Feasibility of Biolatrines in El Salvador

Janet Lin
Fernando Ruiz
Andrew Xia

May 13, 2015

D-Lab: Energy

Abstract

In this project for the D-Lab: energy class, we investigate the feasibility of biodigesters for families in El Salvador. We examine the causes of why biodigesters designed and built by past D-Lab Energy classes have failed to reach their goals, and we consider implementing certain design changes for the future, in an attempt to design a more practical and functional biodigester. After returning from our Spring Break 2015 trip to El Salvador, we designed and implemented a biodigester on the roof of the D-Lab building, and through this process we learned how to maintain a biodigester and also consider future design changes.

Introduction

What exactly is biodigestion? In a sealed environment, bacteria in manure will conduct anaerobic digestion, which produces methane gas. A biodigester is a sealed environment where manure, food waste, and water are inputted to produced methane and fertilizer. This technology both manages waste and provides clean cooking fuel.

We visited the communities of El Coco and La Magdalena in El Salvador. There, we interviewed Mauricio, who is a ranger in the community D-Lab built a biodigester for in Spring 2014. We interviewed families in the area, to assess user needs and feasibility. We also visited local schools and interviewed administrators, teachers, and the schoolchildren, to see whether we could implement a biolatrine with human waste at the schools.

Our overall goal for this project is to develop a successful biodigester design that can be implemented in El Salvador for local families to use. Our hope is that the biodigester will both solve the families' waste management issues and also eliminate or reduce their need to buy propane for cooking. Currently some families do not have methods of managing their manure simply letting the manure stay on the fields and not using the potentially useful resource. Many families are heavily dependent on government subsidies to purchase propane for cooking; availability of propane subsidies have been declining putting these families at risk for future economic hardships. The implementation of a biodigester in these rural communities could be the first step to energy independence. The money previously used to buy propane can be invested in other needs which could advance the socioeconomic level of the families.

Findings from Investigative Trip- Spring 2015

Follow-up from IAP 2015 Compost Toilet Project

- Juanito and Family; Location: Monte Oscuro, Magdalena County
- Current status: less than half full; slightly foul smell (family is still experimenting with adding ash to neutralize odor). Family says they will need ranger's help when it is time to empty it.
- User Concerns for Improvements:
    - Door sagged down at an angle making it difficult to close
    - Steps in the stairs were too high and narrow making it difficult to climb
    - Little legroom when sitting made it uncomfortable to use

Failures in Previous Polyethylene Bag Biodigester Design

Background -Ranger Station Biodigester

In January of 2013, a D-Lab team built a polyethylene bag biodigester with a one meter diameter and five meters in length. It was expected that this size biodigester would produce 0.7lbs gas per day, well above the ranger's estimated gas needs of 0.5lbs gas/day. The biodigester was maintained by adding food waste and slurry twice per week; little sludge waste exited the outlet and the waste that exited had not fully decomposed (mango peels emerged as full peels). After failed attempts, the rangers resorted to bury the biodigester.

The failure of the biodigester was due to a lack of resources and user mistakes. There was not enough cow manure to maintain the system. Originally, the rangers planned to take manure from a farm, but the farm was far which caused issues with transportation. The rangers also added food waste immediately after setting up the biodigester instead of waiting after the first methane flame to ensure a well-developed methanogenic bacteria colony.

Background - Mauricio's Biodigester

In Spring 2014, a bag biodigester of the same size was built at Mauricio's house. Similar to the park ranger's biodigester, this one also failed. The first flame test, conducted after one month, lasted only 57 seconds. This biodigester also had similar problems fully decomposing the waste. Additionally, gas bubbles never emerged from the water safety valve suggesting that the gas never entered the piping and escaped elsewhere.

A possible explanation for failure, suggested by Mauricio, was the biodigester incline being too large (20cm height difference between the inlet and outlet). Waste traveled through the bag too quickly before completely decomposing. Maurcio attempted to move the biodigester in order to fix the incline. However this movement caused the biodigester bag to rip and spill all the contents. Eventually, neighbors complained of the smell, and Mauricio resorted to burying the biodigester.

