A RELIABLE SUSTAINABLE ALTERNATIVE ENERGY SUPPLY FOR THE VILLAGE OF DEVIKULAM, INDIA.

SOLUTION: BIO-DIGESTION

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EXECUTIVE SUMMARY

The Engineers Without Borders Challenge is an opportunity given to students to utilise their problems solving and design skills in a practical context. This is a valuable initiative in itself, though where the greatest value exists is the real possibility for the research and designs being completed to actually bring about positive change in the world we live.

This year students were given the opportunity to assist in the sustainable development of the Devikulam community, in Tamil Nadu, India. Out of the several design areas that were outlined as requiring sustainable solutions, this report focuses on the ENERGY context. The aim of this area was to address the issue of regular black outs in Devikulam and the need for a back-up power source for when this occurs.

The project group, in a systematic manner, conducted research into the background and specific circumstances and requirements of the village and community. Assessment of several renewable technologies and possible solutions to the issue were also considered. At all stages of the project, continuous assessment of the design requirements and criteria (developed by the group at the beginning) took place, with the aim of developing a holistic solution that had significant consideration for the triple bottom line: reliable, self-sufficient, cost-efficient, localised, and environmentally friendly.

In light of the requirements and assessment of possible provisions, the design chosen by the group was the BIO-DIGESTER. This report covers the research and design process, leading to the contention that the developed bio-digester design has the ability to achieve its main purpose (to provide a backup power source), whilst satisfying the requirements for its viability in an environmental, economic and social context. Several links are also made with the other design areas, particularly sanitation and waste management, giving this design further credibility and positive viability.
TEAM REFLECTION

It was great to see that Engineers Without Borders have now changed to Everyone Without Borders, because that change has been clearly shown by the backgrounds of our group members. We come from various disciplines within the University (Engineering, Arts and Science). Not only was it a privilege for students (other than Engineering) to be able to undertake this project, but the group strongly believes that by being able to work with students from other departments, we were able to increase the scope of the project. We were all able to use the knowledge and skills that we have developed in our respective courses and bring various perspectives into the group and the project.

Having not previously known one another, one of the first things that our EWB Challenge team did is list what we thought was good team work. We believed for this project to be successful, it was essential to define what team work is, to give us a guide to follow and develop of our journey. The criteria our team came up with included:

- **Commitment** – to the subject that we are undertaking as well as the project group. This was in regards to being committed to put in the time and effort to research and add to the knowledge base that the group has.

- **Accountability** – This was seen in two main ways. The first being accountable for the various tasks that each of us were appointed and the second being **reliable** as a member of a larger group and making sure to deliver an appropriate level of performance towards the improvement of the group.

- **Respect** – for one another as well as the other stakeholders. For example, respect in the context of Engineers Australia, in particular the community of Devikulam.

- **Honesty** - towards other members of the group. This aspect of group dynamics related to other areas as well. In particular, commitment and accountability. Honest allowed us to see group work from others’ perspectives and therefore be able to accommodated for the commitments that other members had, all the while being able to successfully continue the design process.

- **Support** – This again allowed for the group to support its members. Collaboration and respect for one another played a major role here.
• **Open Mindedness** – to the many aspects of the project: the subject, the EWB project and criteria, the requirements of developing communities and the issues that they face. Overall, open mindedness allowed us to embrace the design process, associate with others from different disciplines and work together to collectively bring about a positive change in the world.

We began as individuals, flourishing as a team through continuous communication and collaboration of work. The major technology we used to communicate was through the wiki provided via the Learning Management System. Here, all of us could add links and new information that could assist our team mates with their own research. It was a great tool that made combining all our information together simpler, and more accessible to one another.

Designing is an intensive and thoughtful process. Our goal was to design a simple straight forward system that would be socially accepted in Devikulam. Past projects implemented in rural areas show that if a project to not socially accepted, it ceases to solve the problems that it was originally placed for.

Additionally, EWB acknowledges that sanitation is a major issue that needs to be dealt with. Our goal was to synchronize a solution to tackle the problem of open defecation and solve their energy crisis.

We committed a great deal of time researching all types of renewable energy. Our knowledge grew, leading us to make more coherent arguments why one solution was more viable than another. The EWB challenge gave our team the opportunity to explore the meaning of sustainable development and design and how we can implement it in a real life situation such as Devikulam. Knowing the foundations of sustainability and sustainable development influenced our thinking and the way we approached the problem given by EWB. We learnt about taking into consideration the social, environmental and economical aspects of implementing our design and how it would affect the needs of future generations.

Our project was successful through our efficient methods of finding and sharing information. By breaking up the tasks at the beginning, we each were experts in different sources of renewable energies. By then sharing our knowledge and receiving feedback on others’ views, our process of gathering information was made somewhat more straight forward.

In particular, all six group members embraced the design process right from the beginning of the project. Whilst group cohesion and development was something that we all saw as being evident throughout the entire process (in particular the first few weeks) our group also had plans and timelines in place, with work being
completed each week. In this context, the EWB challenge was a great opportunity given to us to work with other students, being able to interact with them, developing our interpersonal skills. This project all allowed us to develop our research and report writing skills and, on the other hand, gave us the opportunity to learn about another culture and sustainable development. The challenge provided us with valuable hands on experience of putting theory and ideas into practice. Additionally, it opened our minds to the great work we can do to benefit developing communities in the future by transferring all of the valuable insights and skills we have learn here and applying it to other contexts in the future.
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A RELIABLE SUSTAINABLE ALTERNATIVE ENERGY SUPPLY FOR THE VILLAGE OF DEVIKULAM

INTRODUCTION

India is the world’s eleventh-largest energy producer and the world’s sixth-largest energy consumer.¹ Domestic coal reserves account for 70 percent of India’s energy needs, with the remaining 30 percent being met by oil.² Whilst it is estimated that, at the current level of consumption and production, India’s coal reserves will last for more than 200 years, several other factors need to be considered. These in particular being the environmental concerns behind the use of coal and, more significantly, its inability to meet all of India’s energy needs now and the future in a reliable manner.³

The first city in India to receive electricity was Bangalore in 1906.⁴ With demand for energy expected to double by 2025⁵ and The Ministry of Power having the mission of providing reliable and quality power for all by the year 2012,⁶ the question exists of why many rural villages in India still do not have a reliable source of electricity and how this dilemma can be addressed.

The Engineers Without Borders (EWB) Challenge 2011 is a possible avenue whereby solutions can be formulated for one such village, Devikulam, in the state of Tamil Nadu. As such, this design project outlines the research conducted on the area of ‘energy’ and the design formulated to achieve a clean, renewable and reliable back-up power source to use during black-outs in Devikulam.

AIMS

It is the overall aim of this design project to provide a sustainable solution to the energy issues faced by the Devikulam community. In order to do this, it is aimed that detailed research be conducted into the background and specific circumstances of the village, particularly with a view of developing a solution which incorporates a clear understanding and analysis of the triple bottom line. Particularly, it is aimed that the issue of regular black outs and the need for a back-up power source be addressed, whilst taking into consideration the social, environmental and economic environments.

