BIODIGESTION AS A MEANS OF PROVIDING ELECTRICITY AND ENERGY NEEDS TO THE CITY OF DEVIKULAM

ENGINEERS WITHOUT BORDERS (EWB) CHALLENGE FINAL REPORT

STEPHEN BIVIANO, JOHN MARTINS, JAMES VIRTUE, GRAHAM HAINES, JAMES PAPADIOS
EXECUTIVE SUMMARY:

This report on Biodigestion as a Means of Providing Electricity and Energy Needs to the Community of Devikulam was created by Stephen Biviano, John Martins, James Virtue, Graham Haines, and James Papadios as part of the Engineers Without Borders (EWB) challenge, which is part of the assessment in the ENGG154: Engineering Design and Innovation subject. As part of this assessment, each group in each tutorial is required to design a sustainable object or system that will enhance the lives of the people living in Devikulam, India.

The village of Devikulam is an impoverished community located in the state of Tamil Nadu, India. The people that live here face many issues daily, the most important being unreliable electrical power, and the production of a large amount of waste. This report endeavours to address these problems by discussing and analysing the benefits of the process of bio-digestion as a means of producing a reliable source of energy that can be used to generate electricity, and/or be used for other beneficial services for this community, such as cleaner cooking and heating.

In order to properly complete this task, this report aims to address and accomplish the main aims of the assignment as stipulated on the EWB website. These aims include:

**Demonstrate application of technical knowledge to the specified problem.**

In order to complete this assignment, a systematic approach was undertaken by the group, with each member completing separate tasks that best suited their abilities in order to produce one final design and product. This systematic approach allowed the group to create a design that best suited the needs of the community in a way that was appropriate to the project context. The first step in this systematic approach was to identify the major issues affecting the community of Devikulam, before developing possible solutions and then deciding on an overall design solution that is appropriate to the context of the project and best resolves the issues the community faces.
This systematic process is evident in the way the group decided early in the process that the lack of a consistent supply of energy was one of the most important issues that adversely affected the community. From this identification of the problem, the group was able to develop some solutions that would deal with the issue in the best way, coming to the conclusion that a bio-digester would be the most appropriate device to solve the energy problem. The two design options the group decided on was a bio-digester with storage tank, or a bio-digester with a turbine attached to create electricity. Eventually, after due consideration, design option one was chosen as it was cheaper to run and install, and incurred less maintenance. However, due to the size and design of the bio-digester, a working prototype was impractical to create, however after applying the necessary science and engineering knowledge to the problem, the group concluded that this design option should work in an effective manner.

Develop skills in integrating sustainable development and design context into the decision making process

In solving a problem professional engineers need to take into consideration the social, cultural, and environmental impacts in formulating a design and solution, as well as the ethical implications of their design and design process. This involves ensuring that the rights, freedoms, and livelihoods of the people of Devikulam are protected, and that the community of Devikulam is not provoked, offended, or adversely affected by a design that infringes on social and economic practices, cultural customs or practices, or is environmentally unsound.

The group has ensured that it worked in an ethical manner at all times during the design process, endeavouring to find as much information as possible about the community of Devikulam, to ensure that any design would be able to be installed and maintained in an ethical way that would not disadvantage the community in any way. A bio-digester adequately meets the above criteria as it cheaply produces energy in a way that has minimal social, cultural and environmental costs. It uses the manure produced by animals, and decomposing plant matter as its fuel source, which, once the methane has been extracted, can be reused as fertilizer, thus not affecting the farming...
practices already in place within the community. Cows are sacred animals in the Hindu culture that is a part of the Devikulam community; however, the bio-digester does not rely solely on cattle manure, and therefore the manure from other animals and plant matter can be used instead, thereby not impacting on the cultural practices in the location. While the burning of the methane produced is required to produce the energy, the carbon dioxide, and other pollution created and released into the environment is offset by the lack of methane released into the atmosphere from the decaying plant matter and manure, as this is captured within the bio-digester. Therefore the bio-digester has a minimal impact on the environment.

However, in any project an engineer must liaise with the community to make sure that the required design to be produced is appropriate for that community and is the option that they wish to manufacture for financial, environmental, or cultural reasons. While the group did not liaise directly with the community of Devikulam, the background information that the group researched gave them enough information to inform them of certain requirements and constraints during the design process that ultimately shaped the final design option chosen. After conducting the required research, the group believes it has produced a design that takes into account the needs of the community, while also being more beneficial socially, culturally, and environmentally to the community than the costs that are required to install and maintain it.

**Develop effective communication and teamwork skills for a development context.**

Communication is the most vital part of the design process, not only with other engineers, but with the community at large. The purpose of this report is to communicate the design that the group feels is the most appropriate for the community. As this is a large assignment, the group divided the roles between the members, with each team member needing to communicate their ideas, and any research conducted with the rest of the group so a holistic knowledge of the biodigester and how it can be used was gained by the whole group. Another integral part of the design process is the need to critically and constructively reflect on the community engagement and consultation in the design process. While the community

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of Devikulam was not engaged with directly, other groups were consulted in our design tutorial classes, with the group taking their comments into consideration when producing this report, changing some aspects to create a better quality design product. In writing this report, the group has aimed to make it as simplistic as possible, while still using appropriate technical language and descriptions, to allow for more effective communication between other cultures, other engineering disciplines, and the general community at large.

**Develop an appreciation of some of the complexities of working cross culturally**

In any engineering project; a professional engineer must have an understanding of the social, cultural, global and environmental impacts of their design, and their responsibilities to create a sustainable product. When working with other cultures, these impacts may be different to those experienced in the everyday life of the group of engineers working on the project. Therefore, when solving the energy problem within the Devikulam region, the group has had to take into account the culture and way of life of the inhabitants of Devikulam, and be sensitive to these cultural differences in order to produce an effective design that has economic and cultural merit, and can be used in a way that will not offend the community or force it to change its way of life.

After taking the EWB aims into consideration, the group has proposed a solution to the energy problem in Devikulam by designing a bio-digester. This bio-digester makes use of a readily available fuel source (animal and plant waste) in an economic and reasonably environmentally friendly way to produce methane that can then be burnt in cooking or heating. This design satisfies the EWB aims and is the most appropriate design as it is relatively cheap, requires minimal maintenance, and does not adversely affect the lives or environment of the community of Devikulam.
TEAM REFLECTION

The Group (DT04 Group 6), consisting of Stephen Biviano, John Matins, James Virtue, Graham Haines, and James Papadios, worked well together in an equal and professional manner. The group worked to the best of their abilities to produce a comprehensive and accurate analysis of what it believes is one of the most effective ways to solve the energy problem in the village of Devikulum – the biodigester.

What was the largest obstacle faced while working on the Challenge?

While it was understood that the community of Devikulum was a poor community, the group felt that finding accurate information about the financial status and lives of the inhabitants, in order to determine how well they would cope with the costs of installing and maintaining a biodigester was extremely difficult. Although this information was eventually discovered, the research process was long and laborious. Another issue the group faced was the construction of a physical model. As the biodigester is a large metal object placed in the ground a scale model needed to be made. This proved difficult to complete, as the inner workings of the biodigester and storage tank system were difficult to accurately represent on such a scale. The costing of this project also proved to be quite difficult for our group, due to the number of factors that affect the cost of the materials. These factors include, the type of metal/material used, different import/transport costs, the costs of the formation process, environmental costs, and the change in maintenance costs. As a result, the combination of the cheapest and best quality materials to be used for the biodigester was difficult to decide.

What impact did working as a team have on your project?

Working as a team worked well for the group, and was appropriate for this assignment as each member was able to complete the task that best suited their strengths,
allowing a higher quality overall assignment to be produced. However, the need for quality communication was required to ensure that every member in the group understood every part of the assignment, including the research and parts of the report written by each member.

This teamwork also allowed for more ideas to be proposed and discussed, with this richer discussion allowing the team to determine the very best design that would most appropriately resolve the energy problem in Devikulum. Each group member’s valued opinion and reflection on the assignment has allowed the group to come to the conclusion that a biodigester with a storage tank is the most appropriate design to be built for the people of Devikulum.