Despite the failures, Mauricio is still interested in biodigestion. Growing up on a farm, he was used to working with cow manure and is curious about ways to use the waste for environmental and energy purposes. He is open to the idea of using human waste, but warned that others would be more hesitant. He stressed the importance of education and clear explanations of the technical process.

Project Considerations and Design Criteria

- Importance of Training and User knowledge - making sure the end-user knows how to maintain the biodigester to avoid problems such as adding food waste too early. Drafting a user manual in Spanish could be useful for future dissemination.
- Availability of Resources - making sure resources such as manure are accessible and that the end user is willing to transport the resources.
- Durability- the plastic bag was not durable which caused tearing and large sanitation issues.

Possible Sites of Implementation

During our trip to El Salvador, we visited several farms to assess the user needs and to investigate the feasibility of a biodigester. We also visited two schools to assess the user needs and to investigate the feasibility of a bio latrine which would utilize human waste.

<u>Farm Visits</u>

La Magdalena

Our team visited three families in the La Magdalena community to determine interest in biodigestion and perception towards using human waste. Overall, two out of the three families had not heard of biodigestion before. Most individuals were apprehensive about using human waste but were curious about the possibility; the families were more receptive to using animal waste. All families relied on wood as their main fuel source for cooking, and resorted to propane gas when needed. Overall, the families did not own large animals, thus the implementation of a biodigester would not be feasible due to lack of resources.

El Coco County

Many people were receptive to using biodigesters using only animal feces but were against using human waste. In this community more people owned large animals such as goats and cows. In this community we found the two most appropriate locations to put a biodigester which were at Don Adelso's farm and Don Victor's farm.

	Location	Manure Availability	Fuel Cost/Month	Notes
Adelso	San Nicolas, Coco County	6 Cows; does not use manure	$5; has subsidy	Interested in benefitting his community; humanitarian (has 3 adopted children)
Victor	Las Lomas	12 Goats; uses manure as fertilizer	$4; has subsidy	Seen as a leader in the community; seen as a local innovator

Figure 1: Don Adelso’s farm (left); Don Victor’s farm (right)

<u>School Visits</u>

Centro Escolar Caserio la Reforma, Primary School in San Salvador

We met two university students, Cesar and Elena, who had closely worked with a school in the outskirts of San Salvador. They were interested in installing a biolatrine at the school to solve the energy and waste management problem. The school theoretically served students from Pre-kindergarten to 6th grade. The school is in very poor conditions; they had one school director and one teacher and two classrooms for a group of 72 students. Most of the students’ ages ranged from 5-12 years of age but the school had several students of 2 years of age, and several students from ages 15-17. These students were all taught in the same classroom and by the same teacher.

The school also had problems with waste management and sanitation. The trash collection is inconsistent but conditions have improved over the past several months. Trash collection was previously about once a week and now comes two times a week. The trash is collected next to the school near where the children play.

There were two separate bathrooms containing ceramic flush toilets. Each bathroom was separated between boys and girls bathrooms. The flush toilets did not have plumbing and students had to bucket flush with water taken from a rain barrel near the bathroom that was filled two times a day: 6am and 6pm. After interviewing students about the use of the bathrooms it was clear many students avoided using the bathrooms. The main reasons students avoided the bathrooms included: lack of toilet paper, dirty conditions, and lack of privacy. The school lacked toilet paper in the bathroom and many students brought their own from home. The bathrooms smelled and many students did not bucket flush (the buckets are heavy and the rain barrel was tall making the process difficult). Many of the students were picked on by other kids who would either look over the stall or under the stall or open the door because the doors lacked locks. The girls especially concerned with the lack of privacy and told of boy students picking on them while they used the bathroom. One 13 year old girl interviewed explicitly stated that her parents wanted to take her out of the school.