It is aimed to assess the various renewable technologies available as possible solutions to this issue; the requirements of power and the use of energy within the village; and to continuously assess the design based on design criteria developed by the group at the beginning of the design process, particularly aiming to develop holistic solution that is reliable, self-sufficient, cost-efficient, localised, and environmentally friendly.

This project, which has its main focus on the ‘energy’ design area, also has a major aim to incorporate various other design areas into its implementation, particularly in terms of sanitation and creation of value for the village.
DESIGN REQUIREMENTS

In conducting this project and developing a design to provide an energy back-up source, several criteria were taken into consideration. As mentioned, respect for the triple bottom line played a major role, with particular attention being given to the expectations of the community, sustainable development, ethics and the technical functionality of the design.

An outline of the design requirements are presented below, after which specific evaluation criteria are presented in the following section.

SOCIAL

Whilst the environment is the main category generally associated with ‘sustainable’ design, this project has placed its main focus on the social aspect of sustainability, with the aim of bringing about a design that will help the community of Devikulam to have a design that they would see as providing to their needs and therefore be willing to implement.

As such, the design has kept in mind the target market (the community of Devikulam) and considered the following, with regards to the ability of the design to:

- Bring about beneficial change to the community (provide a back-up power source).
- Create value in the community.
- Improve the lives of the people in the community.
- Provide added benefit to other areas of required improvement/development.
- Ensure capacity building.
- Be culturally sensitive.
- Apply global concepts to a local context.

ENVIRONMENTAL

The environmental aspect of the triple bottom line also played a key role in the design process. As such, the following aspects were considered, with regards to the ability of the design to:

- Have minimal impact on the environment in terms of pollution and contamination.
- Utilise locally available materials where ever possible.
- Utilise renewable or sustainable materials and techniques.
ECONOMIC

It has been acknowledged from the initial stages of the design process that, in order to achieve sustainability, all three aspects of sustainability must be accounted for. As such, the economic aspect addresses the ability of the project to:

- Be affordable to the community as a whole
- Provide added monetary benefit through the utilisation of its end products.
- Have minimal operating and maintenance costs.
- Utilise cost effective materials.
- Provide employment opportunities for the local community.

EVALUATION CRITERIA

From the early stages of the design process several design evaluation criteria were determined by the group to be essential to ensure a successful and sustainable outcome, based on the design requirements outlined earlier. These have been presented in the visualisation 'Heaven and Hell Chart' and Table 1.1 below.

Figure 1.1. Heaven and Hell Chart representing design criteria.
It is determined to be essential that the criteria in the *positive* section be achieved, those in the *notable* section be satisfied and those in the *negative* section be avoided.

<table>
<thead>
<tr>
<th>DESIGN CRITERIA</th>
<th>RATIONALE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back-up energy source</td>
<td>The design and technology should provide a means whereby a back-up energy source is created in the event of power failure through the electricity grid.</td>
</tr>
<tr>
<td>Economic Viability</td>
<td>The infrastructure for the design and technology should be affordable to the community as a whole (i.e. it would not need to be purchased on an individual basis) and should provide added monetary benefit through the utilisation of its end products. It should also have minimal operating and maintenance costs.</td>
</tr>
<tr>
<td>Social Viability</td>
<td>The use of the design should be accepted by the community as bringing benefits and value to them. It should also be compatible with current practices or strive to better current practices where possible, in terms of social wellbeing.</td>
</tr>
<tr>
<td>Environmental Viability</td>
<td>The design should have minimal impact on the environment in terms of pollution and contamination. It should also use locally available materials where ever possible.</td>
</tr>
<tr>
<td>Sustainability</td>
<td>The design should be durable over its life time and have a life expectancy and added value which justifies initial financial investments.</td>
</tr>
</tbody>
</table>

Table 1.1. Design Criteria and Rationale.
2 PROBLEM DEFINITION

This section provides an outline of the significance of the project, the issues being addressed, the required solution and the outcomes expected through the design. As such, the problem scope has been presented, followed by a detailed background analysis of Devikulam, its history, community, local environment and current economy.

PROBLEM SCOPE

The main issue faced by the Devikulam community that this report focuses on addressing is the need for a reliable back-up power source and the provision of power outside that which is provided from the electricity grid. In doing so, it is also aimed to address the issue of open defecation which is said to be practiced by the majority of villages.

TECHNICAL REVIEW

ABOUT THE VILLAGE

The name Devikulam is derived from the words Devi (meaning Goddess) and Kulam (meaning pond) to mean Goddess of the Pond. It is one of several villages located in the Nadukuppam Panchayat (a small sub-division of the Viluppuram District) in the state of Tamil Nadu of India. One of the communities’ most valuable assets is its beautiful landscape which is full of tropical plants and wildlife. Despite this, issues exist due to the poor quality of the infrastructure in the village and the state of the people who live in the area, the majority of whom live below the poverty line.

ENVIRONMENT

A central feature of the village is the beautiful lotus pond, after which Devikulam is significantly named after. The pond was once used as a source of drinking water but in more recent years has been used for bathing, washing cattle and swimming. The ground water levels in Devikulam are relatively high, though there are growing concerns about increased salinity and the effect that this has on drinking water quality.

There is an area of 3 to 4 acres of public land in Devikulam that is largely covered by coconut trees and other plants. This provides a good source of tender coconut for food consumption. The palms and leaves are also utilised for use in brooms and even thatching for roofs.
There are very few transport options in Devikulam and roads in and around Devikulam are generally made of gravel. People walking on these roads often experience unpleasant conditions due to open defecation generally occurring on the roadside.\textsuperscript{13}

**ECONOMY**

Paid employment generally occurs on an irregular basis for people living in the Devikulam village and the main occupations undertaken are farming and agricultural labour. Some people are also employed as prawn farming labourers or by the local fishing industry.

**SOCIAL**

A total of 358 people (86 families) live in the village of Devikulam.\textsuperscript{14} The language spoken is Tamil and the religion Hindu. There are two major castes in Devikulam, with the Scheduled Class (Dalit) living into the colony and the Most Backward Class living in the region known as Devikulam Village.\textsuperscript{15}

In terms of education, there is a crèche in Devikulam for children below 5 years of age. Children aged 5 to 10 years can attend the primary school which was built 27 years ago. Adolescents travel to either Nadukuppam (4km away) or Marakkanam (16km away) to attend secondary school.\textsuperscript{16} It has also been found that nearly 60% of the district population has only attained primary level education or less.\textsuperscript{17}

Houses in Devikulam are mostly huts with either cement or mud floors. Walls are made from mud or burnt brick and the roofs are either thatched or made from palm leaf. These houses generally have thatched bathrooms without a toilet. As a result, open defecation is common practice.\textsuperscript{18}
ENERGY CONTEXT (SELECTED DESIGN AREA)

All households in Devikulam (except for 2) are connected to the grid for electricity. Electricity is provided free to some households in the Dalit caste under a 'one light free' service scheme, while other households pay electricity bills which generally range from 20 to 50 rupees per month. All households also use firewood and kerosene for cooking.