If you had it to do over again what would you change about the project?

Given the sensitive nature of the information, and the difficulty in finding the information about the financial status of the community of Devikulum, if the group was to do the assignment again a rough budget would need to be provided by EWB. This would aid the group in deciding which designs are the most appropriate, given cost is the most influential factor in determining the success of the design, as it would know the rough amount the community would be willing to spend on the project. In knowing this, the group will be able to reject all designs that do not meet this criterion.

Another important change would be for EWB to give an indication of which areas are of the greatest concern for the community of Devikulum. This would enable the group to choose a project that would be of most benefit to the entire community, as this is the aim of the assignment. In knowing this, the group will be able to produce a design that is best suited to the needs of the community.

What was the most enjoyable part of the Challenge experience?

The group found that one of the most enjoyable aspects of this assignment was being able to work with other talented and committed group members on a task that will hopefully be able to benefit an impoverished community by making an important
difference to their everyday lives. A sense of satisfaction was gained in completing the challenge, as the group was able to produce a design that will make a real difference to the community of Devikulam, and enable them to become a more self-sufficient village with a greater quality of life. It is hoped that this design that meets the EWB criteria will be able to be produced in a way that allows the Devikulam community to prosper and improve in the future.

After reflecting on the group’s proposed design, it is evident that the design adequately meets the judging criteria set out on the EWB Website. The group has determined that the design strongly reflects the judging criteria in a highly suitable manner; however, there is a flaw to the bio-digester. The major issue is that, while appropriate for the current population, if the population were to increase, the amount of energy that can be produced by the bio-digester may not be sufficient for the new population. However, this would most likely only affect the community after a period of time, in which the quality of life within the village will have improved enough for the community to develop its own solution that they deem to be most appropriate for them. As this is the case, the group believes a bio-digester is still the best option to solve the energy problem in Devikulam.
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1. Problem Definition

This project design is proposed to Engineers Without Borders to introduce new ideas to support the community of Devikulam whilst staying within design brief criteria. The problem that is addressed in this report is directly related to the lack of sustainable and reliable energy available to the village people of Devikulam. Electricity supply is a concern for the people of Devikulam and black-outs tend to occur on a regular basis due to the inconsistent supply. This has meant that the people of Devikulam have needed to rely on other means of energy supply for various daily tasks such as cooking and heating. The role of this report is to address alternative solutions to supply energy for these tasks that cannot rely on the electricity supply.

1.1 Background Information

Devikulam is a small village located in the state of Tamil Nadu, India. Approximately 358 people as a whole face many challenges and issues in their everyday lives in regards to transportation, clean water supplies, sanitation systems, reliable energy sources, housing, waste management, communication and technology.

Below is a table that provides data of figures about the town and people in 2008

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Households</td>
<td>86</td>
</tr>
<tr>
<td>Population</td>
<td>358</td>
</tr>
<tr>
<td>Number of Males</td>
<td>173</td>
</tr>
<tr>
<td>Number of Females</td>
<td>185</td>
</tr>
<tr>
<td>Under 18 Years Old</td>
<td>109</td>
</tr>
<tr>
<td>Average Household Number</td>
<td>4.16</td>
</tr>
<tr>
<td>Average Yearly Income</td>
<td>19,474</td>
</tr>
<tr>
<td>Average Age Total</td>
<td>28.06</td>
</tr>
<tr>
<td>Average Age Males</td>
<td>28.56</td>
</tr>
<tr>
<td>Average Age Females</td>
<td>27.75</td>
</tr>
</tbody>
</table>

Table 1: Devikulam Population Statistics - Source: buzza.in/Gramap2/Devikulam_Household_Statistics.pdf
1.2 Statement of Problem and Design Requirements

According to 2008 statistics, there are 86 households. These households produce waste, and have limited access to an unreliable source of electricity. Therefore, other means of energy have to be explored and analysed to support their daily needs. This could include producing methane gas through the process of biodigestion for cooking, and if possible, to chain other useful applications, such as a boiler for electricity generation to the bio-digester.

There are a number of requirements that need to be met if the system for energy supply is to be efficient. These are described in the table below:

<table>
<thead>
<tr>
<th>Design Requirement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>The design that is to be chosen, needs to require minimal amount of maintenance since the labour efforts required for maintenance may not be met due to the small population of Devikulam. Another reason why the labour requirements may not be met is that most of the population require time to complete tasks to sustain their living conditions as well as earn a valuable income to support their way of life.</td>
</tr>
<tr>
<td>Energy Efficient</td>
<td>The aim of this task is to provide a solution to the energy problem in Devikulam. Therefore, the design must provide a solution that is energy efficient and easily applied to provide households with a consistent flow of energy.</td>
</tr>
<tr>
<td>Operational Difficulty</td>
<td>The people of Devikulam are not very intelligent and would require direct and simple directions to complete tasks. If the operational difficulty is too high for the people of Devikulam, then the design would be ineffective and inefficient.</td>
</tr>
<tr>
<td>Economically Feasible and sustainable</td>
<td>The design chosen must be cheap however still be efficient and durable so that the money put into the construction, operation and maintenance of the design will not be a waste. It must be sustainable so that the initial cost is justified.</td>
</tr>
<tr>
<td>Compatible with practices already in place</td>
<td>The design must be easily adapted to current practices so that operation of the design will not affect the current lifestyle and practices in a negative way.</td>
</tr>
</tbody>
</table>

Table 2: Design Requirements
1.3 Scope, Limitations and Technical Review

The scope of this project is to provide a more exceptional waste management system and to provide a more reliable source of energy. The major limitation to this project is not being on the "field" to analyse the full situation, do on site research and ask questions to the community to see what would apply best.

Why use Bio-digesters?

It has already been proven that bio-digestive systems are an effective method of producing energy that can be used in India. In the tropical south Indian state of Kerala, there has already been a successful implementation of these systems in a town called Kadakkal in the Kollam district. Today the plant is capable of producing three kilowatts of energy, from digesting a tonne of waste daily. This is enough to power more than a hundred street lamps.

For each biogas plant what is most valuable is wet waste - a rich slurry, which in some cases includes blood and effluents from the local slaughter house. This slurry is run through a pre-digester to optimise bacterial action. Each treatment plant can be tailored to suit the area in which it is placed in. Fuel sources that may be abundant in one area may not be so in another. The usual treatment plants are sometimes not capable of dealing with dry leaves and plants. Treatment of this fibre-rich vegetable matter creates ‘scum’ in the systems; this reduces their efficiency and must therefore be removed.

At the Kadakkal station, there is minimal wastage. Such is the efficiency of this system that even the water used in the system is extracted and recycled so that it can be sent back to flush out abattoirs.

What kind of outputs are we going to get?

Obviously one of the first questions that needs to be addressed when planning to design a bio-digesting system is; “How much energy am I going to get from it?” To answer this question it is important to consider that the performance of a bio-digester
is determined by a range of factors. The gross amount of energy that could potentially be generated is approximated most accurately as the number of people and cows available for fuel and the capacity of the system.