The school had problems obtaining enough fuel to cook for the children. The cook oftentimes cooked beans on her wood stove and brought the food to the children. The government gave the school a $5 subsidy on propane gas but the parents had to pay for the rest of the cost ($8-10); one tank of propane lasted approximately one month.

Figure 2: Flush toilets with rain barrel and bucket to flush (left). School gas stove (right).

San Cristobal School

We assessed the conditions of a high school near La Magdalena, a Forest Preservation Site. It was a high school; students were from 13-18 years of age. The school had four classrooms, 6 teachers, and 246 students. There were typically 25-39 children per grade. The students were divided into a morning and afternoon session lasting approximately 4 hours. The school had problems with sanitation. They contained two pit latrines and had recently installed three ceramic flush toilets. The ceramic toilets were locked and only available for the teachers to use. When the teachers and the director were interviewed, they said they locked the bathroom because they were training the children how to use them and they feared the kids would flush rocks and other things that could damage the plumbing.

We gathered a group of 50 students who were available and introduced them to the idea of a biodigester. We then conducted interviews in smaller groups to gain more information on the current bathroom situation, and the receptiveness of the students to the idea of a biodigester. We separated the groups into male and female groups. The female group interviewed were from ages 13-15. They typically avoided using the bathroom or exclusively used the bathroom only for peeing. Their main concerns with the bathroom was the dirty conditions, graffiti, and lack of privacy. The bathrooms smelled bad and lacked toilet paper. Toilet paper was rarely available even upon request. The girls also said that graffiti included strong insults directed at individuals. The had locks on both the inside and outside and had gaps in between the door and the floor and the ceiling. Many of the boys would look under the bathroom door while the girls were using it or lock them in from the outside. The girls also said that many of the students went to the bathroom at the same time during recreation. They typically had to wait 15-20 minutes to use the bathroom.

The group of boys were from ages 13-17. They only used the bathroom to urinate. They complained of the bathrooms being too dirty and smelly. Some did not use the bathroom out of embarrassment. When asked about the biodigesters the older kids were grossed out about the idea especially when using human waste. The younger kids seemed receptive to utilizing either human or animal feces.

Figure 3: Latrines used by students (left). Locked flush toilets used by teachers only (right).

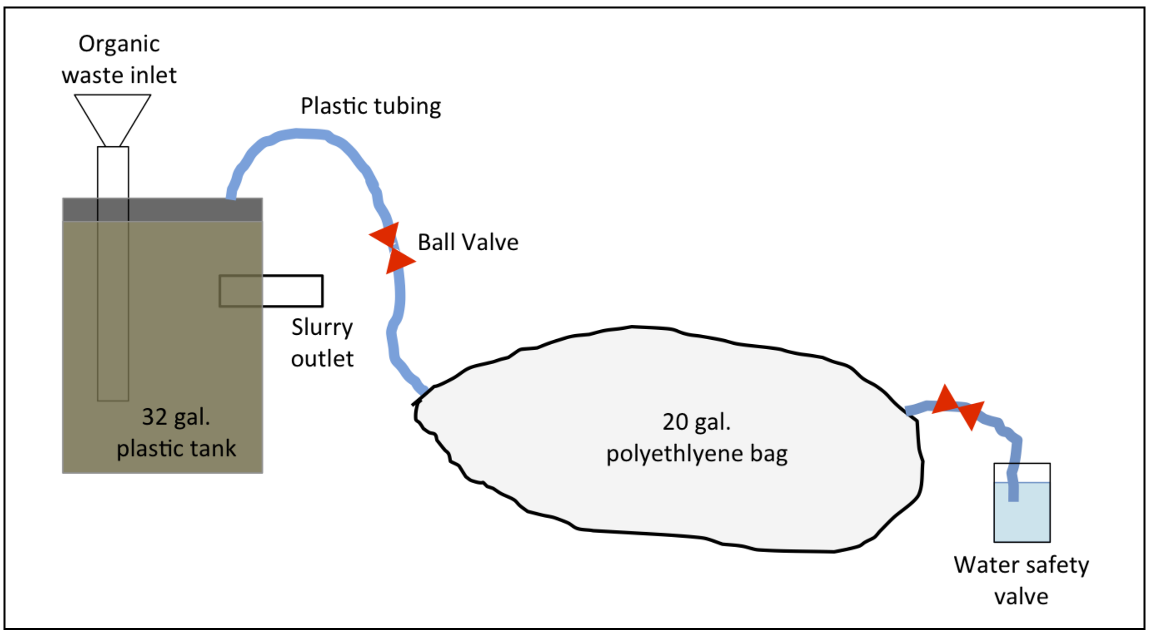
<u>Project Considerations and Design Criteria for School Biolatrine</u>