Energy requirements specific to the village exist for lighting, fans, televisions, mobile phones, grinders, fridges and to be used for cooking.

The opportunity for renewable technologies to replace mains power from the grid exists, though the main issues surrounding the energy design area arise due to the frequent power outages that are experienced in the village. This requirement is further exaggerated due to no alternative energy sources being available to be used as a form of back-up power supply when power outages take place.
The first idea that comes into your mind is never the final outcome. There is a process that you go through: brainstorming different choices, comparing them and refining the concepts until they meet the design criteria. Below is a list of options that were explored in detail. Each contains a rubric. This helps graphically see which alternative best integrates with the criteria provided by EWB.

The different design options considered are outlined below and further detailed in the rest of this section.

<table>
<thead>
<tr>
<th>OPTION 1: HYDRO POWER</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Hydro Power Image]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OPTION 2: METHANE DIGESTER</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Biogas Image]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OPTION 3: WIND TURBINE</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Wind Turbine Image]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OPTION 4: SOLAR POWER</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Solar Power Image]</td>
</tr>
</tbody>
</table>
OPTION 1: HYDRO POWER

ADVANTAGES

1. Stable energy source
   - Wind power relies on the wind speed, and since it’s not constant and really depended on the season. Therefore wind power is not a reliable source.
   - Solar energy only works when the sun is there, and energy often hard to store in a large scale. Thus that, solar power is not really stable.
   - Water flow rate is almost constant and continuous throughout the year, which means that our generator can provide a constant and stable energy output.

2. Efficient
   - Only need a small amount of water current, as little as 6L per minute.
   - Or 0.6m high in different
   - Electricity can transfer to a place where 1.5km away is.

3. Environmental friendly
   - Generator and turbine are put a side of the river (“Run -of-river system”) and no reservoir required, water passed the generator will go back to the stream directly, meaning that there will be little impact on the ecology relativity to other power generation method. (i.e. the material needed to make solar panel is toxic)

4. Cost
   - A Micro hydro-system is around US$1,000 to US$20,000 depending on the amount of electricity required.
   - Compare to other generation method, the maintenance fees for hydroelectricity is relatively low.
   - The water in the river is freshwater, therefore turbine and other components not easy to get rusts.
   - Easy to maintenance, not like wind turbine you have to claim up to few meters high to do the maintenance.

DISADVANTAGES

1. Limited future expansion
   - Energy expansion restrict by the size of the river.

2. Seasonal water current
   - In some river the water current is not constant, most likely low water current in summer. Low water current imply that there will be low power
output. However in the summer time, people love to turn on the air-conditioner, the need of electricity will be huge. That may be a problem.

Table 4.1 Rubric for hydro power.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Poor</th>
<th>Good</th>
<th>Excellent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum requirements</td>
<td>Hilly region</td>
<td>Buy a battery bank but not great with storing energy</td>
<td>Stream of water available</td>
</tr>
<tr>
<td>Store Energy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time before running at full capacity</td>
<td>3 years</td>
<td>Small gestation period</td>
<td></td>
</tr>
<tr>
<td>Number of input materials</td>
<td></td>
<td>4 = Turbine, generator, mechanical coupling, grid tie for connecting to grid</td>
<td></td>
</tr>
<tr>
<td>Cost (materials/maintenance/capital)</td>
<td>$3000 AUS</td>
<td>Cheaper than solar alternative</td>
<td>Run-of-river system requires no expensive damn construction</td>
</tr>
<tr>
<td>Power produced</td>
<td></td>
<td>Up to 100 kW for a micro system enough for a small community</td>
<td></td>
</tr>
<tr>
<td>Sustainable</td>
<td></td>
<td>Clean, pollution free, eco-friendly, no fuel dependence, reduces their contribution of greenhouse gas released into the atmosphere.</td>
<td></td>
</tr>
<tr>
<td>Geography of system</td>
<td>Requires a hilly region, to create potential</td>
<td></td>
<td>Best in rural areas where grid is unavailable, making it a good backup alternative</td>
</tr>
<tr>
<td>Funding available</td>
<td>No funding available at the moment</td>
<td>Funding is achievable, because this project is recognized as an environmental solution</td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Safety</td>
<td>Relatively good distance away in case system fails, fuses incorporated in design to limit damage caused by internal failure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved economy</td>
<td>Revenue increases from reduced fossil fuel use, one of lump cost, and minimum maintenance make this solution economical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved other problems in society</td>
<td>Can be incorporated with solar, wind power.</td>
<td>Standalone system, which can also be connected to grid</td>
<td></td>
</tr>
<tr>
<td>Stand alone, connects to grid?</td>
<td>Machinery is not local</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accessible to parts/ made of local material</td>
<td>May not be accepted do to foreign material, technological thinking</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social Impact</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 4.2 Diagram of how hydropower system would be implemented

Intake water:
Part of the water from the stream move into the pipeline.

Using pipeline can increase the power output by reduce the energy lose when the water running in the water stream.

The energy it can generate is proportional to the vertical high between the intake place and the generator.

Generator:
Water from the pipe go through the generator and makes the turbine to
OPTION 2: METHANE DIGESTER & WASTE MANAGEMENT

When it comes to waste management, the village of Devikulam, to this current date has never had any form of proper system in place to combat the issue of managing their community’s waste. Their usual way of currently managing waste, is to just make deposit of it, behind either their own or other people’s houses within the community. So the result is a vast amount of garbage litter throughout the landscape of the village.

In a village approximately 22km away, in Kadapakkam, a waste management program is already underway. Since Devikulam doesn’t have a cost effective waste management system at the moment, the village could send some of its hard waste to Kadapakkam to be processed.

If the biogas digesters are implemented into the village, people from the village itself could be hired to cover various areas of waste. Firstly the people of the village would have to be educated themselves so that they are taught to not dump all there rubbish behind their homes, but a more central location. Each home throughout the village should be given two types of bins, one for all types of hard waste and recyclable material and another for bio waste, such as household food waste, waste from fruits and vegetables, any other organic waste and even animal dung etc.

Two central locations within the village will be selected where the people of the village can come and dump their bins, at least once a fortnight, one location for the bio waste, close to the biogas system, and the other location for other hard waste and recyclable waste. It should be made so that each household is assigned a certain day every fortnight to come and dispose off their bins. This way it can be ensured that a constant supply of bio waste is fed daily into the bio digester. By having everyone get into a routine like this and do it according to the day they are assigned, it will ensure that everyone comes along and disposes of their own waste. However they should make sure that they dump the hard waste and other bio waste into the two different assigned piles. If the people of the village can be taught also how to separate hard waste into two different piles of recyclable waste and non-recyclable waste, it would help the waste management system even further. One or two people could be hired to sort through the hard waste, and make sure the waste is separated into recycling waste and hard waste in two different piles.

This recyclable waste can always be sold to recyclers as an income generating activity, and if it is sold to recyclers that are willing to drive into the village at least once a month they can not only get rid of the recycling waste then but also make a slight income of it.