Using the anaerobic process, there is a certain amount of methane produced per kilogram of solid matter that is broken down by the bacterium in the system – the gas yield. Quite obviously the amount of fuel available to use will depend on the number and of course species of animals available in the community. An overall analysis depicts exactly this:

<table>
<thead>
<tr>
<th></th>
<th>Swine (68 kilograms)</th>
<th>Dairy (545 Kilograms)</th>
<th>Poultry (1.8 Kilograms)</th>
<th>Beef (454 kilograms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas yield, cubic metre per kilogram</td>
<td>0.75</td>
<td>0.48</td>
<td>0.54</td>
<td>0.94</td>
</tr>
<tr>
<td>Volatile solids voided, kilograms per day</td>
<td>0.32</td>
<td>4.31</td>
<td>0.02</td>
<td>2.27</td>
</tr>
<tr>
<td>Percent reduction of volatile solids</td>
<td>49</td>
<td>31</td>
<td>56</td>
<td>41</td>
</tr>
<tr>
<td>Potential gas production cubic metre per animal unit per day</td>
<td>0.12</td>
<td>0.64</td>
<td>0.006</td>
<td>0.88</td>
</tr>
<tr>
<td>Energy production rate, kilojoules per hour per animal</td>
<td>1139</td>
<td>6279</td>
<td>58</td>
<td>8568</td>
</tr>
<tr>
<td>Available energy kilojoules per hour (after heating digester)</td>
<td>774</td>
<td>4201</td>
<td>339</td>
<td>5749</td>
</tr>
</tbody>
</table>


It is generally accepted, according to Biorock (2011) that “To produce 1 m³ of BIOGAS, to cook 3 meals daily for a small family of 4 you need at least 5 litres of pig manure/day. 8 large pigs (breeding adults) will produce 5+ litres/day and 8 cows will produce 5+ litres/day easily.” A plant of this size producing this amount of methane is sufficient to provide a family of 4-6 with gas for cooking and gas light purposes.

**How much work needs to be put into maintaining and running the bio-digesters?**

After analysing the output for a bio-digesting system it is also important to consider how much work is going to be needed to be put into maintain and running the bio-
digestive system. Due to a wide range of possible designs and operating conditions, accurate estimates of the cost of building digester systems are often difficult to calculate. But with careful consideration the only costs for establishing a system big enough for powering a small village like Devikulam are:

- Materials used to build,
- Animals used to fuel the system (already established though),
- Tools used to install and effectively manage the system,
- Labour (time out of people’s days), and
- Storage.

Maintenance costs are also hard to estimate, it is dependent on the size and demand of the bio-digestive system. There is no cost to power the system, as the local climate is perfect for the process keeping the temperature constant, at about 38°C, and water is abundant.

2 Design Options

2.1 Theory of Bio-digestion

What is a Bio-digester?
A bio-digester is a system which extracts energy in the form of methane gas from organic matter. All types of biomass or organic matter can be used to produce useful energy due their specific make up, on an atomic level. All forms of biomass consist mainly of carbohydrate compounds which contain the useful elements; carbon, oxygen and hydrogen.
There are many processes that can be applied to biomass to extract useful energy, however for the purpose of Devikulam, the best suited extraction process is based on the digestion processes of anaerobic bacteria. This specific form of bacteria can only survive in an oxygen free environment. Therefore, the process of digestion is only possible if all the oxygen that exists within the biomass is removed, and no further access to oxygen is possible. Since, initially, oxygen is present in the biomass, specific bacteria will naturally extract that oxygen as an energy source to live. Once all the oxygen is removed by this specific bacterium, digestion via various types of bacteria can take place, and this is the main source of useful methane gas produced. Specific types of bacteria undergo reactions by feeding on the biomass, producing bi-products for further types of bacteria to develop and feed off.
**Stages of Bio-digestion**

The first stage in the digestion process involves the breaking down of specific organic material that is digestible (e.g. fats and proteins) by acid-producing bacteria into simpler compounds. This acid-producing bacteria aims to produce enzymes, and liquefy the raw materials. The most important compound that is produced from the breakdown of the biomass is acetic acid which is used extensively in the second stage of the digestion process. During the second stage, the methane-producing bacterium is able to feed off the enzymes that break down the acid, causing the production of methane gas. The acetic acid is specifically important as it is responsible for producing about 70% of the total methane produced.

![Figure 2: Bio-digestion Process](http://en.wikipedia.org/wiki/File:Stages_of_anaerobic_digestion.JPG)

**Analysis of output from a bio-digester**

The methane gas produced during this digestion process is insoluble and separated completely from the biomass. Therefore, the collection of the methane gas produced is simple and can act as a very useful energy source. Great care must be taken in the extraction and storage of this gas however, because it is explosive. This is an important concept that will be considered in the design of the bio-digester. Methane gas requires a high pressure to be liquefied (about 34,450 kPa) and therefore, direct usage of the methane in its gaseous state is preferred.

The output of methane increases with temperature increase and so therefore, this method of methane extraction is ideal for India’s climate where in the southern parts
of India experience high temperatures during the majority of the year. Anaerobic digestion can occur at any temperature between 4 and 60 °C however, particular temperature ranges are preferred for specific bacteria. The bacteria named mesophiles are most efficient between 20 and 40 °C where as bacteria named thermophiles are most efficient between 40 and 60 °C. Digestion can also occur at temperatures below 20°C however the speed of methane production is greatly reduced. The methane-producing bacteria also don’t operate to their full potential under temperature changes, so therefore, considering temperature variations is another important concept that must be incorporated into the design of the biodigester.

Maintaining a balance of nutrients in the bio-digester is important to achieve efficient production of methane. Specific nutrients required by the bacteria often consist of nitrogen and phosphorous, and if the quantities of these two elements are not present in large portions in the biomass, then the quality and amount of gas will be reduced. Animal manure contains the most amount of nutrients for bacteria growth compared to crop residues and various other forms of biomass. The most optimum ratio of carbon to nitrogen within the biomass that is fed into the bio-digester is about 15:19.

**Disadvantages of Bio-digesters**

An issue with the bio-digester is that of scum formation, which must be maintained for optimum gas production. The scum is caused by light particles being carried by the methane gas to the top layers and since these particles contain gas, they remain at the top and build up. The rate of removal of this scum depends on the rate of loading, however, an easy removal system needs to be considered in the design of the biodigester. A possible way to prevent major amounts of scum from forming is to remove floating particles from the slurry (biomass mixed with water to reduce particle size) before adding it to the bio-digester. There are also particular solids that are not digested by the bacteria and sink to the bottom of the slurry. This collection of undigested solids needs to be considered in the design of the bio-digester to allow for efficient removal.
2.2 Design Concepts

There are various different design ideas to be used for the bio-digester. In the past the designs for the bio-digester were not aimed at low-income farmers, as the materials used, and the money to actually build the structure were very high. This led engineers to develop various other types of bio-digester systems which enabled low-income farmers to purchase the system. These various other types of systems may have included low-cost plastic, a smaller and simpler system, or even a different design e.g. having the system underground.

The approaches discussed in this report for making bio-digesters much more efficient is to have the gas stored in a tank for later use or to chain a boiler to the bio-digester to use the gas that would otherwise be wasted. Storage of methane gas is only useful if it is stored for a short period of time, since lengthy storage would require energy input to liquefy the methane gas. This applies well to the project because cooking is usually done at midday or night. These are the only times that gas can be used and therefore at other times, instead of wasting the gas, we can store it to maximise usage when it is needed. By doing this, we can also transport the gas to other areas or households where needed via pipes. Storing methane gas into a tank will optimise its use by having it as a backup energy source when the bio-digester is not in direct use or demand of the bio-digester is too high. The boiler could offer many useful applications of the methane gas as a fuel source. Each application would improve the quality of life for the people of Devikulam. Examples include providing energy in the form of electricity through steam, or creating higher quality drinking water via boiling.
2.2.1 Design Concept 1: Bio-Digester

The design for this report is mainly based on the ‘Chinese Way’ of constructing a bio-digester. Yet the group’s design includes modifications to the “Chinese design” so as to make the system more reliable, and easier to maintain. This design of bio-digester system is constructed from either bricks, stone or poured concrete. Either of these materials is used to create a gas-tight chamber which is needed for the production of methane gas. As seen in the image above, the design idea for the bio-digester system is located underground, whereby; all waste to be used to source the bio-digester, is fed into the system via the inlet pipe which is located at ground level.

This design includes an air-tight compartment in the inlet pipe, so, when waste is being fed into the system, very little oxygen enters the vessel. This is needed as oxygen tends to slow down the production process as the oxygen in the system must be removed by bacteria first before digestion can occur.

One of the main problems with bio-digesters is maintenance. As when scum is formed within the vessel, it is needed to be removed for a more productive efficiency rate. As scum rises to the top of the vessel, this design incorporated a separate section at the top of the vessel to trap the scum, and when maintenance is required, the connection...
from the separate section to vessel is sealed tight, so when removing the scum, very little oxygen enters the vessel.