- Project Champion - making sure somebody is responsible for maintenance and upkeep of the biolatrine.
- Quality Assurance - testing before dissemination - a failed school biolatrine can cause harmful health hazards to children.
- Durability - making it durable enough to be around many curious children.
- Resource Availability - making sure the children are comfortable using the toilets in the school; estimating how much poop available and designing accordingly.
- User Knowledge - making sure the children know how to use the divergent toilet seat
- User Acceptance - making sure user is comfortable using his/her own waste to generate biogas.

Design of Batch-process Biodigester for Testing Purposes

After the investigative trip, our team decided to build and maintain a biodigester at MIT for several reasons. First, we wanted to experiment with a new design that was a fixed structure and more durable than the polyethylene-bag design. Second, our team needed more experience and understanding in maintaining and operating a biodigester for an extended period of time. Lastly, we wanted to determine ideal conditions (waste composition, temperature, pH, etc) for optimal gas production.

In order to systematically evaluate factors affecting biogas production, our team designed a small-scale batch-process biodigester. As shown below, the design includes a 32 gallon plastic bin sealed to a lid with silicon that acts as the main digester. An inlet and outlet PVC tube extending below the liquid level allows for waste to be added and removed from the anaerobic chamber. Plastic tubing pipes the gas from the main digester to a 20 gallon double-lined plastic bag where gas is collected and stored. Ball valves allow the bag to be disconnected from the system and transported to locations for easier testing of gas composition. A water safety valve ensure that pressure build-up in the system does not exceed ambient temperatures. This design allows the team to vary conditions with each batch, measure the outputs, and satisfy the safety concerns of MIT's Environmental, Health, and Safety (EHS) and Facilities Department.



Currently, our team has set-up the biodigester and inputted cow manure. However we are waiting for the first production of gas. We suspect the colder temperatures at night slow down the bacteria growth. Additional the initial presence of oxygen would first create an environment for aerobic digestion that produces carbon dixoide. Once all the oxygen is consumed, methanogenic bacteria will begin to produce the desired methane gas.

Once methane is produced, indication of a healthy bacteria culture inside the anaerobic chamber, our team will begin the proposed experimental procedure:

Measured variables:

- temperature fluctuations during the testing period
- pressure measurements inside main digester and gas storage compartments
- volume of gas produced in given time period
- amount of CO_2 produced to indicate digester effectiveness at creating anaerobic environment

Variables to Change:

- feed composition (different food waste, pH, consistency, water to waste ratio)
- temperature (adding reflectors to maximize sunlight onto digester, painting digester black)

Considerations for Final Biodigester Design

Despite not having completed any formal testing of the batch-biodigester, our team has already gained a lot of insight into how to design a better biodigester. Although in our Spring Break 2015 trip to El Salvador we did not build a biodigester, we were able to collect useful information to help us design our biodigester prototype that we built in Boston. With the hands-on experience of working with our biodigester for a month, below are the suggestions that we have for the final biodigester design.