Using this income, keeping a slight amount for the workers themselves, they can pay people of the village who own cows, to pull the rest of the waste load on cow carts all
the way to Kadapakkam, if they even make a high enough amount to arrange a lorry to take all this waste, even better.

At the same time the bio waste that would be in a different pile would be close to the biogas system, where workers could then make sure that only bio waste is put into the system and from the pile could just scoop all of it into the correct tank. However since the bio waste coming from household food waste won’t be enough to be the main driving fuel of this system, a method can be implemented in order to collect all the cow dung, and all other animal dung, and bring it to the location of the biogas system.

This can be done, by getting one or two people from the village, to go around on cow cart to all the households that are willing to pay to have their animal dung collected, and scoop up all the animal dung putting it into the cart. Then have it unloaded directly into the biogas system. Otherwise families could also collect their animal dung themselves and dispose of that also into their bio waste bins, and empty their bins once every week or fortnight when they come to dispose of it.

By the villagers following this method of waste collection, and coming down at least once ever fortnight and if they have more waste to dispose off, once every week to dispose of their waste in their bins, in return they will be receiving electricity, even when the power would usually go out, in order to power certain appliances from lights to small fans in their homes and also have their waste removed and disposed of in a more environmentally friendly and healthy way.

As important as it is to manage this waste and get rid of it and also use it to produce a renewable source of energy. It is also important that the people of the Devikulam village are educated to ensure they are provided with an understanding of the long term consequences of good waste management.

![Figure 4.3. Graph of power generation to solid waste produced](image-url)
Table 4.2. Various applications of a 1 m$^3$ methane digester.

<table>
<thead>
<tr>
<th>Application</th>
<th>1 m$^3$ biogas equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>~ 60-100 watt bulb for 6 hours</td>
</tr>
<tr>
<td>Cooking</td>
<td>Can cook 3 meals for a family of 5-6</td>
</tr>
<tr>
<td>Fuel replacement</td>
<td>0.7 kg of petrol</td>
</tr>
<tr>
<td>Shaft power</td>
<td>Can run 1 horse powered motor for 2 hours</td>
</tr>
<tr>
<td>Electricity generation</td>
<td>~ 1.25 kilowatt hours of electricity</td>
</tr>
</tbody>
</table>

Table 4.3 Rubric comparing the advantages and disadvantages of Methane digesters.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Poor</th>
<th>Good</th>
<th>Excellent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum requirements</td>
<td></td>
<td>open space</td>
<td>materials, inputs all easily available in Devikulam</td>
</tr>
<tr>
<td>Store energy</td>
<td></td>
<td>Gas can be safely stored, does not need to be immediately expended.</td>
<td></td>
</tr>
<tr>
<td>Transition period</td>
<td></td>
<td>At least 2 weeks before usable quantities of methane produced</td>
<td>Can be used as soon as construction is finished</td>
</tr>
<tr>
<td>Number of input materials</td>
<td></td>
<td>Locally used materials easily available (cement, brick, etc.)</td>
<td></td>
</tr>
<tr>
<td>Cost (materials/maintenance/capital)</td>
<td>Approx. $2200</td>
<td>Low maintenance costs, long longevity</td>
<td></td>
</tr>
<tr>
<td>Power produced</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sustainable</td>
<td>Lasts very long, uses natural materials, removes methane from atmosphere</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>------------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geography of system</td>
<td>temperature and clime of Devikulam matches optimum conditions for methane digestion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Funding available</td>
<td>government incentives available for both renewable energy and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety</td>
<td>Gas is combustible → explosive risk If constructed properly, very little risk.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved economy</td>
<td>Buying manure/ selling effluent can stimulate local economy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improves other problems in society</td>
<td>Use of human excrement helps relieve sanitation problem</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stand alone, connects to grid?</td>
<td>Can stand alone and be used for cooking, connected to a generator to produce electricity. Can be used to supplement electricity from the grid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accessible to parts/made of local materials</td>
<td>Materials used are basic: cement, wood, brick, etc. Locally used building materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>social impact</td>
<td>The use of human waste and its collection may require a change of habits, i.e. use of latrine, acceptance of human waste as fuel</td>
<td>Manure has been used historically as a source of fuel; this process merely makes it more efficient and eco-friendly.</td>
<td></td>
</tr>
<tr>
<td>Effect on Health</td>
<td>The removal of waste from the ecosystem means it is less likely to find its way into the water sources, less likely to spread disease.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Life of system and equipment</td>
<td>Sturdy building materials and use of natural processes means digester could be functional for decades with relatively low maintenance.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
OPTION 3: WIND TURBINE

The implementation of wind turbines in the area of Devikulam is an idea that has occurred to the Indian government over the last decade in local districts within Tamil Nadu. We chose wind turbine generation of power as a potential energy source firstly as it is a proven technology already implemented in India as well as the fact that it makes use of a natural energy source that is not completely site specific. As wind power is a style of energy harnessing implemented and subsidized throughout many areas of India, this appeared to be a particularly valid concept to consider for the people of Devikulam but due to certain factors, was not used for the proposal.

The beneficial elements of the wind proposal include the fact that minimal maintenance is required, energy production is immediate, no human influenced energy needs to be provided and it would be able to supply large amounts of energy to the districts households. Wind turbines in terms of maintenance require occasional scheduled services similar to that of a car which are precautionary to maintain smooth operation and prevent damage. In terms of immediate power production, unlike Biogas power production, as soon as wind begins to rotate the turbines, power is being produced ready to be used. Also unlike Biogas energy production, wind power does not require constant human influenced refueling to keep the system in action, and again unlike Biogas, wind turbines can in general produce more energy transferable into electricity due to its efficiency level. All the described elements are strengths for the concept of implementing wind turbines.

The weaker elements of the wind turbine include windy locations, large infrastructure, potential danger in maintenance and large initial costs which have led to putting this proposal behind that of the Biogas production concept. Wind turbines require a certain average wind speed in order to be effective in producing electricity and in the village of Devikulam; the figure is just below the desired speed hence the turbines would have to be located approximately 5km east along the coast from the village. On top of this, wind turbines require quite large and well founded infrastructure which is expensive, much beyond that of a simple Biogas chamber and this also has potential implications as the large infrastructure requires human interaction during maintenance which is dangerous at heights. All these attributes together were contrasted with each individual idea for the proposal but due to the costs and difficulty, fell behind the Biogas proposal which seemed to suit the area more so.
Table 4.4 Rubric comparing the advantages and disadvantages of Wind power.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Poor</th>
<th>Good</th>
<th>Excellent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Requirements</td>
<td>A surface to build on with some wind</td>
<td></td>
<td>A solid surface raised above the tree line with plenty of wind</td>
</tr>
<tr>
<td>Store energy</td>
<td>Improper calibration of frequency could cause explosion or system failure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transition period</td>
<td></td>
<td>If weather and poor conditions slow construction</td>
<td>If conditions are right for construction, immediate generation can take place</td>
</tr>
<tr>
<td>Number of input materials</td>
<td>High level of input materials that are not locally sourced</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost (materials/maintenance/capital)</td>
<td>If a need for extra infrastructure is apparent to accommodate Turbines</td>
<td>If minimal infrastructure is required for accommodation of Turbines</td>
<td></td>
</tr>
<tr>
<td>Power produced</td>
<td>If located low within the village</td>
<td></td>
<td>If located along the coast in a raised position</td>
</tr>
<tr>
<td>Sustainable</td>
<td>If maintenance does not occur and much repairing is required</td>
<td></td>
<td>If full maintenance occurs and turbine works for many decades</td>
</tr>
</tbody>
</table>