After the waste has been used to create the methane gas, the waste must be removed from the vessel to avoid accumulation. The Bio-Digester was designed in way to make the process of removing the waste easier and more time efficient. In the design proposal, a pipe with a pump is to be placed within the structure that connects the base of the vessel, to ground level. After the waste has been used to create the methane gas, the pipe is used to pump out all the excess waste. This way no oxygen will enter the system as the pipe is pumping out all the waste instead of manually opening the system to remove the waste.

### 2.2.2 Design Concept 2: Storage Tank

![Gas Storage Tank Design](image)

The residents of the village would not be able to access the methane gas all at once if the gas was not placed within a storage container; this is why a storage tank also needs to be designed with the Bio-digester system. For our storage tank design we used the water sealed gasometer method of production. This design type is more efficient and durable than other ideas, as it more readily accessible, does not fail over time, and less maintenance is required.
The design idea consists of an above ground cylindrical storage container made of brick and concrete to hold water. Another cylindrical container is placed upside down within the brick container; this will be used to store the methane gas. As more gas is produced by the bio-digester, and fed through the pipes, the cylindrical container rises above the water. This feature is used to help ensure that the gas remains at a compressed state, allowing the gas do be expended when required.

When the gas is formed within the Bio-digester vessel, a pipe will lead the methane gas from the vessel into the storage tank. A gasometer will be used to calculate how much methane is stored within the tank to help ensure that the container does not fail due to overloading.

The storage tank will be designed in a way, so that when the whole village needs to access the gas, e.g. breakfast, lunch, and dinner, the storage supply will be open, by means of a valve located at the top of the tank, to the whole village, then shut off at a certain time. As if the gas was to be open to village at all times of the day, the amount of gas produced would be less than to the amount of gas used.

### 2.2.3 Design Concept 3: Boiler

A boiler is a closed vessel that contains water which is heated through a series of pipes running through the interior. Heat is forced through the pipes by a combustion source at the base of the vessel and is then released through the chimney causing the water to boil thus releasing steam through another pipe.

The focus behind this idea is to have a low cost solution by using a boiler to either have:

a) Cleaner drinking water with steam energy or;

b) Sacrificing steam energy for sterile drinking water.

In both cases of this concept, the combustion process relies on a bio-digesters methane gas as a fuel source.
### 2.2.3.1 Design Concept 3: Boiler Option A:

Boiling water will kill most of the harmful bacterial germs but the water will still contain salts. The steam energy produced can power a small steam turbine that will be able to generate electricity. The electricity produced can be used to power homes directly or recharge batteries that can be used to power a home.

Figure 6: Steam Boiler with Steam Turbine – Source: [http://www.epa.gov/chp/basic/](http://www.epa.gov/chp/basic/)
2.2.3.2 Design Concept 3: Boiler Option B:

If purifying water is the main focus, a float and thermostatic steam trap can be attached to the steam release pipe to create condensation. As steam is formed, it leaves behind any salts inside the boiler. This float and thermostatic steam trap offers a combination of mechanical and thermostatic operation. A closed float is used to sense the density difference between a gas and a liquid. The float is attached to one end of the lever which pivots inside the trap. At the opposite end of the lever is a valve that is seated when the float is at rest. Condensate enters through the top of the trap and raises the float opening the valve. The condensate drains from the trap through the outlet near the bottom leaving the condensate seal between the inlad and the valve. Above this seal is the thermostatic bellows. The bellows responds to temperate change. When the space is filled with hot steam, the thermostatic valve is closed. Other substances that aren't condensation, such as air mixed with the steam cool the space near the top of the trap. When the bellows element cools sufficiently the thermostatic valve will open and vent these gasses into a passage leading to the trap discharge.
Figure 8: Float and Thermostatic Steam Trap – Source:
2.3 Option Selection

<table>
<thead>
<tr>
<th>Design Option</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio-digester</td>
<td>-Cheapest option.</td>
<td>- Gas is wasted when not directly used.</td>
</tr>
<tr>
<td></td>
<td>-Minimal Maintenance.</td>
<td>- When the waste needs to be replaced, the gas supply is disconnected, therefore, multiple bio-digesters would be required if constant gas flow is to be achieved.</td>
</tr>
<tr>
<td></td>
<td>-Easy to use and implement.</td>
<td></td>
</tr>
<tr>
<td>Bio-digester and storage tank</td>
<td>- Gas is stored when not used rather than wasted.</td>
<td>- Extra maintenance required for storage tank.</td>
</tr>
<tr>
<td></td>
<td>-The bio-digester does not need to be running constantly to provide a constant gas supply. Therefore more regular replacements of waste can be made producing a better quality gas.</td>
<td>- Slightly more expensive due to materials for the large storage tank.</td>
</tr>
<tr>
<td>Bio-digester and Boiler (Option A)</td>
<td>-Gas is not wasted because when it is not used by the village, it is used to fuel the boiler.</td>
<td>-Large boiler would require higher budget, and a higher degree of understanding for operational practice.</td>
</tr>
<tr>
<td></td>
<td>-Offers another source of electricity that can be linked to the electricity grid.</td>
<td>-Much more maintenance is required.</td>
</tr>
<tr>
<td>Bio-digester and Boiler (Option B)</td>
<td>-Gas is not wasted because when it is not used by the village, it is used to fuel the boiler.</td>
<td>-Large boiler and steam trap would require higher budget, and a higher degree of understanding for operational practice.</td>
</tr>
<tr>
<td></td>
<td>-Offers a way to purify water, to improve quality of health for people of Devikulam.</td>
<td>-Much more maintenance is required.</td>
</tr>
</tbody>
</table>

Table 4: Option Selection
<table>
<thead>
<tr>
<th>Design Requirement</th>
<th>Design 1</th>
<th>Design 2</th>
<th>Design 3</th>
<th>Design 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>8</td>
<td>6</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Energy Efficient</td>
<td>3</td>
<td>9</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Operational Difficulty</td>
<td>8</td>
<td>7</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Economically Feasible and sustainable</td>
<td>7</td>
<td>8</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Compatible with practices already in place</td>
<td>9</td>
<td>8</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>35</td>
<td>38</td>
<td>26</td>
<td>23</td>
</tr>
</tbody>
</table>

Table 5: Analysis of design options

Scale:
1: Very little to no fulfilment of design requirement.
10: Fulfils design requirement efficiently.

### 2.3.1 Option Selection Analysis

In terms of simplicity, the Bio-digester on its own would be the best option however in this case, energy is wasted, and upon replacement, energy supply is also not consistent. The storage tank is much easier to operate compared to the boiler which fits perfectly with the operational difficulty design requirement. The only operational requirement for the storage tank is to adjust the valve appropriately. Other functions of the storage tank are automatic and require no human interaction.

In terms of maintenance requirements, the storage tank does require regular check-ups on the water quality within the storage tank and secure pipe connections as well as regular cleaning of any algae that may develop within the storage tank.

The boiler on the other hand would require much more maintenance which would also be much more costly than the maintenance of the storage tank. Regular operational assessments as well as safety checks are required to ensure the boiler is in top working condition as well as ensuring the safety of the people in the village.
The boiler would be a new concept to be brought into the village, and therefore, would slightly change the lives of the people of Devikulam. It would have a positive impact, however its applications would be very new to the people and they may not be able to comprehend its potential. This will mean that the cost involved in installing, operating and maintaining the boiler would not be justified resulting in money being wasted. On the other hand, the storage tank simply stores the gas to provide a back up supply for the gas supply to homes. This use of gas for heating and cooking is already in action if Devikulam, and therefore, installation of this design system would only result in boost in energy efficiency.

The materials used for the bio-digester and the storage tank are easily supplied and repaired if needed. These materials will also last a substantial amount of time, if built correctly. The materials and mechanical systems involved in the boiler would be much more difficult to repair if any error were to go wrong. The cost for repair would also be much greater than the cost for repair for materials used in storage tank and bio-digester.