<u>Design Improvement: Include stirring mechanism</u>

While we batch-inserted the slurry, composed of cow manure and water, into our biodigester, we were unable to fill up the biodigester to its 32-gallon capacity. Towards the end of the inserting process, the inlet filled up while we knew that our biodigester had less than 32 gallons of slurry inside. Thus we were unable to insert more slurry into our biodigester, which is a problem because then more oxygen is in the biodigester, which limit the amount of methane producible.

We believe the cause of this situation was because after inserting the slurry composition into the biodigester, the manure and the water separated, with the heavier and less viscous manure sinking to the bottom, and the water floating to the top. As our inlet extends deep into the biodigester -we made this design consideration because we needed the inlet to be airtight -the manure became too dense, and our slurry that we poured into the biodigester would not go down further.

We propose a solution to this issue by including a stirring mechanism built into the biodigester. Through one of the holes on the top of the trash bin, we will insert a stirring device into the biodigester. The stirring mechanism will be a completely mechanical process, making it operational in all environments, including those without electricity. It is important to keep the stirring design simple, so maintenance is easy, and the hole where the stirring device is inserted into the biodigester must also be airtight for the biodigester to be functional.

In the figure above, we are planning to include a stirring shovel that enters the biodigester through the peeping hole, which is currently covered with green duct tape and a plastic sealant.

<u>Design Improvement: Make the Waste Inlet wider</u>

After pouring the slurry into the biodigester, Andrew and Janet realized that our current inlet is too narrow. Large pieces of manure may get stuck in the narrow PVC pipe, having the potential to clog the system. We also plan to use a wider funnel in the future, as most families' buckets are large and may not have the precision to pour into small funnels. Finding a large funnel should not be a problem, and larger diameter PVC tubes should also be quite common.

<u>Design Improvement: Use 55-gallon drum instead of current 32-gallon trash bin</u>

Another potential issue with our current biodigester design is the airtightness. We applied epoxy to seal the lid of the trash can with the main frame, and tested its airtightness by pumping air into the biodigester and checking for leakage. While we didn't find any locations where the airtightness would be compromised, we are also considering using a 55-gallon drum as our biodigester instead of the 32-gallon trash bin, which is inherently a sealed container. We would have a larger volume to work with, allowing more manure to be processed by the biodigester. It may also make more sense to use the 55-gallon drum in our final design, as it seemed more common than our American trash cans.

The figure above is a 55-gallon drum converted into a biodigester. This is a biodigester that we saw at a semi-industrial farm that we visited in El Salvador. We would design something similar to this.

<u>How to implement our Biodigester</u>

Once we have designed a functional and practical biodigester, it is also critical to educate the local families on how to run the biodigester correctly. Some reasons for why past D-Lab designed biodigesters have not worked successfully stems from the local families lack of knowledge of how to run a biodigester. Below, we outline the steps of how to run a biodigester successfully:

1. Fill biodigester with only manure initially. It is extremely important to have the bacteria culture from the manure develop, so we only want to feed the biodigester with manure at first.
2. After a week or two, food waste can be added. The bacteria in theory should be able to digest food waste, but we only want to insert food waste once the bacteria inside has stabilized.
3. Human waste can be added into the biodigester, but maybe for cultural reasons this will not happen.

Business Model for the Biodigester

Currently we mainly focused on designing a functional biodigester, but we realize that we will need a smart business model in order to run our biodigester well. This is a future step that we will need to plan, but for now it is not our focus. Our current plan for implementing the biodigester is to identify families that are leaders in the local community, and deploy our biodigesters there to maximize the chance of running a biodigester successfully, and attain the most amount of publicity. We may consider, in the future, to create a business plan of incentivizing families to run a biodigester successfully with monetary gain, such as a manure transportation system with a centralized biodigester, or other similar ideas.

Financial Analysis

A three year cost analysis was conducted to determine the affordability of a biodigester system. This analysis examined three different scenarios for the typical eight person family we encountered while visiting households in El Salvador. First, an appropriate biodigester system was sized to meet the needs of the representative household. Next this was compared to the family's current use of propane gas and firewood. Lastly the costs and benefits were projected out to three years.