A RELIABLE SUSTAINABLE ALTERNATIVE ENERGY SUPPLY FOR THE VILLAGE OF DEVIKULAM
<table>
<thead>
<tr>
<th>Geography of system</th>
<th>If located low in the village, low levels of power will be produced</th>
<th>If located along the coast in a raised position, lots of power will be produced.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Funding available</td>
<td></td>
<td>Approx. half costs covered by government</td>
</tr>
<tr>
<td>Safety</td>
<td>If no safety equipment is used</td>
<td>If use of correct procedures and safety equipment</td>
</tr>
<tr>
<td>Improved economy</td>
<td></td>
<td>Devikulam could make minor returns from providing power to the grid</td>
</tr>
<tr>
<td>Improves other problems in society</td>
<td></td>
<td>Any production of electricity will improve the problems in Devikulam’s society.</td>
</tr>
<tr>
<td>Stand alone, connects to grid?</td>
<td>If cost limits technology to connect to grid, stand alone may be implemented</td>
<td>If additional elements are implemented it can connect to the grid</td>
</tr>
<tr>
<td>Accessibility to parts/made of local materials</td>
<td>If unique systems are implemented from beyond India, availability and local materials may be scares</td>
<td>If similar systems to Tamil Nadu are implemented, parts will be more likely available</td>
</tr>
<tr>
<td>social impact</td>
<td>If the turbine is not looked after, the</td>
<td>If turbine works as intended,</td>
</tr>
</tbody>
</table>
### Table: Effects and Lifespan of Wind Turbines

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Low Impact Description</th>
<th>High Impact Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Effect on Health</strong></td>
<td>If located low within the village, low levels of noise may have minor effects on residents.</td>
<td>If located along the coast, no impact should result from the turbines.</td>
</tr>
<tr>
<td><strong>Life of system and equipment</strong></td>
<td>If no maintenance occurs at all.</td>
<td>If lubrication and regular maintenance occurs</td>
</tr>
</tbody>
</table>

Figure 4.4 Diagram of how wind turbines would be implemented and located in the area

![Diagram](image-url)
OPTION 4: SOLAR POWER

ADVANTAGES
1. No pollution, no effect of the environment
   - There will be no noise when it is running, no emission of poison gas when we use it properly.

2. Reliable, long life expectance
   - Some company’s modules will have up to 20, 25 years of warranty.
   - By theory, life of a module is more than a 100 year.
   - In record, the first module is still working and producing energy after 50 years.
   - Due to its long life expectance, solar energy becomes one of the cheapest energy sources. And it would not produce any harmful side produce like nuclear energy.

3. Completely renewable
   - The sun will still give out energy even when we are not using it.
   - The sun would not use up quicker when we using solar energy.

4. Less maintenance
   - There are no moving parts in a solar panel.
   - Annual cleaning and health check only

5. Easy to install

DISADVANTAGES
1. The first purchase cost is quite expensive
   - Around AU$4,000 to AU$10,000 PER house

2. Solar energy only work on sunny day
Table 4.5 Rubric comparing the advantages and disadvantages of Wind power.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Poor</th>
<th>Good</th>
<th>Excellence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum requirements</td>
<td>Cloudy day</td>
<td>Good sunny day with no cloud on the sky</td>
<td></td>
</tr>
<tr>
<td>Store Energy</td>
<td>Using battery bank</td>
<td>Using a battery bank (= expensive)</td>
<td>There are no excellence solution to store energy in a large scale</td>
</tr>
<tr>
<td>Life expectance</td>
<td>Less 50 years (bad luck)</td>
<td>More than 100 years</td>
<td>Your grand-grand……grandson can still using it</td>
</tr>
<tr>
<td>Number of input materials</td>
<td>Depend on how much power you want to generate. Most likely 12-16 panels and 1 or 2 battery bank(s) per house</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td>$2,000 per house</td>
<td>$5,000 per house</td>
<td>$9,000 per house</td>
</tr>
<tr>
<td>Power produced</td>
<td>100W per panels</td>
<td>180W per panels</td>
<td>300W per panels</td>
</tr>
<tr>
<td>Sustainable</td>
<td></td>
<td></td>
<td>No pollution, renewable, environmental friendly</td>
</tr>
<tr>
<td>Funding available</td>
<td></td>
<td></td>
<td>Funding is achievable, because this project is recognized as an environmental solution</td>
</tr>
<tr>
<td>Safety</td>
<td></td>
<td></td>
<td>Panels are put on top of the house and connect directly into the household power system.</td>
</tr>
<tr>
<td>Improved economy</td>
<td></td>
<td></td>
<td>Less maintenance</td>
</tr>
<tr>
<td>Stand alone, connects to grid?</td>
<td></td>
<td></td>
<td>Both, up to the user</td>
</tr>
<tr>
<td>Accessible to parts/ made of local material</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social Impact</td>
<td>The first purchase cost is expensive, small village cannot offer it</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
OVERALL OPTION SELECTION

Each design options is comprised by a number of advantages and disadvantages. The next step is to distinguish each option, and choose which solution best fits the criteria outlined. Firstly, by comparing the rubric for each design option, it is clear to see which system contains the most benefits. However, it does not end there. Using the Heaven and Hell chart, figure (1.1) in collaboration with the rubrics, we can rank which design criteria is most important. This assists us extensively to reduce the numbers of options initially available. During this process it was clear that Methane Digesters was the best option. It is cost effective, and uses local resources. Further in the report, it explains the benefits to society, economy and the environment.

ALTERNATIVE SOLUTION: NO BIO-DIGESTER

EWB and Devikulam ask for a sustainable and reliable alternative energy supply to their current situation. Comparing the benefits to the social, economic and environmental standards from implementing methane digesters, it is easy to see how much better of the community would be.

Currently, Devikulam is a poor village, will low sanitation and unreliable electricity connection to the grid. Figure 1.1, the Heaven and Hell chart looks at the design criteria for any new system. Some main factors include dependable energy source, reduce health implications, and improves the lives of people. We must now asses Devikulam’s life currently, without implementing Methane Digesters.

Firstly let’s consider the social aspects. The village of Devikulam does not have an irrigation system. So waste is left to rot outside. Whilst then can make being outdoors unpleasant, it also attracts flies and other insects which can also infest food. Therefore food cannot be kept long, and flies may be carrying diseases which can be transmitted to the entire family.