The boiler and the storage tank are both much more energy efficient compared to the bio-digester on its own, however due to the assessments of other design requirements, the storage tank is better suited for the needs of the people of Devikulam. Therefore, the final design option chosen for the report is the Bio-digester and storage tank.
3 Design Description

3.1 Design Summary

The design chosen consists of a bio-digester system connected to a storage tank. The bio-digester system is designed to be built underground with a supply pipe and exit pipe to supply and remove the waste products required for bio-digestion. The bio-digester is mainly built of concrete and PVC piping with a black plastic sheet to cover the bio-digester to capture the gas produced. The PVC pipes are connected to the bio-digester and feed the gas from the bio-digester to the storage tank as well as to the village stoves in households. The valves are used to direct the gas to the desired location and require little effort to adjust. The bio-digester also contains a mixing rope with jugs filled with sand connected to it to break up any solid wastes that emerge to the top of the mixture. Another feature added, is bent plastic pipes which prevent the black plastic cover from contacting the waste mixture when gas production is beginning. Connected to the exit pipe is also a vacuum pump which is used to prevent a build up of undigested solids at the bottom of the bio-digester.

The storage tank is mainly built of brick with a concrete slab base. This storage tank uses water in conjunction with a plastic container to capture the gas so that it can be used when it is required. There are entry and exit pipes which are directed through to brick to the plastic container. These are used to supply and remove the gas from the storage container as the gas is produced and used. The plastic container has weights above it to contain the gas inside the plastic in a slightly pressurised state so that when the gas is needed, gas flow is smooth and efficient.
3.2 Functional Block Diagrams

Figure 9: Bio-digester
Figure 10: Storage Tank
3.3 Functional Description

Referring to the function black diagrams, below is a summarised list of the functions of the bio-digester and storage tank:

1. Supply pipe, which is used to feed the waste into the bio-digester. The width of the pipe is 6 inches to provide adequate flow if waste products into the bio-digester whilst limiting cost.

2. 1-way valve, which is opened and closed at appropriate times to supply the bio-digester with the waste whilst restricting the amount of oxygen entering the bio-digester tank.

3. Cement wall, which is used to contain the nutrients inside the bio-digester. It is also a cheap material which relates directly to the cost efficiency which is mentioned in the design requirements.

4. Plastic cover, used to prevent oxygen entering the tank as well as expand and contract when gas is produced and expended.

5. Curved plastic tubes, used to hold up the plastic cover to prevent it from touching the waste mixture when refuelling is required.

6. Jugs half filled with sand which are hung by a connector rope. These are used to separate any solid waste that has not broken down properly.

7. Gas sealed PVC pipe, which is used to transfer the methane gas from the bio-digester to the pipe system.

8. Exit pipe, which is an oxygen free pathway for any excess waste that has not been broken down by bacteria.

9. Vacuum pump, which is used to extract the waste from the bio-digester that hasn’t been broken down by the bacteria.

10. Pipe system, which supplies the methane gas to the 3-way valve.

11. 3-way valve, which is used to direct the gas flow to the village, and the storage tank.

12. Brick wall, which is used to enclose the water within that tank that is essential to contain the methane gas.
13. Concrete slab, provides a base for the storage tank.

14. Gas supply pipe, used to provide the storage system with methane gas produced in the bio-digester.

15. Plastic container, used to trap the gas in a slightly compressed state.

16. Water, which is also used to trap the gas so no leakage occurs.

17. 2 5kg weights, which are used to supply compression for the gas inside the plastic container. This is needed for easy gas flow when needed.

18. Exit pipe, used to extract the methane gas from the storage system, and direct it to the 3 way valve.

3.4 Computer Aided Design (ProEngineer)

Figure 11: Front View of Bio-digester

Figure 12: Eagle View of Bio-digester and Storage System
Figure 13: Storage System

Figure 14: Front view of Bio-digester and Storage System
3.4 Manufacturing Procedure

3.4.1 Materials Required for the Bio-digester and storage system

- 12 50-kilogram sacks of cement.
- 1.5 cubic metres of rock mixture.
- 2.5 cubic metres of sand.
- Plastic sheet measuring 6 metres by 3 metres.
- 4 metres of PVC tubing with a 6 inch diameter.
- 15 metres of PVC tubing with a ½ inch diameter.
- PVC pipe elbow joints with the ability to fit a ½ inch diameter pipe.
- Vacuum pump able to fit a 6 inch diameter PVC pipe.
- 2 Valves, 1 with the ability to fit a 6 inch diameter, and the other with the ability to fit a ½ inch diameter pipe. Both are to be operated by a turning handle.
- A 3-way valve that is hand operated, and will fit a 6 inch diameter PVC pipe.
- 6 solid plastic pins with a radius of 1 centimetre and a length of 15 centimetres.
- Drill, with drill bit measuring 2 centimetres in diameter.
- 40 cement blocks of size 12 cm x 20cm x 40cm.
- 6 curved plastic tubes, measuring 60 centimetres long.
- PVC rubber cement
- 3 litre jugs.
- 1 rope 5 metres long
- 2 straight plastic tubes measuring 30 centimetres.
- Rubber plug to fit a 6 inch diameter pipe.
- A sufficient amount of bricks required to build a square storage system that is 5 metres long and 5 metres wide and 2 metres high.
- 2 Steel weights, measuring 5kg each.
- 1 hollow plastic container measuring 4 metres wide, 4 metres long and 1 metre high.
3.4.2 Manufacture of the Bio-digester

Steps

1. Use a shovel to dig a hole in the ground that is 1.5 metres wide, 3 metres long and 2 metres deep.

2. Use a shovel to dig a ditch leading to the larger hole that is 45° from the horizontal. This ditch should travel to the larger hole so that the entrance to the large hole is about 50 centimetres above the floor of the bio-digester. This ditch is used for the supply tube.

3. Use the shovel to dig another ditch on the other side of the bio-digester that is 30° from the horizontal, and meets the large hole about 30 centimetres above the floor of the bio-digester. This ditch is used for the exit pipe.

4. Cut the 6 inch diameter PVC pipe in half using one for the exit pipe and one for the supply pipe. Make sure the PVC pipe has a sufficient length to reach the ground level from the bio-digester tank.

5. Cut a section about 30 centimetres long off the supply pipe and connect the valve to the two pieces of pipe. This will allow efficient supply of slurry to the bio-digester, without allowing oxygen to enter the tank.

6. Connect the vacuum pump to the end of the exit pipe, making sure that it is sealed well enough to allow no oxygen to enter the bio-digester.

7. Create the cement for the walls with a cement mixer making sure the sacks of cement are mixed with the sand and the rock in the ratio given in the materials section.

8. Create the cement wall making sure that the supply pipe and exit pipe are inserted to the height and angle required to ensure the cement dries correctly around the pipes. The length and width dimensions of the cement wall should be the same as the hole that has been dug in the ground, allowing for a wall thickness of 20 centimetres. The height of the wall should be 1.8 metres.

9. Place one layer of cement blocks around the top of the cement wall placing 2 plastic curved tubes bent upright on each side of the wall between 2 cement blocks, and 1 curved tube on each end of the wall curved upright between 2 cement
blocks. Make sure the plastic curved tubes reach at least 40 centimetres from the cement wall to the interior of the bio-digester tank. These pipes are used to hold up the plastic sheet and ensure that none of the plastic sheet touches the slurry beneath when the slurry is being loaded.

10. Put 2 straight plastic tubes on opposite corners of the bio-digester wall. These tubes are used to allow the rope to be fed through to the bio-digester tank.

11. Feed the rope through the straight tubes and glue the rope to the tubes using PVC rubber cement ensuring that the rope is tight across the tank.

12. Apply cement to the joins of the bricks so that the layer is sealed and no gas can leak through. Also apply PVC rubber cement around the tubes to reinforce the cement seal.

13. Half fill the 3 jugs with sand and attach the jugs to the rope so that it is evenly spaced across the bio-digester tank.