Sizing Biodigester System for Household of Eight Individuals

Most families we spoke to indicated a fuel useage of one 25-lb propane tank per month with additional firewood collected to supplement the cooking needs. Therefore, we sized the biodigester to the family's current propane gas useage since replacement of one gas fuel should be similar to another, whereas switching from firewood to biogas might involve other behavior changes. Using the D-Lab Biodigester Manual, it was calculated that this representative household would need at least a biodigster of ~2000 liters (see calculations below). A biodigester of this size would cost ~$415. Prices found during the investigative trip were used to make the cost estimation.

Monthly Energy Needed:

- Representative family of eight individuals uses one 25lb-propane-tank in one month.
- Propane energy content ~45MJ/kg.

$$\frac{25\ lb\ propane}{month} \times \frac{0.4536\ kg}{1\ lb} \times \frac{45\ MJ}{kg} = 510\ MJ\ needed\ monthly$$

Monthly Biogas Needed:

- 1 mole CH4 has 0.89MJ energy
- Molar mass of CH4 = 16 grams
- CH4 density = 650g/m³
- Assume biogas is 60% methane

$$\frac{510\ MJ}{month}\ needed \times \frac{1\ mol\ CH4}{0.89\ MJ} \times \frac{16\ g}{1\ mol\ CH4} \times \frac{1\ m^3}{650\ g}\ CH4 \times \frac{1\ m^3\ biogas}{0.60\ m^3\ CH4} = 23\ m^3\ \text{biogas/month}$$

Volume of Biodigester Needed:

- Assume slurry produces 25% its volume in biogas
- Need volume for both slurry and gas that is produced daily

$$\frac{23\ m^3}{month} \times \frac{1\ m^3\ slurry}{0.25\ m^3} \times \frac{1\ month}{30\ days} \times \frac{1000\ L}{1\ m^3} \times \frac{1.25\ m^3\ tank\ needed}{1\ m^3\ slurry} = 2000\ L\ tank\ needed$$

Item	Quantity	Cost	Total
Tinaco Rotoplas Tank 1700L	1	$222.65	$222.65
PVC 3" ($/m)	5	$6.35	$31.75
Valves ($/ea.)	5	$3.60	$18.00
T joints ($/ea.)	5	$0.35	$1.75
PVC caps ($/ea.)	2	$1.50	$3.00
Plastic Tubing ($/m)	10	$0.45	$4.50
Connection Pieces ($/set)	5	$3.00	$15.00
PVC glue ($/950mL)	3	$26	$78
Teflon Tape ($/roll)	3	$3.65	$10.95
Others-nozzle, connection pieces, missing items ($)	1	$30	$30
Total			**$415.60**