Devikulam consist of two castes, the Scheduled Class and the Most Backwards Class. Without any systems in place, each group lives relatively separate lives. Community involvement and activities shared amongst each other is rare. Woman would spend more time in the kitchen cleaning soot from kitchen utensils than spending time with their family. Additionally, the use of firewood is likely to cause glaucoma and heart disease by smoke inhalation.

Economically, Devikulam does not have many sources of trade except farming plants. A bad season can critically hurt their source of income. The cost of kerosene and LPG is a constant expense that each household have to pay. It is critical that
many of the people in the village can work, to source income to sustain a regular income.

Environmentally, Devikulam will be continuing to contribute to the greenhouse effect, through burning firewood, kerosene and LPG. Not only is it damaging to the eco system, to harms the health and wellbeing of humans.
Methane is a flammable, naturally occurring gas most commonly released by cattle waste. Being a greenhouse gas (considered more dangerous than carbon dioxide), the release of methane into the air has become a pressing environmental problem, contributing to both global warming and the depletion of the o-zone layer. Methane can be harnessed and used as natural gas, either burnt to provide heat or to power a generator.

Methane digestion is the process by which naturally occurring bacteria break down organic material, releasing methane gas in the process. This can occur in one of two ways: *aerobic digestion*, where the process is exposed to oxygen, and *anaerobic digestion*, where it occurs in an oxygen-deprived environment. *Aerobic digestion*, such as occurs in composting, happens when the microorganisms that break down methane are freely exposed to surrounding oxygen, resulting a reaction in which heat, oxygen and carbon dioxide are released, in addition to ammonia being left in the residue. *Anaerobic digestion*, which occurs naturally inside a cow's stomach, or in this case, a digester, happens when the organic waste decomposes in an oxygen-deprived space, allowing methagenic microorganisms to draw their oxygen from the waste itself in a reaction which releases large amounts of combustible methane, as well as carbon dioxide and hydrogen, and enriches the waste with nitrogen, making it an excellent fertilizer.

The gas given off from cow dung in a digester is approximately 60% methane, 32% Carbon Dioxide, with the rest being mainly hydrogen and nitrogen. This compares to an 80% methane content of Natural Gas. Approximately one cubic foot of gas is produced per pound of manure at 23°C, although the optimum temperature for methane production is between 32°C and 35°C. This is enough gas to cook a day's meals for a family of between 4 and 6 people, and the temperature can be controlled by simply providing shade to the digester to prevent direct sunlight from warming it too much.
DESIGNS

There are several designs for anaerobic methane digesters, all of which take advantage of the same natural processes. They generally consist of an airtight tank, which can be above or below ground. Waste is fed into this tank, and as digestion occurs methane is collected within the tank and can be piped out through a hose at the top. The expended waste left in the tank, known as “slurry”, is nitrogen rich and makes an excellent fertilizer.

Digester designs differ based on the type of waste to be used:

SOLID WASTE

Solid waste, such as vegetable matter, are digested using a “batch” feeding process, by which large quantities of matter are left to be digested entirely before the digester has to be opened up to remove the slurry. The slurry must be stirred periodically to ensure the top layer does not dry out. This is a very simple design, but it causes fluctuations in methane production as the breakdown occurs, and production must be stopped entirely to remove the slurry. This type of digestion is much slower, taking between 2 and 4 weeks to start producing methane, and continuing to do so before expending itself after 3 or 4 months. For this reason, this type of digester is best built in groups, so that one is always at peak production.

LIQUID OR SUSPENDED SOLID WASTE

Common examples of this type of waste are sewage and cow dung mixed with water. This type of digester is fed continuously, which allows for constant production of methane. Conventional designs utilize pumps and pipework to move the waste through the system, but simpler, gravity fed systems exist which allow the tank to overflow as new waste is added, removing the need for pumps. Because this simpler system does not have pipes to clog, solid waste can be added to the mixture to improve methane production and nitrogen content in the slurry. At optimum temperature, 30% of total biogas is produced in the first week, followed by 25% in the second, with the rest being expended in the following 6 weeks.

Digesters can be built above or below ground. Building them above ground allows for easier maintenance and access to the slurry, but requires reinforcement and is generally more expensive to build. By building the digester below ground, less reinforcement is needed and gravity can be used to move the waste.

Anaerobic digesters also have the possibility of having one significant variation: i.e. the addition of a “floating drum”. The “floating drum” design adds a free-moving, inverted drum to act as the top of the main tank. This drum has its edges extending down into the slurry, forming an airtight seal. As the gas is produced, the drum moves up and down, with its weight providing constant pressure, allowing gas to flow.
out at a steady rate. This variation is superior to a drum-free digester, which although being less complex, does not allow for constant pressure to occur.

The Khadi & Village Industries Commission of India has a simple, widely used digester which consists of a concrete structure and metallic floating drum. This digester is intended to be fed with cow dung, mixed in equal parts with water, and is designed specifically for rural India.

Figure 4.1 – Plan of “KVIC Model Floating Gas Holder”

The digester is built below ground and using locally-available materials. Cow dung is mixed with water in the mixing tank, and then let flow down into the digester. The digester itself has a middle partition that the waste is forced over as more is added, preventing newly added waste from overflowing at the other end. Gas builds up in the metal drum at the top, which rises and falls according to the amount of gas being produced. The gas is tapped through a hose at the top, and as material is added, it overflows and exits at the compost pit, ready to be used as fertilizer.

Here is an example of a digester designed without a floating drum:

Figure 4.2 – Plan of “Deenbandhu Model”
This digester is a lower-cost variation of the first one, but does not provide constant gas pressure.

An option exists to directly integrate a latrine system into the digester, whereby a toilet replaces the mixing area and human waste is dropped directly into the digester.

Figure 4.3 – Plan of “Sanitary Latrine biogas plant”

A major drawback of this design is that it negates the opportunity of using animal and vegetable waste, and also makes it difficult to properly mix the waste with equal parts water, and to achieve the correct consistency. With this in mind, the group came up with a “hybrid” version of this design, combining a latrine and a mixing area.

Figure 4.4 – Plan of “Power Rangers Hybrid Latrine Digester”
The group eventually decided against this “hybrid” design, due to several factors:
- unlike the other designs, it has never been tested in the real world,
- it is more complex and so more difficult and expensive to build, and detracts from the simplistic appeal of the original designs
- the added input tube means it will may clog more easily, and be more difficult to maintain,
- And finally, the latrine system would be a departure from traditional ways of going to the bathroom and would add another learning curve to the project.

We ultimately decided to recommend a certain type of digester:

- Floating-drum design, size varying depending on village's enthusiasm and perceived energy needs
- Single mixing area with single input tube to keep things simple and to allow for a good slurry mix to be produced
- No latrine, villagers to preferably go to the bathroom in a household container, which can be covered when not in use and transported to the digester to be added to the slurry.