14. Using the drill and drill bit, create 6 holes 7.5 centimetres deep through the top surface of the cement blocks exactly in the centre. 1 hole is to be drilled on each of the ends of the wall, and 2 holes are to be drilled on each of the sides of the wall.

15. Insert one plastic pin in each hole, making sure PVC rubber cement is used to fix them into place.

16. Lay cement on the base of the bio-digester to create the floor, so that no nutrients can seep through the ground. Allow this to dry before proceeding.

17. Select 6 cement blocks that have not been used and using the drill, create a hole 7.5 centimetres deep in each block exactly in the centre. These bricks are to be used later to place on top of the plastic pins in the final cement block layer.

18. Lay out the black plastic sheet on the ground and mark out a rectangular section measuring 30 centimetres from the edge.

19. Fold the ends back to the marked line so that the edges have double thickness.

20. Place the plastic sheet over the cement wall and mark the sections on the plastic where the pins are pointing out and cut holes at those points so that the plastic sheeting can slot through the pins.

21. Cut a hole ½ an inch in diameter in the exact centre of the plastic sheet.
22. Glue a section of the ½ inch diameter PVC pipe 40 centimetres long to the hole with PVC rubber cement, allowing no section for oxygen to enter the bio-digester.

23. Place the last layer of cement blocks over the top of the plastic sheet ensuring that the blocks containing the holes are placed in the correct positions. Apply cement mix to join the blocks together and seal the plastic sheeting to the cement wall, allowing no air to escape the bio-digester.

24. Attach a PVC elbow joint to the ½ inch diameter pipe and connect a 1 metre long section of ½ inch diameter PVC pipe to the other end of the elbow joint.

25. At the end of the ½ inch PVC pipe, connect the 3-way valve, which will allow user control of the direction of methane gas flow. One section of pipe can be connected to one output section of the valve to supply direct gas for cooking. Another output section of the valve will be connected to the storage container. The last output section will also be connected to the storage container however this pipe will direct gas back to the valve when needed.

3.4.3 Manufacture of the Storage System

Steps

1. The first task is to create a cement slab measuring 5 metres by 5 metres and 20 centimetres high.

2. Create the brick frame for the storage tank. The dimensions required are 5 metres wide, 5 metres long and 2 metres high. Use the cement slab as the base to build the storage tank up from. Make sure two ½ inch diameter PVC pipes are placed on either side of the storage tank through the brick layer. These should be placed half a metre high and must be placed in the join between 4 surrounding bricks. These must be sealed so that no water can escape the inside of the tank.

3. Once the brick frame is completed, elbow joints must be attached both of the pipes protruding though the brick frame. Another section of pipe must be connected to these elbow joints measuring 1 metre and must be vertically upwards.

4. At the other end of the pipes, which is pointing out of the tank, attach another elbow joint to each pipe and cut two 3 metre long sections of ½ inch diameter PVC
pipe to connect to the other end of the elbow joint, directed horizontal to the ground.

5. Connect another elbow joint to each vertical section of pipe directing the pipes towards each other in front of the storage tank.

6. Cut a sufficient length of ½ inch PVC pipe for each end to connect to the 3 way valve from the bio-digester.

7. Attach the steel weights to the top of the plastic container.

8. Fill the storage tank with water up to a level of 1 metre above ground.

9. Place the plastic container upside down inside the storage tank, so that it submerges into the water. Also ensure that the plastic container is placed over the two pipes.

4 Design Description Supporting Documents

4.1 Implementation Plan

This implementation plan will describe in depth how the design will be put to use. There are four parts which include: a designated compost pit, starting the bio-digester, operating the bio-digester, and a Trouble Shooting Guide.

4.1.1 Implementation Procedure

4.1.1.1 Compost Pit

To operate the bio-digester efficiently, it would be wise if it was built next to an animal pen with a designated compost pit so that there is less movement in transferring the materials. The compost pit will be a three stage process where the first stage should only be fed organic scraps such as fruits, vegetables, etc. No regular garbage should ever be used such as plastics, metals, and paper materials. Stage two of the process is when organic waste is fed into stage one. It takes a fortnight with proper mixing and aeration for it to reach to the third stage which should look like dirt with some existing pieces of organic materials. If the season is dry, each stage should be watered
substantially once a week to assist the decomposition process. The third stage should be prepared within 6-8 weeks to charge the bio-digester which will be discussed in 4.1.1.3.

4.1.1.2 Starting the bio-digester
To start the bio-digester, open all gas valves, including valves leading to stoves and storage containers. Next, remove the cap over the main chamber being cautious not to cause any sparks or break/damage any gas pipes exiting the bio-digester. Stir the contents inside the bio-digester with a large pole or stick. Add the solids removal pump into the main chamber of the bio-digester (DO NOT ENTER THE CHAMBER). It would be preferable to pump the contents away from the area. Fill the bio-digester halfway with water and continue stirring. Next test the water pH level with a chemical test kit, aiming for a pH level below 8.0. If above, clean out the bio-digester and continue process until it reads below 8.0. When pH level is 8.0, fill the bio-digester with water until it reaches to the level top of the effluent pipe. Then charge the bio-digester with approximately 150kg (depending on size of bio-digester) of cow manure (cow manure works best). Next is to close all valves on stoves and storage containers and replace the cap over the main chamber with an air tight seal (plug) because without an air tight seal, the bio-digester will lose its gas and pressure, thus, becoming useless. Allow the bio-digesters contents to sit between 4-6 weeks before using gas. After 2 weeks compost may be added.

4.1.1.3 Operating the bio-digester
After adding the first charge of cow manure and allowing it to sit for 2 weeks, charges of compost (stage 3) should be added at regular intervals such as 2-3 times a week. A suggested pattern is Monday, Wednesday, and Friday. If a charge is skipped, it may be added the day after. After 4-6 weeks, the chamber should be filled with methane gas and be ready to supply to stoves and storage containers. Before lighting the stoves, check to see if there is gas blowing out from the stove, this can be done with something light such as a feather. Place the feather on top of the outlet and if it blows
away, it is then ready for use. If the feather is sucked into the outlet then it is highly dangerous and can cause an explosion if lit. The bio-digester should provide enough gas for 1 outlet for at least 4 hours at a time. If the valve to the outlets is switched off, gas will then follow a path into a storage container for later use whilst the bio-digester continues to create methane gas.

4.1.4 Trouble Shooting

1. If the bio-digester fails to operate properly, check to make sure the pH level is between 7.0 and 8.5.
   - Stir the contents in the main chamber with a large pole or stick.
   - Add water and obtain a sample to check pH level again.
   - If pH level is higher than 8.5, repeat the steps from part 1. If pH level is under 8.5, continue to part 2.

2. Check to make sure the chamber is air tight.
   - This can be done by making sure all the valves are closed from the outlets and that the gas pipes are not damaged.
   - Check to see if the seal on the cap, to the main chamber, is air tight and not broken. If broken or damaged, replace the seal.
   - If the bio-digester continues to not produce gas from step 2, follow through instructions of step 1.

4.1.2 Additional Uses

The bio-digester can also be used as an effective waste management system where organic materials can be decomposed into either methane gas or fertilizer by compost pits to effectively grow grass or crops.
5 Discussion

5.1 Strengths and Weaknesses

With every project it is important to evaluate the effectiveness of the action, as to determine its strongest and weakest aspects. With this project, the positives and negatives are as follows:

<table>
<thead>
<tr>
<th>Positives</th>
<th>Negatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean Energy: Methane is burnt with little carbon emissions</td>
<td>Might not produce enough methane for demand from community without spending large amounts of money on multiple systems</td>
</tr>
<tr>
<td>Cheap to run</td>
<td>Community may not be interested in using faecal matter to fuel the system</td>
</tr>
<tr>
<td>Easy to use storage devices</td>
<td>Isolation of community may make it difficult to get the materials necessary, transported in.</td>
</tr>
<tr>
<td>Methane is produced naturally and efficiently</td>
<td>Methane is very flammable so naturally explosions can occur if safety precautions are not taken, eg good ventilation and emergency stopping switches.</td>
</tr>
<tr>
<td>Reduce methane emissions from the breaking down of cow excrement: which is linked to global warming.</td>
<td></td>
</tr>
<tr>
<td>Reliable source of energy</td>
<td></td>
</tr>
<tr>
<td>Fuel is an abundant, renewable source</td>
<td></td>
</tr>
<tr>
<td>Climate is perfect for the use of bio-digesters: hot and humid.</td>
<td></td>
</tr>
</tbody>
</table>

Table 6: Strengths and Weaknesses of the Bio-digester
5.2 Recommendations

The only recommendation to improve this project is to ensure quality materials are sourced, not only efficiency could be detrimentally affected but also the safety of those using it. We have chosen to build just the one bio-digester to minimise complications and effort, and have sourced relatively cheap materials. However if the quality of the system is not up to standard, leaks could occur and possible explosions take place. Therefore it is important that make sure that quality isn’t compromised for cost minimisation.