<u>Three-Year Cost Analysis</u>

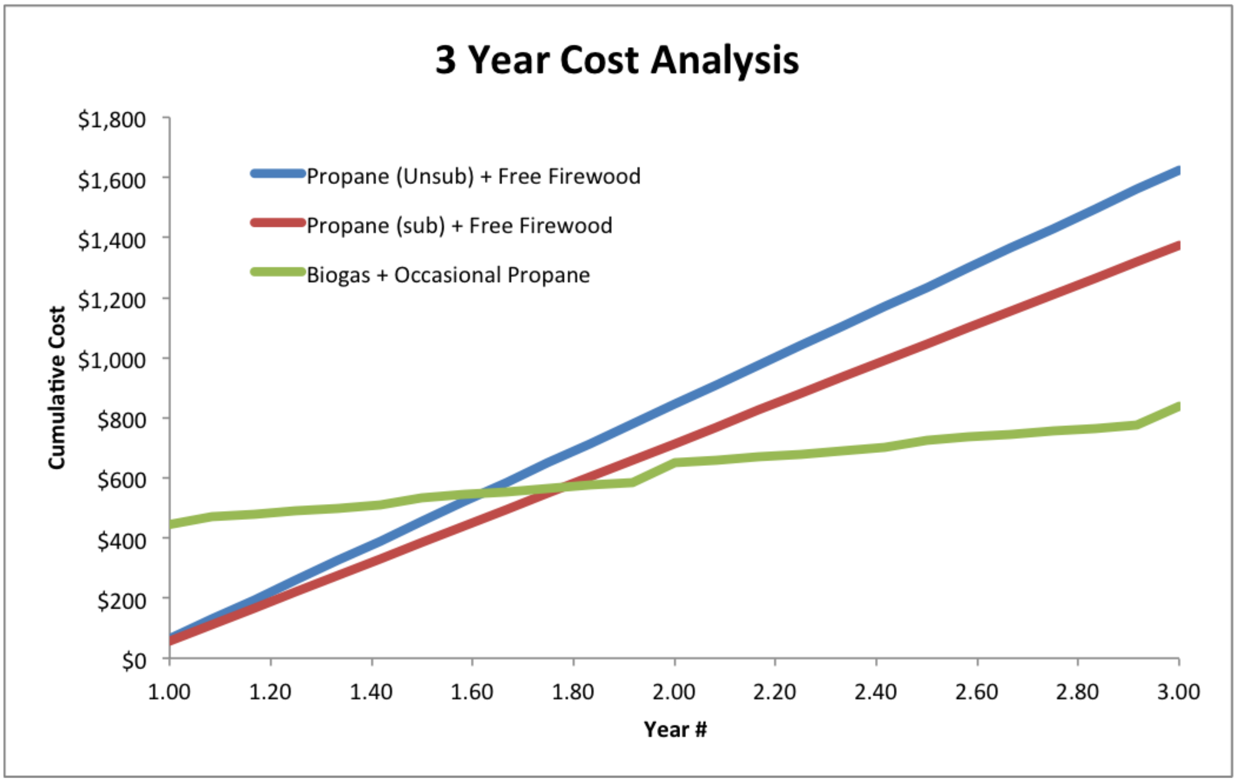
Next, the biodigestion system three year cost analysis was compared to current fuel expenditures. The first scenario is the use of propane gas without subsidy ($15/month) in addition to collection of firewood. Cost associated with wood collection was calculated by determining the wages lost (see calculations below). The typical family we spoke to made ~$200/month. Assuming an 8-hr work day, this amounts to a wage of less than a dollar per hour. We assumed families spend roughly 2hrs/day gathering wood. Therefore if this time was instead spent working, there is a $50/month income loss associated with firewood collection. Therefore the total montly cost for a family to purchase a 25 lb propane tank and collect firewood is $65/month. The second scenario assumes a subsidy for propane so that the cost is reduced ($5/month) and wood collection is still necessary. Thus, the monthly fuel cost is $55 for a family on government subsidy.

Income ($/month)	$200
work day (hrs/day)	8
$/hr	$0.83
Gathering wood (hrs/day)	2
Lost Income ($/month)	50

The third case is the use of biodigestion system in addition to occasional use of propane (or firewood). Therefore in the first month there is a capital cost associated with the construction of the biodigester. Because the biodigester requires daily waste input, we quantify this work as $10/month. Additionally, the biodigester may need yearly repairs which we estimate as $50/year. Lastly, we still expect families to occasionally supplement their cooking fuel with either propane gas or firewood in the case that sufficient biogas is not produced. We estimate the cost for supplementing biogas as $15 every half year. But for the first month, when the biodigester has yet to start, we calculated a $30 expenditure for propane fuel. Below is a table comparing all three scenarios.