CONSTRUCTION

The size and output of a digester varies depending on the amount of people it is to provide for and the number of animals providing waste to feed it. The specifications for a small digester, built for 4-5 people and using the waste of 4 animals, assuming each animal produces 10kg of waste a day, are as follows:
- Well size (diameter and depth) : 1.25m/3m
- 1:1 Water and Dung per day: 80kg
- Gas produced per day: 2m³
- Fertilizer produced per day: 4-8kg
- Building materials:
  - 2800 bricks
  - 22 bags (50kg) of cement
  - 9m³ of sand

And for a much larger one, for providing daily gas for 20-30 people with 20 animals:
- Well size (diameter and depth) : 2.2m x 4.3m
- 1:1 Water and Dung per day: 400kg
- Gas produced per day: 10m³
- Fertilizer produced per day: 20-40kg
- Building materials:
  - 6400 bricks
  - 35 bags (50kg) of cement
  - 18m³ of sand
These are just 2 examples, giving us an idea of the input and output differences in digester sizes as well as an estimated number of materials needed to build them. Digesters can be even larger than the given examples.

We believe that an underground, gravity-fed methane digester with a floating-drum storage system would be the best choice for Devikulam. The continuous feeding system of liquid waste would allow the people of Devikulam to take advantage of their natural resources (i.e. animal dung) as well as provide them with a nitrogen-rich and effective fertilizer. The above designs are specifically tailored for rural Indian villages, being constructed with locally available materials (such as brick and cement) and designed to take advantage of the warm climate. If constructed properly, the digester would require little or no maintenance, and have a lifespan of up to 25 years.
5 STRENGTHS AND WEAKNESSES

Each design option has an inherent number if strengths and weakness. These differ with each individual project. Each proposal is set in a different environment and has different needs and requirements. However all projects impact on the social, economical and environmental nature of communities.

SOCIAL IMPACT

In Devikulam, human waste is left to rot in backyards. The manure is the perfect breeding ground for flies and insects. By having systems in place to collect waste, it eradicates swarms of flies from infesting plants and indoors and outdoors\(^28\). Gardening and being outdoors is a more enjoyable experience. Food can be kept fresh for longer, free from diseases and bacteria carried by flies.

Additionally with methane gas being provided in cans, the community can burn the gas to cook meals, rather than the harsh alternation, kerosene. Cooking utensils are easier to clean as soot accumulation on tools is eliminated. Health problems correlating with kerosene and fire wood include Glaucoma, asthma and heart disease\(^29\). There are all dramatically reduced by use the operation of bio digesters. Moreover, the majority of people will find cooking is quicker, as methane heats relatively faster than firewood. Families would have more time to interact, as time required see seek and prepare firewood is no longer necessary\(^30\).

Education is improved from having a reliable source of electricity for better lighting when studying\(^31\). Training courses will be provided on using the new system. This education would be passed onto the community, making them more aware of what may have been a foreign concept. It also opens their eyes to renewable energy, and a sustainable way of life integrated in their culture now.

Additionally, families have a more enjoyable time watching television together without the power going out. Being able to watch Television as a family, without power outages, increases peoples' wellbeing and happiness.

Community involvement is forged by the contribution of everyone's cow and goat manure to providing energy to power their village. It gives a sense of achievement, having contributed to a better future. Also, it installs responsibility, into each person, that because of their involvement, a constant energy supply can be provided to all people. Lastly, the whole community is educated in a sustainable way of life. The people are more aware of the harm and damage that kerosene causes, to their atmosphere and to their health. Bio digestion systems improve Devikulam's standard on living and creates a sustainable and community involved environment.
The difficulties with implementing any new system, is cultural resistance. For generations wood had been used to cook. Acceptance of radical systems such as solar energy is not likely to be accepted. Bio Digestion, uses material which comes from the village; bricks, concrete and municipal waste. It still uses the same concept of burning the substance to produce light and electricity, only with a few additional steps before. Thus, it makes bio digestion a more acceptable option to a village requiring power.

**ECONOMIC IMPACT**

Methane bio digesters can be known as an 'economic multiplier'. It has a huge impact on the productivity and living standards of Devikulam. For example, shop owners could keep their shop open for longer, and make greater revenue. Additionally, people with fridges can keep their food fresher for longer.

The system increases the average level of education. Additionally, it attracted skilled and unskilled employment. The community is responsible for operating the Methane Digester. Required duties are available before, during and after construction of the Methane Digester. Including, supervisors, construction workers, people to collect municipal waste and feeding it into the machine, and stirring the machine for efficient production of Methane gas. An influx of Methane production could be sold off to nearby communities in exchange for money. Increasing the wealth and standards of living.

The bio-product from methane production, slurry, is rich in Nitrogen, which can be used as a fertiliser, enriching soil, and increasing harvest, thus increasing revenue. As suggested above, fertiliser can also be sold for profit.

The community of Devikulam may be initially hesitant to implementing this new system, in question of its cost. However, the demand for renewable energy and the use of Biomass has attracted investments of over IND 600 cores per year. The Ministry of New and Renewable Energy (MNRE) introduced the National Biogas and Manure Management Programme (NBMMP). Under this program the Central Financial Assistance (CFA) group provide subsidies as incentives for communities to take on board renewable energy. Involvement by State Nodal departments and agencies, including State Level Biogas Development and Training Centres all contribute towards building and educating villages on Biogas energy. TNUA. Coimbatore, in Tamil Nadu is the closest centre for Devikulam.

The table shows the some available subsidies for different sized digesters. It also gives a general idea of the cost of Methane Digesters. However, size, complexity needs to be considered when quoting price.
Table 5.1. Analysis of subsidy provided for different sized biogester

<table>
<thead>
<tr>
<th>Biodigester size (m³)</th>
<th>Estimated total cost at 2010-11 (Rs.)</th>
<th>Subsidy from CFA Maximum of 10,000 Rs.</th>
<th>Farmer Cost ** (Rs.)</th>
</tr>
</thead>
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<td>9,703</td>
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<tr>
<td>4</td>
<td>23,350</td>
<td>10,000</td>
<td>13,350</td>
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</table>

* NBMMMP will pay maximum 50% of the cost of biogas plant for low cost models. Given values are maximum pay out.

** Farmer cost is likely to be less due to new initiatives created by Ministry of New and Renewable Energy

Bio digesters replace the need for kerosene, LPG and firewood, thus reducing the expenditure on these items.

**ENVIRONMENTAL IMPACT**

Currently, 7 households use LPG and all households use firewood. Burning the gas releases CO₂ into the atmosphere contributing to the greenhouse effect. Methane Digesters, recycle the organic matter that is in waste. Rather than producing more Carbon dioxide, it reuses it, thus we call it carbon neutral. This recycling system assists with better sanitation, and gets rid of nasty smells outdoors. People can travel around their garden freely without flies swarming about, and dried waste lying around. It is a more pleasant experience.

The elimination of firewood means that there isn't an imbalance in the ecosystem. The forest is preserved and trees can flourish, proving shelter for people and organisms, and absorb Carbon Dioxide.

The slurry is rich in Nitrogen gas, which can be used as fertiliser. The sludge feeds essential nutrients into plants, increasing the quality and quantity of harvest.