6 Evaluation

6.1 Evaluation Plan

In order for our design to work effectively and efficiently, it must meet the design requirements, as stated in section 1.2 of this report.

<table>
<thead>
<tr>
<th>Design Requirement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>The design that is to be chosen needs to require minimal amount of maintenance since the labour efforts required for maintenance may not be met due to the small population of Devikulam. Another reason why the labour requirements may not be met is that most of the population require time to complete tasks to sustain their living conditions as well as earn a valuable income to support their way of life.</td>
</tr>
<tr>
<td>Energy Efficient</td>
<td>The aim of this task is to provide a solution to the energy problem in Devikulam. Therefore, the design must provide a solution that is energy efficient and easily applied to provide households with a consistent flow of energy.</td>
</tr>
<tr>
<td>Operational Difficulty</td>
<td>The people of Devikulam are not well educated, and would therefore require direct and simple directions to complete tasks. If the operational difficulty is too high for the people of Devikulam, then the design would be ineffective and inefficient.</td>
</tr>
<tr>
<td>Economically Feasible and sustainable</td>
<td>The design chosen must be cheap however still be efficient and durable so that the money put into the construction, operation and maintenance of the design will not be a waste. It must be sustainable so that the initial cost is justified.</td>
</tr>
<tr>
<td>Compatible with</td>
<td>The design must be easily adapted to current practices so that</td>
</tr>
</tbody>
</table>
practices already in place operation of the design will not affect the current lifestyle and practices in a negative way.

TABLE 2: Design Requirements

Through conducting effective and insightful research into the way in which biodigesters function, and how they operate best to obtain maximum energy output, while also investigating the way in which this can be achieved with ease of use and minimal maintenance requirements; many of the above design requirements can be adequately tested. While we have not made a prototype of our design (as it is outside the bounds of this assignment, and would be impractical to build and complete in the time given) the research conducted will be able to give a sufficient description of how well our design meets the maintenance, energy efficiency, operational difficulty, and compatibility with current practice criteria. A full cost analysis of construction, operational, and maintenance costs will provide the financial details that will determine the bio-digester’s economic viability and feasibility.

6.2 Evaluation Results

As a result of our research into the materials and procedures required to construct, operate and maintain the bio-digester system, it can be concluded that a bio-digester is one of the most appropriate forms of energy production for the Devikulam area. This is due to the amount, and uses of energy the community requires, as well as its prime location to provide a fuel source for the bio-digester. Although, due to the amount and cost of the initial materials, the initial construction of the bio-digester will cost a large amount, particularly given the community of Devikulam is not particularly wealthy, the long term benefits that a bio-digester provides, make the bio-digester the most feasible option for this village.

The bio-digester is made of sturdy and durable materials that, although initially expensive to produce and install, will increase the life of the bio-digester, thereby minimising the maintenance required for the actual bio-digester. Some maintenance
will be required, however, within the bio-digester system, to remove the residual waste from the system after it has fermented and produced the methane that will be used as the energy source. This is necessary to ensure that the system functions properly and efficiently in a way that will produce a maximum amount of methane gas for use in heating and cooking. This maintenance is important and requires little effort, time and money, if continuously and thoroughly checked.

The design of the bio-digester produces and stores enough methane gas to provide enough energy to meet the needs of the community of Devikulam. The bio-digester uses a constant supply of readily available materials as its fuel source (animal and plant waste) to produce methane gas that can be used for the cooking and heating needs of the community, while the waste from the bio-digester can be used as fertiliser after it has undergone the fermentation process. Therefore the bio-digester system is an extremely efficient way of producing the required amount of energy in Devikulam village.

It is also relatively easy to operate, as the clearing of the residual waste to prevent a build up in the bio-digester and controlling the pressure in the storage tank is the only human interaction required to operate the system. Both of these things are simple to operate as they are controlled by opening and closing valves that allow either the waste to enter the pipe that leads away from the bio-digester, or the gas to enter the pipes for use in cooking and heating.

Given that Devikulam is a rural community, building a bio-digester in this region decreases the cost and amount of energy required to operate the bio-digester, as the fuel source (animal waste and compost) is not needed to be transferred large distances, and any residual waste from the bio-digester, after the methane has been taken out to be used, can be used as fertilizer. In this way, a bio-digester will generate a constant flow of energy with little impact on practices already in place, as farmers will still be able to use the animal and plant waste as fertilizer after it has gone through the...
bio-digester. The methane gas produced by the bio-digester can then be used for cooking and heat generation, allowing the little electrical supply the village has to be used for other purposes.

6.3 Cost Analysis

To be able to effectively produce enough methane to store and then be able to distribute for use in the community, a substantial amount of money will need to be spent. Both the storage container and the bio-digester, will be need to be of a size that is able to meet the demand of producing enough gas for the needs of a reasonable sized community. Cheap materials have been sourced as to minimise costs. The following budget has been estimated:

<table>
<thead>
<tr>
<th>Bio-Digester and Storage System Materials</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 12 x 50kg Cement</td>
<td>$220</td>
</tr>
<tr>
<td>- 1.5 cubic metres Blue Metal</td>
<td>$270</td>
</tr>
<tr>
<td>- 2.5 Cubic metres of Sand</td>
<td>$220</td>
</tr>
<tr>
<td>- PVC Tubing &amp; Joints</td>
<td>$120</td>
</tr>
<tr>
<td>- 40 Cement Blocks (12x20x40)</td>
<td>$200</td>
</tr>
<tr>
<td>- 3-Way Valve</td>
<td>$20</td>
</tr>
<tr>
<td>- Bricks for Storage Walls (20x10x7)</td>
<td>$150</td>
</tr>
<tr>
<td>- Vacuum Pump</td>
<td>$300</td>
</tr>
</tbody>
</table>

| Transportation                          | $100  |
| Miscellaneous                           | $150  |
| **Total**                               | **$1,750** |

Table 7: Cost Analysis

All prices are approximations, using CES Edupack 2010. Prices at time of purchase may vary.