Year	Propane (non-subsidy) & Wood				Propane (subsidy) & Wood				Biodigester & Occasional Propane			
	Monthly Propane Cost	Gathering Wood Cost	Total Monthly	Cumulative	Monthly Propane Cost	Gathering Wood Cost	Total Monthly	Cumulative	Construction & Maintenance	Supplemental Propane	Total Monthly	Cumulative
1.00	$15	$50	$65	$65	$5	$50	$55	$55	$415	$30	$445	$445
1.08	$15	$50	$65	$130	$5	$50	$55	$110	$10	$15	$25	$470
1.17	$15	$50	$65	$195	$5	$50	$55	$165	$10	$0	$10	$480
1.25	$15	$50	$65	$260	$5	$50	$55	$220	$10	$0	$10	$490
1.33	$15	$50	$65	$325	$5	$50	$55	$275	$10	$0	$10	$500
1.42	$15	$50	$65	$390	$5	$50	$55	$330	$10	$0	$10	$510
1.50	$15	$50	$65	$455	$5	$50	$55	$385	$10	$15	$25	$535
1.58	$15	$50	$65	$520	$5	$50	$55	$440	$10	$0	$10	$545
1.67	$15	$50	$65	$585	$5	$50	$55	$495	$10	$0	$10	$555
1.75	$15	$50	$65	$650	$5	$50	$55	$550	$10	$0	$10	$565
1.83	$15	$50	$65	$715	$5	$50	$55	$605	$10	$0	$10	$575
1.92	$15	$50	$65	$780	$5	$50	$55	$660	$10	$0	$10	$585
2.00	$15	$50	$65	$845	$5	$50	$55	$715	$50	$15	$65	$650
2.08	$15	$50	$65	$910	$5	$50	$55	$770	$10	$0	$10	$660
2.17	$15	$50	$65	$975	$5	$50	$55	$825	$10	$0	$10	$670
2.25	$15	$50	$65	$1,040	$5	$50	$55	$880	$10	$0	$10	$680
2.33	$15	$50	$65	$1,105	$5	$50	$55	$935	$10	$0	$10	$690
2.42	$15	$50	$65	$1,170	$5	$50	$55	$990	$10	$0	$10	$700
2.50	$15	$50	$65	$1,235	$5	$50	$55	$1,045	$10	$15	$25	$725
2.58	$15	$50	$65	$1,300	$5	$50	$55	$1,100	$10	$0	$10	$735
2.67	$15	$50	$65	$1,365	$5	$50	$55	$1,155	$10	$0	$10	$745
2.75	$15	$50	$65	$1,430	$5	$50	$55	$1,210	$10	$0	$10	$755
2.83	$15	$50	$65	$1,495	$5	$50	$55	$1,265	$10	$0	$10	$765
2.92	$15	$50	$65	$1,560	$5	$50	$55	$1,320	$10	$0	$10	$775
3.00	$15	$50	$65	$1,625	$5	$50	$55	$1,375	$50	$15	$65	$840
Total	**$375**	**$1,250**	**$1,625**		**$125**	**$1,250**	**$1,375**		**$735**	**$105**	**$840**	

As expected the unsubsidized propane scenario is more costly than subsidized gas. Biodigestion proves to be a costly initial investment. However after roughly one and a half years, the biodigester becomes much more cost effective. The ~$400 initial capital cost needed and the 1.5 year payoff period may be too high for the typical family. Therefore it is crucial to partner with an organization that can either help cover the initial cost or work with the family to set up payment plans and microfinance loans.



Future Work

We are still maintaining the biodigester on the roof of N51 which will be experimented with until late June. We hope to gain valuable insight on our biodigester design and different factors related to methane gas production. We hope to learn how to troubleshoot a biodigester,

D-Lab and Asaprosar have worked together to implement both compost toilets and biodigesters; for future work we would like to combine both systems and make a biolatrine. Before beginning a biolatrine project, we believe it is necessary to have successfully designed and disseminated a biodigester. Once a biodigester has been successful, the design process of the biolatrine can be started. We hope that a future D-Lab class can take on this project and that our team can provide support in the process.