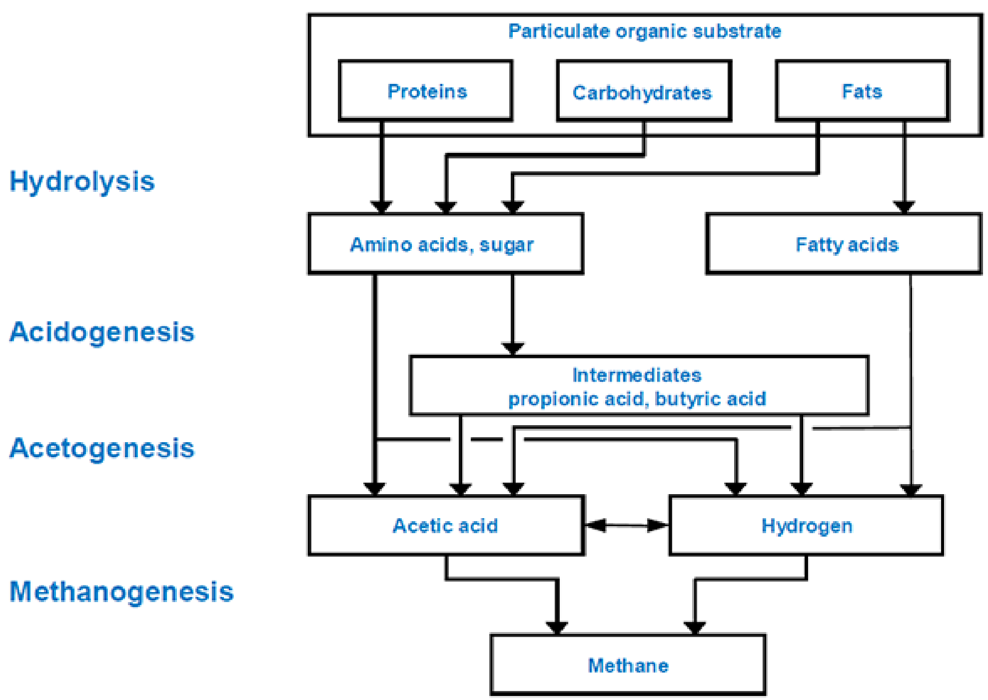

Figure 5: Anaerobic Digestion of Organics [10].

In the bio-battery, the live aerobic bacteria will consume the oxygen and turn it into CO_2 instantaneously through respiration as follows:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_20 + heat.$$

Thus, the atmosphere in the bio-battery and bio-digester will turn to CO_2 and water and gain heat. The hot, anaerobic environment, will then follow anaerobic reactions to create the potential.

First, hydrolysis must take place. In general hydrolysis is the ionization of water molecules into OH- and H+ ions.

$$H_2O \rightarrow H_3O^+ + OH^-$$

In this case it is the ionization of the solute, or carbohydrates, proteins and fats as they dissolve in water. So the bacteria transform the lignocellulose into its complex ionic constituents as they dissolve in the solvent.

Acidogenesis is the next step. This is where the acidogenic bacteria convert the ionized complex sugars into short chain volatile acids, alcohols, ketones, hydrogen and carbon dioxide. The products such as propionic acid, acetic acid, ethanol, butyric acid, methanol, etc are still too large for methane production and so they are then used in acetogenesis. The equation for the acidogenic breakdown of glucose (simple sugar) into alcohols is as follows:

$$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH+2CO_2$$

$$C_6H_{12}O_6 +2H_2 \rightarrow 2CH_3CH_2COOH+2H_2O$$

$$C_6H_{12}O_6 \rightarrow 3CH_3COOH$$

In the acetogenesis step, the bacteria will break down alcohols, acids into acetic acid, carbon dioxide. In this step, the hydrogen ion partial pressure needs to be very low. The low hydrogen ion partial pressure can be achieved only because of the hydrogen-hungry bacteria. The negatively charged bacteria will raise the pH and eat the hydrogen ions. Measuring the pH throughout the process is essential. The higher pH solutions provide a more efficient manure consumption. Because we are using a clay pot to hold the electrolytic solution, and clay has cations in it, the negatively charged bacteria will be attracted to the clay pot and stripped from the solution to die. The acetogenesis is described below in equation form:

$$CH_3CH_2OH + 2H_2O \leftrightarrow CH_3COO^- + 2H_2 + H^+$$

$$CH_3CH_2COO^- + 3H_2O \leftrightarrow CH_3COO^- + H^+ + HCO_3^- + 3H_2$$

We want to keep the acetic acid in solution, because the ions are ideal for the electrolytic solution. In order to stop this process, a small amount of air can be added, because the methanogens are strict anaerobes and will not survive in the presence of oxygen.

In the bio-digester, the walls are made of metal. Therefore the bacteria stays in solution and methanogenesis is allowed to proceed. The methanogenesis will use bacteria to breakdown the acetic acid and the hydrogen ions into methane and carbon dioxide. The transformation process is described below.

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

$$2C_2H_5OH + CO_2 \rightarrow CH_4 + 2CH_3COOH$$

$$CH_3COOH \rightarrow CH_4 + CO_2$$

While these processes are all dependent on the presence of glucose in the manure, this presence is not unlikely, especially for grass-fed cattle. According to the University of Limerick, in a study called Advanced Biomass Research for Beyond the Petroleum Age, the constituents of cattle manure is as follows [12].

Table 12: Relevant Mass Compositions (% dry matter) of Cattle Fed Four Different Diets

Constituent	**Diet**			
	1	**2**	**3**	**4**
Dry matter	25.15	22.48	28.97	25.59
pH	4.68	4.96	4.81	5.74
Noncell wall content	47.13	45.41	51.50	60.10
Cell wall content	52.87	54.29	48.50	39.90
Ash	6.89	8.02	7.55	11.50
Glucose	19.63	18.40	17.07	18.87
Galactose	4.31	4.20	2.75	5.48
Mannose	1.71	3.87	1.32	2.41
Arabinose	2.22	2.94	2.58	1.29
Xylose	5.41	5.27	7.41	9.18
Ribose	2.05	1.00	1.38	2.80
TOTAL SUGARS	**35.33**	**35.86**	**32.51**	**40.03**