**NEXT STEPS**

The village of Devikulam would be a cleaner place to live. The people will take responsibility to keep it at its new standards. Some people will be responsible for collecting waste and transporting it to the Methane digester. Other people would be responsible for mixing the slurry, to produce Methane gas. Each person is responsible to give waste and to look after the system to prevent black outs. People have the option to gradually stop buying kerosene and switch to using natural biogas for cooking.
The implementation of the Biogas digesting unit requires integration with the villagers of Devikulam as well as comprehension of how the system works and how to maintain smooth and effective operation to benefit the system and themselves. The plan for the system is to construct the system in the Devikulam community which would be followed by an educational process to outline how the village could incorporate the digester into its everyday routines as well as maintain the technical system effectively.

The group currently accepts the proposal to educate the village people of the function of transporting waste to the digesters to benefit energy production, increased sanitary practice as well as providing high quality fertiliser for the farming community.

The implementation plan will be carried out in step by step phases that gradually introduce the individual important elements of the system that need to be understood in order to gain the full benefits of the system.

**Phase 1:**
The initial stage of the implementation will aim to educate and begin to involve the community of Devikulam in sanitary practice of removing faecal matter from open areas to designated points for the Methane digester. This aim strives to encourage the community through education and rewards to fill the digester for higher energy outputs but also to remove the unpleasant and potentially unhealthily large quantities of faecal matter from roadsides and other village areas. However, for this first phase to work, education into the potential harm that open deification along roadsides can cause is a must, hence the villagers must completely understand that removing waste to specific points for the digester is going to reward their health.

**Phase 2:**
The second stage of the implementation will aim at educating the villagers of the ways of harnessing the methane gas as well as using it within households and as an energy generator. In linkage to phase 1, phase 2 is only valid if phase 1 succeeds which must be made apparent to the villagers as they will not gain anything in terms of the desired backup power supply as desired if the phases are not carried out as intended. In this provision, certain people of Devikulam will be educated on the gas harnessing process as well as the transporting of it to households and can potentially receive royalties with this job leading into phase 3 if the job is carried out in a reasonable manner. Lastly, the general community can be educated in new tools and equipment for cooking with this resource before choosing what they wish to implement as a whole.

**Phase 3:**
The final stage of the implementation process is selling the digested and composted mass as high quality fertiliser to the farmers in the surrounding districts to potentially repay the initial expenses of the digester as well as provide royalties to those who have duties related to it. The monetary element as royalties paid to those who work with the system acts as motivation to follow the phases and keep the system in efficient working order to benefit the community as it has been outlined that no
incentives may lead to the system being abandoned. Providing the steps are followed, farmers from around the district and possibly beyond will be making Devikulam more economically stable, environmentally friendly as well as enjoyable.

**WHY BIOGAS IS A GOOD FUEL**

The Biogas is considered as good fuel because it is a clean fuel that is easily produced and easily used to benefit a village such as Devikulam. Biogas does not produce smoke during the burning process\textsuperscript{35} which means it does not cause as much pollution to the environment or in small scale, houses. Biogas also has a high calorific value\textsuperscript{36} which essentially means that more heat is produced in the burning process in comparison to other types of gas which in the case where it is being produced on site; efficiency will pay off for the village in not having to produce huge quantities of the gas to burn. Lastly, Biogas is a combustible fuel that can be converted into other desirable energy forms\textsuperscript{37} with ease through a number of different processes to produce essential needs for people and households.

**HOT WATER BOILER FUEL**

Hot water can be generated with the use of Biogas with the aid of a boiler and combustion chamber. Biogas can be used in a similar way to the natural gas used all around the world in common appliances in the way that it can be fed along gas lines and burned in a chamber below a body of water in a specifically designed unit to efficiently and effectively produce sufficient volumes of hot water. The benefit of such a system in Devikulam is that it is incredibly simple and should not require difficult maintenance on a regular basis which may lead to it being a more likely contender for acceptance in the community as less training would be required as well as less potential for confusion in its operation.

**ELECTRICITY GENERATION WITH HOT WATER GENERATION**

Similarly to the process of purely generating hot water in a boiler with Biogas, electricity can be generated in the overheating process where steam can be utilized to propel turbines to produce an electrical output from the generator linked to the boiler. This system benefits from its dual action where production of two very important elements occurs, but in this system in relation to power production, in times where the water in the boiler is below 100 degrees, power cannot be produced therefore making this system far more attention based in terms of heating and keeping up water supply. From the attributes, it can be assumed that the system is likely to produce a far weaker bond with the local people due to its complexity, maintenance requirements.
STEAM POWERED ELECTRICITY PRODUCTION

STEAM ENGINES

This is one way of converting steam energy produced by the Biogas heated water into electricity where the pressurized vapor is used in a similar way to a train with pistons and valves to turn the crank of a generator in order to produce electricity\(^{38}\). This method has been understood for many decades but its implementation is noisy and would require constant care and lubrication of moving parts hence it is unlikely to be accepted by the people of Devikulam.

STEAM TURBINES

This is the most common way of producing electricity today and has been for many decades where superheated gas is released in the direct path of a set of turbine blades where this pressure rotates the blades, hence spinning the axle which drives a generator and produces electricity\(^{39}\). Steam turbines are far easier to maintain than steam powered engines but the requirement for superheated gas under very high pressures is present which is potentially dangerous and may not be adopted readily by locals due to this draw back.

INTERNAL COMBUSTION ENGINE

This style of engine or design for energy transfer is more than likely the most understood in the Devikulam district where the fuel is converted into a rotating shaft through combustion, pistons and valves\(^{40}\) and this process is widely accepted around the world. The only down side to the combustion engine is the nose it produces but it still has potential to work due to it being a known technology in the district.
CONCLUSION AND RECOMMENDATIONS

The design process has been a systematic one throughout this project. After having developed design criteria for the specific issues and requirements of the community of Devikulam, and evaluated various engineering technologies against these, it is believed that this project group has found the bio-digestion system to be most beneficial. As outlined, it has the community needs at the centre of considerations and the bio-digester proposal integrates sustainable development and design for the community for Devikulam. It takes into account the triple bottom line and has incorporated these impacts into its design.

Overall, it is believed that this design achieves the groups’ targets of researching and developing a back-up energy source for the use of the community in the event of power failure in the electricity grid. The infrastructure for the design and technology has also been decided with affordability in mind for the community and it is envisioned that the added beneficial outcomes will be achieved through the utilisation of the bio-digestion end products. The design also has minimal operating and maintenance costs and minimal (if not positive) environmental impacts, and it is hoped that with proper education and community integration, the design will be accepted by the community as being valuable for many aspects of sustainable development of their community.

It is further recommended that the community be responsible for building and maintaining the bio-digester, with prior training and education being provided. This is to allow a sense of ownership and empowerment. Research into this system and design is also suggested. Much research has gone into this design project, nevertheless, it is recommended that specific tests and designs be developed by professionals prior to the implementation of the design.
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