A cash-flow diagram has chosen not to be used as an analysis tool as there will be only one transaction - that is the initial purchase of the specified materials.
# 6.4 Environmental Analysis

### Environmental Parameters

<table>
<thead>
<tr>
<th>Environmental Parameters</th>
<th>Concept #1: Bio-Digester</th>
<th>Concept #2: Bio-Digester w/ Storage System</th>
<th>Concept #3&amp;4: Bio-Digester w/ Boiler</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Physio-Chemical Environment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Earth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Mineral Resources</td>
<td>None</td>
<td>-med</td>
<td>None</td>
</tr>
<tr>
<td>2. Construction Material</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>3. Soils</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>4. Land Form</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>5. Radiation</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>6. Unique Physical Features</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>B. Water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Quantity</td>
<td>low</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>2. Quality</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>3. Temperature</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>4. Snow, ice and permafrost</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>C. Atmosphere</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Quality</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>2. Climate</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>3. Temperature</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>D. Processes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Floods</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>2. Erosion</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>3. Deposition</td>
<td>-med</td>
<td>-med</td>
<td>-med</td>
</tr>
<tr>
<td>4. Sorption</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>5. Compaction and Settling</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>6. Stability</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>7. Stress-strain</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>8. Air movements</td>
<td>None</td>
<td>-low</td>
<td>None</td>
</tr>
<tr>
<td>II. Biological Environment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Flora</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Trees</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>2. Shrubs</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>3. Grass</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
</tbody>
</table>
### IV. Crops

- **4. Crops**: None
- **5. Microflora**: None
- **6. Aquatic components**: None
- **7. Endangered Species**: None

### B. Fauna

- **1. Birds**: None
- **2. Land animals including reptiles**: None
- **3. Fish and Shellfish**: None
- **4. Benthic organisms**: -low
- **5. Insects**: -low
- **6. Microfauna**: +high
- **7. Endangered Species**: -low

### III. Socio-economic environment

#### A. Land use

- **1. Wilderness and open spaces**: -70
- **2. Wetlands**: -med
- **3. Forestry**: -low
- **4. Grazing**: -low
- **5. Agriculture**: -med
- **6. Residential**: -high
- **7. Commercial**: -high
- **8. Industrial**: -med
- **9. Mining and quarrying**: None

#### B. Recreation

- **1. Hunting**: None
- **2. Fishing**: None
- **3. Boating**: None
- **4. Swimming**: None
- **5. Camping and hiking**: None
- **6. Picnicking**: -low
- **7. Resorts**: -med

#### C. Aesthetics and human interest

- **1. Scenic views and vistas**: -10
- **2. Wilderness qualities**: None
- **3. Open spaces qualities**: None
- **4. Landscape design**: None
- **5. Unique physical features**: -low
- **6. Parks and reserves**: None
- **7. Monuments**: None
Table 8: Environmental Analysis

Therefore from the above table it can be concluded that the most environmentally beneficial option would be either concept number 2 or number 3/4.

### 6.5 Regulatory and Safety Considerations

As the bio-digester produces methane gas and the storage tank stores this gas, there are some precautions which need to be taken into account to avoid any damage being done to the bio-digester, or members of the community. To avoid dangers such as gas explosions or leaking gas, the bio-digester needs to be made of appropriately strong materials, and be operated and maintained correctly. By building the bio-digester and
storage tank out of concrete, the chance of a gas leak is minimised as the strength of the concrete should make it more resistant to cracking, allowing the gas to escape. However, if the pressure in the storage tank or bio-digester is not properly monitored, then a pressure build up will occur within the system, possibly causing an explosion when the pressure is too great. Similarly, care must be taken when using the methane gas produced by the bio-digester. As it is being burnt when it is used for cooking and heating, the operator must be careful that all seals are properly in place to avoid air being sucked back into the bio-digester, causing an explosion that could damage the bio-digester or hurt humans and animals nearby.

In order to minimise the risk, the bio-digester needs to be built to the specifications as outlined in this report, and any person operating the bio-digester system must be made aware of the dangers involved, and how to best avoid them, by operating and maintaining the system in the appropriate way.

7 Conclusion

Biodigestion is an easy and efficient way of producing abundant energy for use in the community of Devikulum. In addition, the use of a storage tank is required for the methane gas produced to be used in a more efficient and continuous way. In building a biodigester with an appropriate storage tank, it is envisaged that the energy needs of the Devikulum community will be met in a suitable and effective manner.

Based on the research conducted and presented in this report, our design for a biodigester and storage tank would produce enough methane gas to adequately meet the energy requirements of the community of Devikulum, as well as appropriately meeting the criteria for the Engineers Without Borders (EWB) assignment.
8 RESOURCES

9 APPENDIX

Team Meetings

MEETING 1:

Date: 02/08/2011
Location: ENGG 154 Tutorial Classroom
Purpose: Decide group and begin assignment
Attendance: James Virtue, Stephen Biviano, John Martin, James Papadios, Graham Haines
Agenda:
- Deciding on Group members All Members
- Separating roles for each group member All Members
Next Meeting: 09/08/2011

MEETING 2:

Date: 09/08/2011
Location: ENGG 154 Tutorial Classroom
Purpose: Start assignment, Progress
Attendance: James Virtue, Stephen Biviano, John Martin, James Papadios, Graham Haines
Agenda:
- Deciding what aspect of EWB challenge the group will undertake
- Energy Topic chosen from suggestions on EWB website All Members
Next Meeting: 12/08/2011
MEETING 3:

Date: 12/08/2011
Location: Library
Purpose: Progress
Attendance: James Virtue, Stephen Biviano, John Martin, James Papadios, Graham Haines

Agenda:
- Deciding which aspect of the Energy Topic will be the focus for the assignment
  - Biodigestion as a means of providing electricity and energy needs to the city of Devikulam chosen from suggestions on EWB website
  - Division of roles for group members
    - Background of problem/village of Devikulam
      - Stephen Biviano
    - Design of Biodigester
      - John Martins
    - Use of bio-digester and how it can be employed in different ways to give the most benefit to the community
      - James Papadios
    - Economics and effectiveness of bio-digester
      - Graham Haines
    - Collating and formatting of report
      - James Virtue

Next Meeting: 16/08/2011

MEETING 4:

Date: 16/08/2011
Location: ENGG 154 Tutorial Classroom
Purpose: Progress
Attendance: James Virtue, Stephen Biviano, John Martin, James Papadios, Graham Haines
Agenda:
- Discussion and evaluation of information gathered  All Members

Next Meeting: 23/08/2011

MEETING 5:

Date: 23/08/2011
Location: ENGG 154 Tutorial Classroom
Purpose: Progress
Attendance: James Virtue, Stephen Biviano, John Martin, James Papadios, Graham Haines

Agenda:
- Discussion and evaluation of draft preliminary report  All Members
  -Discussion and evaluation of peer feedback, and how to incorporate this into report  All Members

MEETING 6:

Date: 31/08/2011
Location: Library
Purpose: Progress
Attendance: James Virtue, Stephen Biviano, John Martin, James Papadios, Graham Haines

Agenda:
- Decide on which design to create
  - Design option 1 chosen, biodigester with storage tank  All Members
- Discuss feedback given in tutorial class
  -Decide on how to improve report  All Members
- Division of roles for group members
  - Manufacturing process and materials used  Stephen Biviano
MEETING 7:

Date: 11/09/2011
Location: ENGG 154 Tutorial Classroom
Purpose: Progress
Attendance: James Virtue, Stephen Biviano, John Martin, James Papadios, Graham Haines

Agenda:
- Discussion and reflection of work done so far All Members
- Discuss feedback given in tutorial class
  - Decide on how to improve report All Members

Next Meeting: 18/09/2011

MEETING 8:

Date: 18/09/2011
Location: ENGG 154 Tutorial Classroom
Purpose: Progress
Attendance: James Virtue, Stephen Biviano, John Martin, James Papadios, Graham Haines

Agenda:
- Discussion and reflection of work done so far All Members

Next Meeting: 18/09/2011
- Discuss improvements to report and how to implement them

Next Meeting: 25/09/2011

MEETING 9:

Date: 25/09/2011
Location: Library
Purpose: Progress and completion of draft report
Attendance: James Virtue, Stephen Biviano, John Martin, James Papadios, Graham Haines

Agenda:
- Completion of tasks for reports
- Compilation of Draft Final Report

Next Meeting: 04/10/2011

MEETING 10:

Date: 04/10/2011
Location: ENGG 154 Tutorial Classroom
Purpose: Progress
Attendance: James Virtue, Stephen Biviano, John Martin, James Papadios, Graham Haines

Agenda:
- Discuss feedback given in tutorial class
  - Decide on how to improve report
- Division of roles for group members
  - Discussion and explanation of design option chosen
  - Create computer model in Pro-Engineer
  - Create scale model and Executive summary

OCTOBER 2011
MEETING 11:

Date: 11/10/2011
Location: Library
Purpose: Completion

Attendance: James Virtue, Stephen Biviano, John Martin, James Papadios, Graham Haines

Agenda:
- Discuss individual parts  All Members
- Compile individual parts to finish assignment Stephen Biviano
  James Virtue